

Infinispan 9.0 User Guide

The Infinispan community

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Welcome to the official Infinispan user guide. This comprehensive document will guide you through every last detail of Infinispan, however can be a poor starting point if you are new to Infinispan.



For newbies, starting with the [Getting Started Guide](#) or one of the [Quickstarts](#) is probably a better bet.

The [Frequently Asked Questions](#) and [Glossary](#) are also useful documents to have alongside this user guide.

Chapter 1. Configuring cache

Infinispan offers both declarative and programmatic configuration.

Declarative configuration comes in a form of XML document that adheres to a provided Infinispan configuration XML [schema](#).

Every aspect of Infinispan that can be configured declaratively can also be configured programmatically. In fact, declarative configuration, behind the scenes, invokes programmatic configuration API as the XML configuration file is being processed. One can even use combination of these approaches. For example, you can read static XML configuration files and at runtime programmatically tune that same configuration. Or you can use a certain static configuration defined in XML as a starting point or template for defining additional configurations in runtime.

There are two main configuration abstractions in Infinispan: `global` and `default` sections.

Global configuration

Global cache configuration defines global settings shared among all cache instances created by a single `EmbeddedCacheManager`. Shared resources like thread pools, serialization/marshalling settings, transport and network settings, JMX domains are all part of global configuration.

Default configuration

Default cache configuration is more specific to actual caching domain itself. It specifies eviction, locking, transaction, clustering, cache store settings etc. The default cache can be retrieved via the `CacheManager.getCache()` API.

Named caches

However, the real power of default cache mechanism comes to light when used in conjunction with *named caches*. Named caches have the same XML schema as the default cache. Whenever they are specified, named caches inherit settings from the default cache while additional behavior can be specified or overridden. Named caches are retrieved via the `CacheManager.getCache(String name)` API. Therefore, note that the *name* attribute of named cache is both mandatory and unique for every named cache specified.

Do not forget to refer to Infinispan configuration [reference](#) for more details.

1.1. Configuring Cache declaratively

One of the major goals of Infinispan is to aim for zero configuration. A simple XML configuration file containing nothing more than a single `infinispan` element is enough to get you started. The configuration file listed below provides sensible defaults and is perfectly valid.

infinispan.xml

```
<infinispan />
```

However, that would only give you the most basic, local mode, non-clustered cache. Non-basic

configurations are very likely to use customized global and default cache elements.

Declarative configuration is the most common approach to configuring Infinispan cache instances. In order to read XML configuration files one would typically construct an instance of `DefaultCacheManager` by pointing to an XML file containing Infinispan configuration. Once configuration file is read you can obtain reference to the default cache instance.

```
EmbeddedCacheManager manager = new DefaultCacheManager("my-config-file.xml");
Cache defaultCache = manager.getCache();
```

or any other named instance specified in `my-config-file.xml`.

```
Cache someNamedCache = manager.getCache("someNamedCache");
```

The name of the default cache is defined in the `<cache-container>` element of the XML configuration file, and additional caches can be configured using the `<local-cache>`, `<distributed-cache>`, `<invalidation-cache>` or `<replicated-cache>` elements.

Refer to Infinispan configuration [reference](#) for more details. If you are using XML editing tools for configuration writing you can use provided Infinispan [schema](#) to assist you.

1.2. Configuring cache programmatically

Programmatic Infinispan configuration is centered around `CacheManager` and `ConfigurationBuilder` API. Although every single aspect of Infinispan configuration could be set programmatically, the most usual approach is to create a starting point in a form of XML configuration file and then in runtime, if needed, programmatically tune a specific configuration to suit the use case best.

```
EmbeddedCacheManager manager = new DefaultCacheManager("my-config-file.xml");
Cache defaultCache = manager.getCache();
```

Let assume that a new synchronously replicated cache is to be configured programmatically. First, a fresh instance of `Configuration` object is created using `ConfigurationBuilder` helper object, and the cache mode is set to synchronous replication. Finally, the configuration is defined/registered with a manager.

```
Configuration c = new ConfigurationBuilder().clustering().cacheMode(CacheMode
    .REPL_SYNC).build();

String newCacheName = "repl";
manager.defineConfiguration(newCacheName, c);
Cache<String, String> cache = manager.getCache(newCacheName);
```

The default cache configuration (or any other cache configuration) can be used as a starting point

for creation of a new cache. For example, lets say that `infinispan-config-file.xml` specifies a replicated cache as a default and that a distributed cache is desired with a specific L1 lifespan while at the same time retaining all other aspects of a default cache. Therefore, the starting point would be to read an instance of a default Configuration object and use `ConfigurationBuilder` to construct and modify cache mode and L1 lifespan on a new `Configuration` object. As a final step the configuration is defined/registered with a manager.

```
EmbeddedCacheManager manager = new DefaultCacheManager("infinispan-config-file.xml");
Configuration dcc = manager.getDefaultCacheConfiguration();
Configuration c = new ConfigurationBuilder().read(dcc).clustering().cacheMode(
    CacheMode.DIST_SYNC).l1().lifespan(60000L).build();

String newCacheName = "distributedWithL1";
manager.defineConfiguration(newCacheName, c);
Cache<String, String> cache = manager.getCache(newCacheName);
```

As long as the based configuration is the default named cache, the previous code works perfectly fine. However, other times the base configuration might be another named cache. So, how can new configurations be defined based on other defined caches? Take the previous example and imagine that instead of taking the default cache as base, a named cache called "replicatedCache" is used as base. The code would look something like this:

```
EmbeddedCacheManager manager = new DefaultCacheManager("infinispan-config-file.xml");
Configuration rc = manager.getCacheConfiguration("replicatedCache");
Configuration c = new ConfigurationBuilder().read(rc).clustering().cacheMode(
    CacheMode.DIST_SYNC).l1().lifespan(60000L).build();

String newCacheName = "distributedWithL1";
manager.defineConfiguration(newCacheName, c);
Cache<String, String> cache = manager.getCache(newCacheName);
```

Refer to [CacheManager](#) , [ConfigurationBuilder](#) , [Configuration](#) , and [GlobalConfiguration](#) javadocs for more details.

1.2.1. ConfigurationBuilder Programmatic Configuration API

However, users do not have to first read an XML based configuration and then modify it in runtime; they can start from scratch using only programmatic API. This is where powerful ConfigurationBuilder API comes to shine. The aim of this API is to make it easier to chain coding of configuration options in order to speed up the coding itself and make the configuration more readable. This new configuration can be used for both the global and the cache level configuration. GlobalConfiguration objects are constructed using GlobalConfigurationBuilder while Configuration objects are built using ConfigurationBuilder. Let's look at some examples on configuring both global and cache level options with this new API:

One of the most commonly configured global option is the transport layer, where you indicate how an Infinispan node will discover the others:

```
GlobalConfiguration globalConfig = new GlobalConfigurationBuilder().transport()
    .defaultTransport()
    .clusterName("qa-cluster")
    .addProperty("configurationFile", "jgroups-tcp.xml")
    .machineId("qa-machine").rackId("qa-rack")
    .build();
```

Sometimes you might also want to enable collection of [global JMX statistics](#) at cache manager level or get information about the transport. To enable global JMX statistics simply do:

```
GlobalConfiguration globalConfig = new GlobalConfigurationBuilder()
    .globalJmxStatistics()
    .enable()
    .build();
```

Please note that by not enabling (or by explicitly disabling) global JMX statistics you are just turning off statistics collection. The corresponding MBean is still registered and can be used to manage the cache manager in general, but the statistics attributes do not return meaningful values.

Further options at the global JMX statistics level allows you to configure the cache manager name which comes handy when you have multiple cache managers running on the same system, or how to locate the JMX MBean Server:

```
GlobalConfiguration globalConfig = new GlobalConfigurationBuilder()
    .globalJmxStatistics()
    .cacheManagerName("SalesCacheManager")
    .mBeanServerLookup(new JBossMBeanServerLookup())
    .build();
```

Some of the Infinispan features are powered by a group of the thread pool executors which can also be tweaked at this global level. For example:

```
GlobalConfiguration globalConfig = new GlobalConfigurationBuilder()
    .replicationQueueThreadPool()
    .threadPoolFactory(ScheduledThreadPoolExecutorFactory.create())
    .build();
```

You can not only configure global, cache manager level, options, but you can also configure cache level options such as the [cluster mode](#):

```
Configuration config = new ConfigurationBuilder()
    .clustering()
    .cacheMode(CacheMode.DIST_SYNC)
    .sync()
    .l1().lifespan(25000L)
    .hash().numOwners(3)
    .build();
```

Or you can configure [eviction and expiration settings](#):

```
Configuration config = new ConfigurationBuilder()
    .eviction()
    .maxEntries(20000).strategy(EvictionStrategy.LIRS).expiration()
    .wakeUpInterval(5000L)
    .maxIdle(120000L)
    .build();
```

An application might also want to interact with an Infinispan cache within the boundaries of JTA and to do that you need to configure the transaction layer and optionally tweak the locking settings. When interacting with transactional caches, you might want to enable recovery to deal with transactions that finished with an heuristic outcome and if you do that, you will often want to enable JMX management and statistics gathering too:

```
Configuration config = new ConfigurationBuilder()
    .locking()
    .concurrencyLevel(10000).isolationLevel(IsolationLevel.REPEATABLE_READ)
    .lockAcquisitionTimeout(12000L).useLockStriping(false).writeSkewCheck(true)
    .versioning().enable().scheme(VersioningScheme.SIMPLE)
    .transaction()
    .transactionManagerLookup(new GenericTransactionManagerLookup())
    .recovery()
    .jmxStatistics()
    .build();
```

Configuring Infinispan with chained cache stores is simple too:

```
Configuration config = new ConfigurationBuilder()
    .persistence().passivation(false)
    .addSingleFileStore().location("/tmp").async().enable()
    .preload(false).shared(false).threadPoolSize(20).build();
```

1.2.2. Advanced programmatic configuration

The fluent configuration can also be used to configure more advanced or exotic options, such as advanced externalizers:

```
GlobalConfiguration globalConfig = new GlobalConfigurationBuilder()
    .serialization()
    .addAdvancedExternalizer(998, new PersonExternalizer())
    .addAdvancedExternalizer(999, new AddressExternalizer())
    .build();
```

Or, add custom interceptors:

```
Configuration config = new ConfigurationBuilder()
    .customInterceptors().addInterceptor()
        .interceptor(new FirstInterceptor()).position(InterceptorConfiguration.Position
    .FIRST)
        .interceptor(new LastInterceptor()).position(InterceptorConfiguration.Position
    .LAST)
        .interceptor(new FixPositionInterceptor()).index(8)
        .interceptor(new AfterInterceptor()).after(NonTransactionalLockingInterceptor
    .class)
        .interceptor(new BeforeInterceptor()).before(CallInterceptor.class)
    .build();
```

For information on the individual configuration options, please check the [configuration guide](#) .

1.3. Configuration Migration Tools

Infinispan has a number of scripts for importing configurations from other cache and data grid products. Currently we have scripts to import configurations from:

- JBoss Cache 3.x
- EHCACHE 1.x
- Oracle Coherence 3.x

JBoss Cache 3.x itself supports configuration [migration](#) from previous (2.x) versions, so JBoss Cache 2.x configurations can be migrated indirectly.



If you wish to help write conversion tools for other caching systems, please contact [infinispan-dev](#).

There is a single scripts for importing configurations: `${INFINISPAN_HOME}/bin/importConfig.sh` and an equivalent .BAT script for Windows. Just run it and you should get a help message to assist you with the import:

```
C:\infinispan\bin> importConfig.bat
Missing 'source', cannot proceed
Usage:
importConfig [-source <the file to be transformed>]
[-destination <where to store resulting XML>]
[-type <the type of the source, possible values being: [JBossCache3x, Ehcache1x,
Coherence35x] >]
```

```
C:\infinispan\bin>
```

Here is how a JBoss Cache 3.x configuration file is imported:

```
C:\infinispan\bin>importConfig.bat -source in\jbossccache_all.xml -destination out.xml
-type JBossCache3x
WARNING! Preload elements cannot be automatically transformed, please do it manually!
WARNING! Please configure cache loader props manually!
WARNING! Singleton store was changed and needs to be configured manually!
IMPORTANT: Please take a look at the generated file for (possible) TODOs about the
elements that couldn't be converted automatically!
New configuration file [out.xml] successfully created.
C:\infinispan\bin>
```

Please read all warning messages *carefully* and inspect the generated XML for potential TODO statements that indicate the need for manual intervention. In the case of JBoss Cache 3.x this would usually have to do with custom extensions, such as custom CacheLoaders that cannot be automatically migrated.

For EHCache and Coherence these may also contain suggestions and warnings for configuration options that may not have direct equivalents in Infinispan.

1.4. Clustered Configuration

Infinispan uses [JGroups](#) for network communications when in clustered mode. Infinispan ships with *pre-configured* JGroups stacks that make it easy for you to jump-start a clustered configuration.

1.4.1. Using an external JGroups file

If you are configuring your cache programmatically, all you need to do is:

```
GlobalConfiguration gc = new GlobalConfigurationBuilder()
    .transport().defaultTransport()
    .addProperty("configurationFile", "jgroups.xml")
    .build();
```

and if you happen to use an XML file to configure Infinispan, just use:


```

<infinispan>
  <jgroups>
    <stack-file name="external-file" path="jgroups.xml"/>
  </jgroups>
  <cache-container default-cache="replicatedCache">
    <transport stack="external-file" />
    <replicated-cache name="replicatedCache"/>
  </cache-container>

  ...

</infinispan>

```

In both cases above, Infinispan looks for *jgroups.xml* first in your classpath, and then for an absolute path name if not found in the classpath.

1.4.2. Use one of the pre-configured JGroups files

Infinispan ships with a few different JGroups files (packaged in *infinispan-core.jar*) which means they will already be on your classpath by default. All you need to do is specify the file name, e.g., instead of *jgroups.xml* above, specify */default-configs/default-jgroups-tcp.xml*.

The configurations available are:

- *default-jgroups-udp.xml* - Uses UDP as a transport, and UDP multicast for discovery. Usually suitable for larger (over 100 nodes) clusters *or* if you are using [replication](#) or [invalidation](#). Minimises opening too many sockets.
- *default-jgroups-tcp.xml* - Uses TCP as a transport and UDP multicast for discovery. Better for smaller clusters (under 100 nodes) *only if* you are using [distribution](#), as TCP is more efficient as a point-to-point protocol
- *default-jgroups-ec2.xml* - Uses TCP as a transport and [S3_PING](#) for discovery. Suitable on [Amazon EC2](#) nodes where UDP multicast isn't available.
- *default-jgroups-kubernetes.xml* - Uses TCP as a transport and [KUBE_PING](#) for discovery. Suitable on [Kubernetes](#) and [OpenShift](#) nodes where UDP multicast is not always available.

Tuning JGroups settings

The settings above can be further tuned without editing the XML files themselves. Passing in certain system properties to your JVM at startup can affect the behaviour of some of these settings. The table below shows you which settings can be configured in this way. E.g.,

```
$ java -cp ... -Djgroups.tcp.port=1234 -Djgroups.tcp.address=10.11.12.13
```

Table 1. *default-jgroups-udp.xml*

System Property	Description	Default	Required?
-----------------	-------------	---------	-----------

jgroups.udp.mcast_address	IP address to use for multicast (both for communications and discovery). Must be a valid Class D IP address, suitable for IP multicast.	228.6.7.8	No
jgroups.udp.mcast_port	Port to use for multicast socket	46655	No
jgroups.udp.ip_ttl	Specifies the time-to-live (TTL) for IP multicast packets. The value here refers to the number of network hops a packet is allowed to make before it is dropped	2	No

Table 2. default-jgroups-tcp.xml

System Property	Description	Default	Required?
jgroups.tcp.address	IP address to use for the TCP transport.	127.0.0.1	No
jgroups.tcp.port	Port to use for TCP socket	7800	No
jgroups.udp.mcast_address	IP address to use for multicast (for discovery). Must be a valid Class D IP address, suitable for IP multicast.	228.6.7.8	No
jgroups.udp.mcast_port	Port to use for multicast socket	46655	No
jgroups.udp.ip_ttl	Specifies the time-to-live (TTL) for IP multicast packets. The value here refers to the number of network hops a packet is allowed to make before it is dropped	2	No

Table 3. default-jgroups-ec2.xml

System Property	Description	Default	Required?
jgroups.tcp.address	IP address to use for the TCP transport.	127.0.0.1	No

jgroups.tcp.port	Port to use for TCP socket	7800	No
jgroups.s3.access_key	The Amazon S3 access key used to access an S3 bucket		No
jgroups.s3.secret_access_key	The Amazon S3 secret key used to access an S3 bucket		No
jgroups.s3.bucket	Name of the Amazon S3 bucket to use. Must be unique and must already exist		No

Table 4. default-jgroups-kubernetes.xml

System Property	Description	Default	Required?
jgroups.tcp.address	IP address to use for the TCP transport.	eth0	No
jgroups.tcp.port	Port to use for TCP socket	7800	No

1.4.3. Further reading

JGroups also supports more system property overrides, details of which can be found on this page: [SystemProps](#)

In addition, the JGroups configuration files shipped with Infinispan are intended as a jumping off point to getting something up and running, and working. More often than not though, you will want to fine-tune your JGroups stack further to extract every ounce of performance from your network equipment. For this, your next stop should be the JGroups manual which has a [detailed section](#) on configuring each of the protocols you see in a JGroups configuration file.

Chapter 2. The CacheManager API

Infinispan provides the `EmbeddedCacheManager`, as mentioned in the configuration section, as the API for exposing various operations related to the Infinispan cache container and its supporting elements. This section is to go over some of these pieces as well as when you may need to use them.

2.1. 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).

2.1.1. 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.

2.1.2. Other methods

getTransport

This method provides you access to the underlying Transport that is used to send messages to other nodes. In most cases a user wouldn't ever need to go to this level, but if you want to get Transport specific information (in this case JGroups) you can use this mechanism.

getStats

The stats provided here are coalesced from all of the active caches in this manager. These stats can be useful to see if there is something wrong going on with your cluster overall.

2.2. Cluster Executor

The cache manager comes with a nice utility that allows you to execute arbitrary code in the cluster. Note this is unlike the Distributed Execution Service as this requires no Cache to be used. This `cluster executor` can be retrieved by calling `executor()` of the `EmbeddedCacheManager`.

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.

Below you will see an example of how to use the new executor.

2.2.1. Example: Dynamically Start and Stop Clustered Cache

This example shows how you can use the ClusterExecutor to dynamically start and stop a cache.

Non-Clustered

Start start/stop cache in non-clustered mode is simple. You can use *EmbeddedCacheManager.defineConfiguration(cacheName, configuration)* to define a cache, and then call *EmbeddedCacheManager.getCache(cacheName)*.

If you don't define a specific configuration for the cache and directly call *EmbeddedCacheManager.getCache(...)*, then a new cache would be created with default configurations.

To stop a cache, call *EmbeddedCacheManager.remove(cacheName)*

Clustered

To start a clustered cache, you'll need to do the above on every clustered node, while making sure the cache mode is clustered, of course.

You can start the cache by calling *EmbeddedCacheManager.getCache(...)* To do this on every single node though, you could write your own service to do that, or with JMX, or use the ClusterExecutor.

StartCache.java

```
EmbeddedCacheManager manager = null;
String cacheName = "start-this-cache";
manager.executor().submitConsumer(localManager -> {
    localManager.getCache(cacheName);
    return null;
}, (address, value, throwable) -> {
    if (throwable != null) {
        log.fatal("Cache startup encountered exception on node " + address, t);
    }
}).join();
```

The first argument is a **Function** that when invoked will pass the **EmbeddedCacheManager** local to each node. Normally this also allows for a return value to be sent back, but unfortunately a **Cache** instance is not serializable so we can't send that back to the calling node. Thus we have to return null. In this case the second argument **TriConsumer** would be called back for each node and will contain who this response is from (address), the return value (if there was one, in our case this is always null), and a throwable if a problem occurred. The value and throwable variables will never both be non null. That is if the throwable is non null the value will always be null. Lastly this returns a **CompletableFuture** that will be complete after all of the node's responses have been fully processed.

Chapter 3. The Cache API

3.1. The Cache interface

Infinispan exposes a simple, [JSR-107](#) compliant [Cache](#) interface.

The Cache interface 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.



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. Example of Using Expiry and Mortal Data

See [these examples](#) of using mortal data with Infinispan.

3.1.4. putForExternalRead operation

Infinispan's [Cache](#) class contains a different 'put' operation called [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead\(K,](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead(K)

V)[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 consider 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 [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead\(K, V\)\[putForExternalRead\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead(K,V)[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;
}
```

Please note that [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead\(K, V\)\[putForExternalRead\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead(K,V)[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 [link:http://docs.oracle.com/javase/6/docs/api/java/util/Map.html#put\(K, V\)\[put\]](http://docs.oracle.com/javase/6/docs/api/java/util/Map.html#put(K,V)[put]) operation, otherwise the possibility of caching corrupt data is likely.

3.2. The AdvancedCache interface

In addition to the simple Cache interface, Infinispan offers an [AdvancedCache](#) interface, geared towards extension authors. The AdvancedCache offers the ability to inject custom interceptors, 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");
```

3.2.2. Custom Interceptors

The AdvancedCache interface also offers advanced developers a mechanism with which to attach custom interceptors. Custom interceptors allow developers to alter the behavior of the cache API methods, and the AdvancedCache interface allows developers to attach these interceptors programmatically, at run-time. See the AdvancedCache Javadocs for more details.

For more information on writing custom interceptors, see [this chapter](#).

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 [POJO](#)s 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:


```
@Listener
public class PrintWhenAdded {

    @CacheEntryCreated
    public void print(CacheEntryCreatedEvent event) {
        System.out.println("New entry " + event.getKey() + " created in the cache");
    }

}
```

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;
    }

    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.

Please see the [Javadocs on 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 notifications are dispatched in the same thread that generates the event. This means that you *must* write your listener such that it does not block or do anything that takes too long, as it would prevent the thread from progressing. Alternatively, you could annotate your listener as *asynchronous*, in which case a separate thread pool will be used to dispatch the notification and prevent blocking the event originating thread. To do this, simply annotate your listener such:

```
@Listener (sync = false)
public class MyAsyncListener { .... }
```

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 `Future` containing the actual result of the operation.

For example, in a cache parameterized as `Cache<String, String>`, `Cache.put(String key, String value)` returns a `String`. `Cache.putAsync(String key, String value)` would return a `Future<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<Future<?>> futures = new HashSet<Future<?>>();
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 (Future<?> 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

As of Infinispan 4.0, 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. In future, we plan to take these offline as well. See [this developer mail list thread](#) about this topic.

3.4.3. Notifying futures

Strictly, these methods do not return JDK Futures, but rather a sub-interface known as a [NotifyingFuture](#) . The main difference is that you can attach a listener to a NotifyingFuture such that you could be notified when the future completes. Here is an example of making use of a notifying future:

```
FutureListener futureListener = new FutureListener() {  
  
    public void futureDone(Future future) {  
        try {  
            future.get();  
        } catch (Exception e) {  
            // Future did not complete successfully  
            System.out.println("Help!");  
        }  
    }  
};  
  
cache.putAsync("key", "value").attachListener(futureListener);
```

3.4.4. Further reading

The Javadocs on the [Cache](#) interface has some examples on using the asynchronous API, as does [this article](#) by Manik Surtani introducing the API.

3.5. Invocation Flags

An important aspect of getting the most of Infinispan is the use of per-invocation flags in order to provide specific behaviour to each particular cache call. By doing this, some important optimizations can be implemented potentially saving precious time and network resources. One of the most popular usages of flags can be found right in Cache API, underneath the link:[http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead\(K,V\)\[putForExternalRead\(\)\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/Cache.html#putForExternalRead(K,V)[putForExternalRead()]) method which is used to load an Infinispan cache with data read from an external resource. In order to make this call efficient, Infinispan basically calls a normal put operation passing the following flags: [FAIL_SILENTLY](#) , [FORCE_ASYNCHRONOUS](#) , [ZERO_LOCK_ACQUISITION_TIMEOUT](#)

What Infinispan is doing here is effectively saying that when putting data read from external read, it will use an almost-zero lock acquisition time and that if the locks cannot be acquired, it will fail silently without throwing any exception related to lock acquisition. It also specifies that regardless of the cache mode, if the cache is clustered, it will replicate asynchronously and so won't wait for responses from other nodes. The combination of all these flags make this kind of operation very efficient, and the efficiency comes from the fact this type of *putForExternalRead* calls are used with the knowledge that client can always head back to a persistent store of some sorts to retrieve the data that should be stored in memory. So, any attempt to store the data is just a best effort and if not possible, the client should try again if there's a cache miss.

3.5.1. DecoratedCache

Another approach would be to use the [DecoratedCache](#) wrapper. This allows you to reuse flags. For example:

```
AdvancedCache cache = ...
DecoratedCache strictlyLocal = new DecoratedCache(cache, Flag.CACHE_MODE_LOCAL, Flag
.SKIP_CACHE_STORE);
strictlyLocal.put("local_1", "only");
strictlyLocal.put("local_2", "only");
strictlyLocal.put("local_3", "only");
```

This approach makes your code more readable.

3.5.2. Examples

If you want to use these or any other flags available, which by the way are described in detail the [Flag enumeration](#) , you simply need to get hold of the advanced cache and add the flags you need via the [withFlags\(\)](#) method call. For example:

```
Cache cache = ...
cache.getAdvancedCache()
    .withFlags(Flag.SKIP_CACHE_STORE, Flag.CACHE_MODE_LOCAL)
    .put("local", "only");
```

It's worth noting that these flags are only active for the duration of the cache operation. If the same flags need to be used in several invocations, even if they're in the same transaction, [withFlags\(\)](#) needs to be called repeatedly. Clearly, if the cache operation is to be replicated in another node, the flags are carried over to the remote nodes as well.

Suppressing return values from a put() or remove()

Another very important use case is when you want a write operation such as `put()` to *not* return the previous value. To do that, you need to use two flags to make sure that in a distributed environment, no remote lookup is done to potentially get previous value, and if the cache is configured with a cache loader, to avoid loading the previous value from the cache store. You can see these two flags in action in the following example:

```
Cache cache = ...
cache.getAdvancedCache()
    .withFlags(Flag.SKIP_REMOTE_LOOKUP, Flag.SKIP_CACHE_LOAD)
    .put("local", "only")
```

For more information, please check the [Flag enumeration](#) javadoc.

3.6. Tree API Module

[Infinispan's tree API module](#) offers clients the possibility of storing data using a tree-structure like API. This API is similar to the one [provided by JBoss Cache](#), hence the tree module is perfect for those users wanting to migrate their applications from JBoss Cache to Infinispan, who want to limit changes their codebase as part of the migration. Besides, it's important to understand that Infinispan provides this tree API much more efficiently than JBoss Cache did, so if you're a user of the tree API in JBoss Cache, you should consider migrating to Infinispan.

3.6.1. What is Tree API about?

The aim of this API is to store information in a hierarchical way. The hierarchy is defined using paths represented as [Fqn or fully qualified names](#), for example: */this/is/a/fqn/path* or */another/path*. In the hierarchy, there's a special path called root which represents the starting point of all paths and it's represented as: */*

Each FQN path is represented as a node where users can store data using a key/value pair style API (i.e. a Map). For example, in */persons/john*, you could store information belonging to John, for example: *surname=Smith, birthdate=05/02/1980...etc.*

Please remember that users should not use root as a place to store data. Instead, users should define their own paths and store data there. The following sections will delve into the practical aspects of this API.

3.6.2. Using the Tree API

Dependencies

For your application to use the tree API, you need to import *infinispan-tree.jar* which can be located in the Infinispan binary distributions, or you can simply add a dependency to this module in your *pom.xml*:

pom.xml

```
<dependencies>
  ...
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-tree</artifactId>
    <version>${put-infinispan-version-here}</version>
  </dependency>
  ...
</dependencies>
```

3.6.3. Creating a Tree Cache

The first step to use the tree API is to actually create a tree cache. To do so, you need to [create an Infinispan Cache](#) as you'd normally do, and using the `TreeCacheFactory`, create an instance of `TreeCache`. A very important note to remember here is that the `Cache` instance passed to the factory must be configured with `<<_batching, invocation batching`. For example:

```
import org.infinispan.config.Configuration;
import org.infinispan.tree.TreeCacheFactory;
import org.infinispan.tree.TreeCache;
...
Configuration config = new Configuration();
config.setInvocationBatchingEnabled(true);
Cache cache = new DefaultCacheManager(config).getCache();
TreeCache treeCache = TreeCacheFactory.createTreeCache(cache);
```

3.6.4. Manipulating data in a Tree Cache

The Tree API effectively provides two ways to interact with the data:

Via [TreeCache](#) convenience methods: These methods are located within the `TreeCache` interface and [enable](#) [users](#) [to](#) [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#put\(java.lang.String, K, V\)\[store\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#put(java.lang.String, K, V)[store]), [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#get\(org.infinispan.tree.Fqn, K\)\[retrieve\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#get(org.infinispan.tree.Fqn, K)[retrieve]), [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#move\(org.infinispan.tree.Fqn, org.infinispan.tree.Fqn\)\[move\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#move(org.infinispan.tree.Fqn, org.infinispan.tree.Fqn)[move]), [link:http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#remove\(org.infinispan.tree.Fqn, K\)\[remove\]](http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/tree/TreeCache.html#remove(org.infinispan.tree.Fqn, K)[remove]) ...etc data with a single call that takes the [Fqn](#), in `String` or `Fqn` format, and the data involved in the call. For example:

```
treeCache.put("/persons/john", "surname", "Smith");
```

Or:


```
import org.infinispan.tree.Fqn;
...
Fqn johnFqn = Fqn.fromString("persons/john");
Calendar calendar = Calendar.getInstance();
calendar.set(1980, 5, 2);
treeCache.put(johnFqn, "birthdate", calendar.getTime());
```

Via [Node](#) API: It allows finer control over the individual nodes that form the FQN, allowing manipulation of nodes relative to a particular node. For example:

```
import org.infinispan.tree.Node;
...
TreeCache treeCache = ...
Fqn johnFqn = Fqn.fromElements("persons", "john");
Node<String, Object> john = treeCache.getRoot().addChild(johnFqn);
john.put("surname", "Smith");
```

Or:

```
Node persons = treeCache.getRoot().addChild(Fqn.fromString("persons"));
Node<String, Object> john = persons.addChild(Fqn.fromString("john"));
john.put("surname", "Smith");
```

Or even:

```
Fqn personsFqn = Fqn.fromString("persons");
Fqn johnFqn = Fqn.fromRelative(personsFqn, Fqn.fromString("john"));
Node<String, Object> john = treeCache.getRoot().addChild(johnFqn);
john.put("surname", "Smith");
```

A node also provides the ability to access its [parent](#) or [children](#) . For example:

```
Node<String, Object> john = ...
Node persons = john.getParent();
```

Or:

```
Set<Node<String, Object>> personsChildren = persons.getChildren();
```

3.6.5. Common Operations

In the previous section, some of the most used operations, such as addition and retrieval, have been shown. However, there are other important operations that are worth mentioning, such as remove:

You can for example remove an entire node, i.e. */persons/john* , using:

```
treeCache.removeNode("/persons/john");
```

Or remove a child node, i.e. persons that a child of root, via:

```
treeCache.getRoot().removeChild(Fqn.fromString("persons"));
```

You can also remove a particular key/value pair in a node:

```
Node john = treeCache.getRoot().getChild(Fqn.fromElements("persons", "john"));
john.remove("surname");
```

Or you can remove all data in a node with:

```
Node john = treeCache.getRoot().getChild(Fqn.fromElements("persons", "john"));
john.clearData();
```

Another important operation supported by Tree API is the ability to move nodes around in the tree. Imagine we have a node called "john" which is located under root node. The following example is going to show how to we can move "john" node to be under "persons" node:

Current tree structure:

```
/persons
/john
```

Moving trees from one FQN to another:

```
Node john = treeCache.getRoot().addChild(Fqn.fromString("john"));
Node persons = treeCache.getRoot().getChild(Fqn.fromString("persons"));
treeCache.move(john.getFqn(), persons.getFqn());
```

Final tree structure:

```
/persons/john
```

3.6.6. Locking in the Tree API

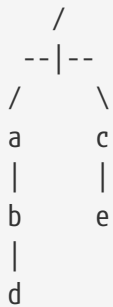
Understanding when and how locks are acquired when manipulating the tree structure is important in order to maximise the performance of any client application interacting against the tree, while at the same time maintaining consistency.

Locking on the tree API happens on a per node basis. So, if you're putting or updating a key/value under a particular node, a write lock is acquired for that node. In such case, no write locks are acquired for parent node of the node being modified, and no locks are acquired for children nodes.

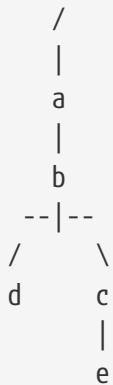
If you're adding or removing a node, the parent is not locked for writing. In JBoss Cache, this behaviour was configurable with the default being that parent was not locked for insertion or removal.

Finally, when a node is moved, the node that's been moved and any of its children are locked, but also the target node and the new location of the moved node and its children. To understand this better, let's look at an example:

Imagine you have a hierarchy like this and we want to move c/ to be underneath b/:



The end result would be something like this:



To make this move, locks would have been acquired on:

- /a/b - because it's the parent underneath which the data will be put
- /c and /c/e - because they're the nodes that are being moved
- /a/b/c and /a/b/c/e - because that's new target location for the nodes being moved

3.6.7. Listeners for tree cache events

The current Infinispan listeners have been designed with key/value store notifications in mind, and hence they do not map to tree cache events correctly. Tree cache specific listeners that map directly to tree cache events (i.e. adding a child...etc) are desirable but these are not yet available. If you're

interested in this type of listeners, please follow [this issue](#) to find out about any progress in this area.

Chapter 4. Eviction

Infinispan supports eviction of entries, such that you do not run out of memory. Eviction is typically used in conjunction with a cache store, so that entries are not permanently lost when evicted, since eviction only removes entries from memory and not from cache stores or the rest of the cluster.



Passivation is also a popular option when using eviction, so that only a single copy of an entry is maintained - either in memory or in a cache store, but not both. The main benefit of using passivation over a regular cache store is that updates to entries which exist in memory are cheaper since the update doesn't need to be made to the cache store as well.



that eviction occurs on a *local* basis, and is not cluster-wide. Each node runs an eviction thread to analyse the contents of its in-memory container and decide what to evict. Eviction does not take into account the amount of free memory in the JVM as threshold to starts evicting entries. You have to set `maxEntries` attribute of the eviction element to be greater than zero in order for eviction to be turned on. If `maxEntries` is too large you can run out of memory. `maxEntries` attribute will probably take some tuning in each use case.

4.1. Enabling Eviction

Eviction is configured by adding the `<eviction />` element to your `<*-cache />` configuration sections or using [EvictionConfigurationBuilder](#) API programmatic approach.

All cache entry are evicted by piggybacking on user threads that are hitting the cache. Periodic pruning of expired cache entries from cache is done on a dedicated thread which is turned on by enabling reaper in expiration configuration element/API.

4.1.1. Eviction strategies

NONE

This eviction strategy effectively disables the eviction thread. This is the default configuration.

UNORDERED

UNORDERED eviction strategy is a legacy eviction strategy that has been deprecated. If UNORDERED strategy is specified LRU eviction algorithm will be used.

LRU

If LRU eviction is used cache entries are selected for eviction using a well known least-recently-used pattern.

LIRS

LRU eviction algorithm, although simple and easy to understand, under performs in cases of weak access locality (one time access entries are not timely replaced, entries to be accessed soonest are unfortunately replaced, and so on). Recently, a new eviction algorithm - LIRS has gathered a lot of

attention because it addresses weak access locality shortcomings of LRU yet it retains LRU's simplicity. Eviction in LIRS algorithm relies on history information of cache entries accesses using so called Inter-Reference Recency (a.k.a IRR) and the Recency. The IRR of a cache entry A refers to number of other distinct entries accessed between the last two consecutive accesses to cache entry A, while recency refers to the number of other entries accessed from last reference to A up to current time point. If we relied only on cache recency we would essentially have LRU functionality. However, in addition to recency LIRS tracks elements that are in low IRR and high IRR, aptly named LIR and HIR cache entry blocks respectively. LIRS eviction algorithm essentially keeps entries with a low IRR in the cache as much as possible while evicting high IRR entries if eviction is required. If recency of a LIR cache entry increases to a certain point and entry in HIR gets accessed at a smaller recency than that of the LIR entry, the LIR/HIR statuses of the two blocks are switched. Entries in HIR may be evicted regardless of its recency, even if element was recently accessed.

MANUAL

This eviction strategy is identical to NONE, in that it disables automatic eviction altogether, but signals the intention that the user wants to evict entries manually. The effect is to disable misleading warning validation messages.

4.1.2. More defaults

By default when no `<eviction />` element is specified, no eviction takes place.

In case there is an eviction element, this table describes behaviour of eviction based on information provided in the xml configuration ("-" in Supplied maxEntries or Supplied strategy column means that the attribute wasn't supplied)

Supplied maxEntries	Supplied strategy	Example	Eviction behaviour
-	-	<code><eviction /></code>	no eviction
> 0	-	<code><eviction max-entries="100" /></code>	the strategy defaults to LIRS and eviction takes place
> 0	NONE	<code><eviction max-entries="100" strategy="NONE" /></code>	the strategy defaults to LIRS and eviction takes place
> 0	!= NONE	<code><eviction max-entries="100" strategy="LRU" /></code>	eviction takes place with defined strategy
0	-	<code><eviction max-entries="0" /></code>	no eviction
0	NONE	<code><eviction max-entries="0" strategy="NONE" /></code>	no eviction
0	!= NONE	<code><eviction max-entries="0" strategy="LRU" /></code>	ConfigurationException
< 0	-	<code><eviction max-entries="-1" /></code>	no eviction

Supplied maxEntries	Supplied strategy	Example	Eviction behaviour
< 0	NONE	<code><eviction max-entries="-1" strategy="NONE" /></code>	no eviction
< 0	!= NONE	<code><eviction max-entries="-1" strategy="LRU" /></code>	ConfigurationException

4.2. Expiration

Similar to, but unlike eviction, is expiration. Expiration allows you to attach lifespan and/or maximum idle times to entries. Entries that exceed these times are treated as invalid and are removed. When removed expired entries are not passivated like evicted entries (if passivation is turned on).



Unlike eviction, expired entries are removed globally - from memory, cache stores, and cluster-wide.

By default entries created are immortal and do not have a lifespan or maximum idle time. Using the cache API, mortal entries can be created with lifespans and/or maximum idle times. Further, default lifespans and/or maximum idle times can be configured by adding the `<expiration />` element to your `<*-cache />` configuration sections.

4.2.1. Difference between Eviction and Expiration

Both Eviction and Expiration are means of cleaning the cache of unused entries and thus guarding the heap against OutOfMemory exceptions, so now a brief explanation of the difference.

With *eviction* you set *maximal number of entries* you want to keep in the cache and if this limit is exceeded, some candidates are found to be removed according to a chosen *eviction strategy* (LRU, LIRS, etc...). Eviction can be setup to work with passivation (evicting to a cache store).

With *expiration* you set *time criteria* for entries, *how long you want to keep them* in cache. Either you set maximum *lifespan* of the entry - time it is allowed to stay in the cache or *maximum idle time*, time it's allowed to be untouched (no operation performed with given key).

4.3. Eviction Examples

1. *Expiration* is a top-level construct, represented in the configuration as well as in the cache API.
2. While eviction is *local to each cache instance*, expiration is *cluster-wide*. Expiration lifespans and maxIdle values are replicated along with the cache entry.
3. Expiration lifespan and maxIdle are also persisted in CacheStores, so this information survives eviction/passivation.
4. Four eviction strategies are shipped, `EvictionStrategy.NONE`, `EvictionStrategy.LRU`, `EvictionStrategy.UNORDERED`, and `EvictionStrategy.LIRS`.

4.3.1. Configuration

Eviction may be configured using the Configuration bean or the XML file. Eviction configuration is on a per-cache basis. Valid eviction-related configuration elements are:

```
<eviction strategy="LRU" max-entries="2000"/>
<expiration lifespan="1000" max-idle="500" interval="1000" />
```

Programmatically, the same would be defined using:

```
Configuration c = new ConfigurationBuilder().eviction().strategy(EvictionStrategy.LRU)
    .maxEntries(2000).expiration().wakeUpInterval(5000).lifespan(1000)
    .maxIdle(500)
    .build();
```

4.3.2. Default values

Eviction is disabled by default. If enabled (using an empty `<eviction />` element), certain default values are used:

- strategy: `EvictionStrategy.NONE` is assumed, if a strategy is not specified..
- `wakeUpInterval`: 60000 is used if not specified.
- If you wish to disable the eviction thread, set `wakeUpInterval` to -1.
- `maxEntries`: -1 is used if not specified, which means unlimited entries.
- 0 means no entries, and the eviction thread will strive to keep the cache empty.

Expiration lifespan and `maxIdle` both default to -1.

4.3.3. Using expiration

Expiration allows you to set either a lifespan or a maximum idle time on each key/value pair stored in the cache. This can either be set cache-wide using the configuration, as described above, or it can be defined per-key/value pair using the `Cache` interface. Any values defined per key/value pair overrides the cache-wide default for the specific entry in question.

For example, assume the following configuration:

```
<expiration lifespan="1000" />
```



```
// this entry will expire in 1000 millis
cache.put("pinot noir", pinotNoirPrice);

// this entry will expire in 2000 millis
cache.put("chardonnay", chardonnayPrice, 2, TimeUnit.SECONDS);

// this entry will expire 1000 millis after it is last accessed
cache.put("pinot grigio", pinotGrigioPrice, -1,
        TimeUnit.SECONDS, 1, TimeUnit.SECONDS);

// this entry will expire 1000 millis after it is last accessed, or
// in 5000 millis, whichever triggers first
cache.put("riesling", rieslingPrice, 5,
        TimeUnit.SECONDS, 1, TimeUnit.SECONDS);
```

4.4. Eviction designs

Central to eviction is an `EvictionManager` - which is only available if eviction or expiration is configured.

The purpose of the `EvictionManager` is to drive the eviction/expiration thread which periodically purges items from the `DataContainer`. If the eviction thread is disabled (`wakeupInterval` set to -1) eviction can be kicked off manually using `EvictionManager.processEviction()`, for example from another maintenance thread that may run periodically in your application.

The eviction manager processes evictions in the following manner:

1. Causes the data container to purge expired entries
2. Causes cache stores (if any) to purge expired entries
3. Prunes the data container to a specific size, determined by `maxElements`

Chapter 5. Persistence

Persistence allows configuring external (persistent) storage engines complementary to the default in memory storage offered by Infinispan. An external persistent storage might be useful for several reasons:

- **Increased Durability.** Memory is volatile, so a cache store could increase the life-span of the information store in the cache.
- **Write-through.** Interpose Infinispan as a caching layer between an application and a (custom) external storage engine.
- **Overflow Data.** By using eviction and passivation, one can store only the "hot" data in memory and overflow the data that is less frequently used to disk.

The integration with the persistent store is done through the following SPI: `CacheLoader`, `CacheWriter`, `AdvancedCacheLoader` and `AdvancedCacheWriter` (discussed in the following sections).

This SPI was refactored in Infinispan 6. It brings the following improvements over the previous (up to 5.x) persistence integration

- **Alignment with JSR-107.** The `CacheWriter` and `CacheLoader` interface are similar to the the loader and writer in JSR 107. This should considerably help writing portable stores across JCache compliant vendors.
- **Simplified Transaction Integration.** All necessary locking is handled by Infinispan automatically and implementations don't have to be concerned with coordinating concurrent access to the store. Even though concurrent writes on the same key are not going to happen (depending locking mode in use), implementors should expect operations on the store to happen from multiple/different threads and code the implementation accordingly.
- **Parallel Iteration.** It is now possible to iterate over entries in the store with multiple threads in parallel.
- **Reduced Serialization.** This translates in less CPU usage. The new API exposes the stored entries in serialized format. If an entry is fetched from persistent storage for the sole purpose of being sent remotely, we no longer need to deserialize it (when reading from the store) and serialize it back (when writing to the wire). Now we can write to the wire the serialized format as read from the storage directly.

5.1. Data Migration

The format in which data is persisted has changed in Infinispan 6.0, so this means that if you stored data using Infinispan 4.x or Infinispan 5.x, Infinispan 6.0 won't be able to read it. The best way to upgrade persisted data from Infinispan 4.x/5.x to Infinispan 6.0 is to use the mechanisms explained in the [Rolling Upgrades section](#). In other words, by starting a rolling upgrade, data stored in Infinispan 4.x/5.x can be migrated to a Infinispan 6.0 installation where persistence is configured with a different location for the data. The location configuration varies according to the specific details of each cache store.

Following sections describe the SPI and also discuss the SPI implementations that Infinispan ships

out of the box.

5.2. API

The following class diagram presents the main SPI interfaces of the persistence API:

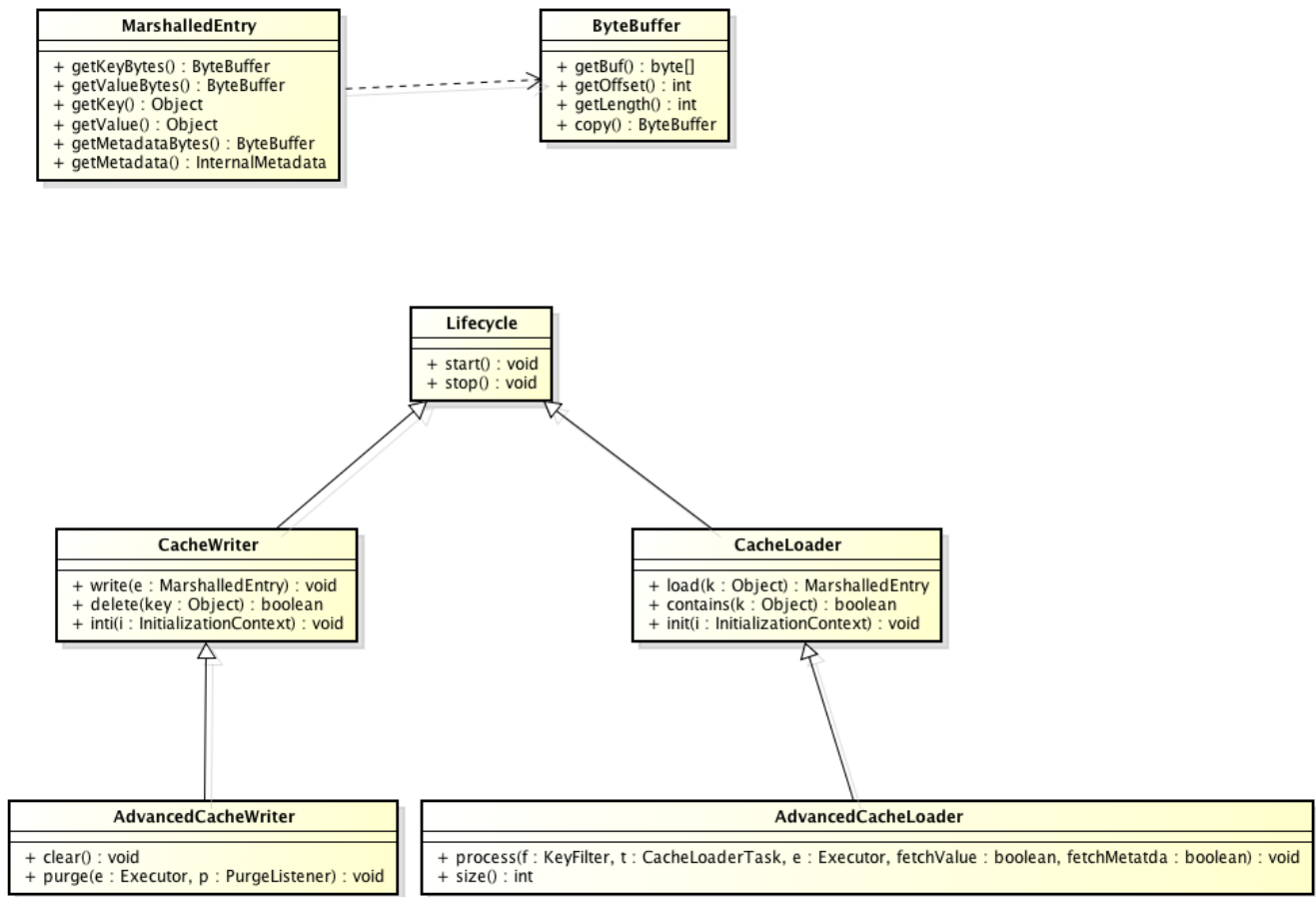


Figure 1. Persistence SPI

Some notes about the classes:

- [ByteBuffer](#) - abstracts the serialized form of an object
- [MarshalledEntry](#) - abstracts the information held within a persistent store corresponding to a key-value added to the cache. Provides method for reading this information both in serialized ([ByteBuffer](#)) and deserialized (Object) format. Normally data read from the store is kept in serialized format and lazily deserialized on demand, within the [MarshalledEntry](#) implementation
- [CacheWriter](#) and [CacheLoader](#) provide basic methods for reading and writing to a store
- [AdvancedCacheLoader](#) and [AdvancedCacheWriter](#) provide operations to manipulate the underlying storage in bulk: parallel iteration and purging of expired entries, clear and size.

A provider might choose to only implement a subset of these interfaces:

- Not implementing the [AdvancedCacheWriter](#) makes the given writer not usable for purging expired entries or clear
- If a loader does not implement the [AdvancedCacheWriter](#) interface, then it will not participate in

preloading nor in cache iteration (required also for stream operations).

If you're looking at migrating your existing store to the new API or to write a new store implementation, the [SingleFileStore](#) might be a good starting point/example.

5.3. Configuration

Stores (readers and/or writers) can be configured in a chain. Cache read operation looks at all of the specified `CacheLoader` s, in the order they are configured, until it finds a valid and non-null element of data. When performing writes all cache `CacheWriter` s are written to, except if the `ignoreModifications` element has been set to true for a specific cache writer.



Implementing both a CacheWriter and CacheLoader

it is possible and recommended for a store provider to implement both the `CacheWriter` and the `CacheLoader` interface. The stores that do this are considered both for reading and writing (assuming `read-only=false`) data.

This is the configuration of a custom (not shipped with Infinispan) store:

```
<local-cache name="myCustomStore">
  <persistence passivation="false">
    <store
      class="org.acme.CustomStore"
      fetch-state="false" preload="true" shared="false"
      purge="true" read-only="false" singleton="false">

      <write-behind modification-queue-size="123" thread-pool-size="23" />

    <property name="myProp">${system.property}</property>
    </store>
  </persistence>
</local-cache>
```

Explanation of the configuration options:

- `passivation` (false by default) has a significant impact on how Infinispan interacts with the loaders, and is discussed in the [Cache Passivation](#) section.
- `class` defines the class of the store and must implement `CacheLoader`, `CacheWriter` or both
- `fetch-state` (false by default) determines whether or not to fetch the persistent state of a cache when joining a cluster. The aim here is to take the persistent state of a cache and apply it to the local cache store of the joining node. Fetch persistent state is ignored if a cache store is configured to be shared, since they access the same data. Only one configured cache loader may set this property to true; if more than one cache loader does so, a configuration exception will be thrown when starting your cache service.
- `preload` (false by default) if true, when the cache starts, data stored in the cache loader will be pre-loaded into memory. This is particularly useful when data in the cache loader is needed immediately after startup and you want to avoid cache operations being delayed as a result of

loading this data lazily. Can be used to provide a 'warm-cache' on startup, however there is a performance penalty as startup time is affected by this process. Note that preloading is done in a local fashion, so any data loaded is only stored locally in the node. No replication or distribution of the preloaded data happens. Also, Infinispan only preloads up to the maximum configured number of entries in [eviction](#).

- **shared** (false by default) indicates that the cache loader is shared among different cache instances, for example where all instances in a cluster use the same JDBC settings to talk to the same remote, shared database. Setting this to true prevents repeated and unnecessary writes of the same data to the cache loader by different cache instances.
- **purge** (false by default) empties the specified cache loader (if **read-only** is false) when the cache loader starts up.
- **read-only** (false by default) prevents new data to be persisted to the store.
- **write-behind** (disabled by default) element has to do with a persisting data asynchronously to the actual store. It is discussed in detail [here](#).
- **singleton** (disabled by default) attribute enables modifications to be stored by only one node in the cluster, the coordinator. Essentially, whenever any data comes in to some node it is always replicated(or distributed) so as to keep the caches in-memory states in sync; the coordinator, though, has the sole responsibility of pushing that state to disk. This functionality must be configured by setting the enabled attribute to true in all nodes. Only the coordinator of the cluster will persist data, but all nodes must have this configured to prevent others from persisting as well. You cannot configure a store as shared and singleton.
- additional attributes can be configured within the **properties** section. These attributes configure aspects specific to each cache loader, e.g. the **myProp** attribute in the previous example. Other loaders, with more complex configuration, also introduce additional sub-elements to the basic configuration. See for example the JDBC cache store configuration examples below

The configuration above is used for a generic store implementation. However the store implementation provided by default with Infinispan have a more rich configuration schema, in which the **properties** section is replaced with XML attributes:

```
<persistence passivation="false">
  <!-- note that class is missing and is induced by the fileStore element name -->
  <file-store
    shared="false" preload="true"
    fetch-state="true"
    read-only="false"
    purge="false"
    path="{java.io.tmpdir}">
    <write-behind thread-pool-size="5" />
  </file-store>
</persistence>
```

The same configuration can be achieved programmatically:

```

ConfigurationBuilder builder = new ConfigurationBuilder();
builder.persistence()
    .passivation(false)
    .addSingleFileStore()
        .preload(true)
        .shared(false)
        .fetchPersistentState(true)
        .ignoreModifications(false)
        .purgeOnStartup(false)
        .location(System.getProperty("java.io.tmpdir"))
    .async()
        .enabled(true)
        .threadPoolSize(5)
    .singleton()
        .enabled(true)
        .pushStateWhenCoordinator(true)
        .pushStateTimeout(20000);

```

5.4. Cache Passivation

A CacheWriter can be used to enforce entry passivation and activation on eviction in a cache. Cache passivation is the process of removing an object from in-memory cache and writing it to a secondary data store (e.g., file system, database) on eviction. Cache activation is the process of restoring an object from the data store into the in-memory cache when it's needed to be used. In order to fully support passivation, a store needs to be both a CacheWriter and a CacheLoader. In both cases, the configured cache store is used to read from the loader and write to the data writer.

When an eviction policy in effect evicts an entry from the cache, if passivation is enabled, a notification that the entry is being passivated will be emitted to the cache listeners and the entry will be stored. When a user attempts to retrieve a entry that was evicted earlier, the entry is (lazily) loaded from the cache loader into memory. When the entry and its children have been loaded, they're removed from the cache loader and a notification is emitted to the cache listeners that the entry has been activated. In order to enable passivation just set passivation to true (false by default). When passivation is used, only the first cache loader configured is used and all others are ignored.

5.4.1. Cache Loader Behavior with Passivation Disabled vs Enabled

When passivation is disabled, whenever an element is modified, added or removed, then that modification is persisted in the backend store via the cache loader. There is no direct relationship between eviction and cache loading. If you don't use eviction, what's in the persistent store is basically a copy of what's in memory. If you do use eviction, what's in the persistent store is basically a superset of what's in memory (i.e. it includes entries that have been evicted from memory). When passivation is enabled, there is a direct relationship between eviction and the cache loader. Writes to the persistent store via the cache loader only occur as part of the eviction process. Data is deleted from the persistent store when the application reads it back into memory. In this case, what's in memory and what's in the persistent store are two subsets of the total

information set, with no intersection between the subsets.

The following is a simple example, showing what state is in RAM and in the persistent store after each step of a 6 step process:

1. Insert keyOne
2. Insert keyTwo
3. Eviction thread runs, evicts keyOne
4. Read keyOne
5. Eviction thread runs, evicts keyTwo
6. Remove keyTwo

When passivation is disabled

1. **Memory:** keyOne **Disk:** keyOne
2. **Memory:** keyOne, keyTwo **Disk:** keyOne, keyTwo
3. **Memory:** keyTwo **Disk:** keyOne, keyTwo
4. **Memory:** keyOne, keyTwo **Disk:** keyOne, keyTwo
5. **Memory:** keyOne **Disk:** keyOne, keyTwo
6. **Memory:** keyOne **Disk:** keyOne

When passivation is enabled

1. **Memory:** keyOne **Disk:** (none)
2. **Memory:** keyOne, keyTwo **Disk:** (none)
3. **Memory:** keyTwo **Disk:** keyOne
4. **Memory:** keyOne, keyTwo **Disk:** (none)
5. **Memory:** keyOne **Disk:** keyTwo
6. **Memory:** keyOne **Disk:** (none)

5.5. Cache Loaders and transactional caches

When a cache is transactional and a cache loader is present, the cache loader won't be enlisted in the transaction in which the cache is part. That means that it is possible to have inconsistencies at cache loader level: the transaction to succeed applying the in-memory state but (partially) fail applying the changes to the store. Manual recovery would not work with caches stores.

5.6. Write-Through And Write-Behind Caching

Infinispan can optionally be configured with one or several cache stores allowing it to store data in a persistent location such as shared JDBC database, a local filesystem, etc. Infinispan can handle updates to the cache store in two different ways:

- Write-Through (Synchronous)

- Write-Behind (Asynchronous)

5.6.1. Write-Through (Synchronous)

In this mode, which is supported in version 4.0, when clients update a cache entry, i.e. via a `Cache.put()` invocation, the call will not return until Infinispan has gone to the underlying cache store and has updated it. Normally, this means that updates to the cache store are done within the boundaries of the client thread.

The main advantage of this mode is that the cache store is updated at the same time as the cache, hence the cache store is consistent with the cache contents. On the other hand, using this mode reduces performance because the latency of having to access and update the cache store directly impacts the duration of the cache operation.

Configuring a write-through or synchronous cache store does not require any particular configuration option. By default, unless marked explicitly as write-behind or asynchronous, all cache stores are write-through or synchronous. Please find below a sample configuration file of a write-through unshared local file cache store:

```
<persistence passivation="false">
  <file-store fetch-state="true"
    read-only="false"
    purge="false" path="${java.io.tmpdir}"/>
</persistence>
```

5.6.2. Write-Behind (Asynchronous)

In this mode, updates to the cache are asynchronously written to the cache store. Normally, this means that updates to the cache store are done by a separate thread to the client thread interacting with the cache.

One of the major advantages of this mode is that the performance of a cache operation does not get affected by the update of the underlying store. On the other hand, since the update happens asynchronously, there's a time window during the which the cache store can contain stale data compared to the cache. Even within write-behind, there are different strategies that can be used to store data:

Unscheduled Write-Behind Strategy

In this mode, which is supported in version 4.0, Infinispan tries to store changes as quickly as possible by taking the pending changes and applying them in parallel. Normally, this means that there are several threads waiting for modifications to occur and once they're available, they apply them to underlying cache store.

This strategy is suited for cache stores with low latency and cheap operation cost. One such example would a local unshared file based cache store, where the cache store is local to the cache itself. With this strategy, the window of inconsistency between the contents of the cache and the cache store are reduced to the lowest possible time. Please find below a sample configuration file of

this strategy:

```
<persistence passivation="false">
  <file-store fetch-state="true"
    read-only="false"
    purge="false" path="${java.io.tmpdir}">
    <!-- write behind configuration starts here -->
    <write-behind />
    <!-- write behind configuration ends here -->
  </file-store>
</persistence>
```

Scheduled Write-Behind Strategy

First of all, please note that this strategy is not included in version 4.0 but it will be implemented at a later stage. [ISPN-328](#) has been created to track this feature request. If you want it implemented, please vote for it on that page, and watch it to be notified of any changes. The following explanation refers to how we envision it to work.

In this mode, Infinispan would periodically store changes to the underlying cache store. The periodicity could be defined in seconds, minutes, days, etc.

Since this strategy is oriented at cache stores with high latency or expensive operation cost, it makes sense to coalesce changes, so that if there are multiple operations queued on the same key, only the latest value is applied to cache store. With this strategy, the window of inconsistency between the contents of the cache and the cache store depends on the delay or periodicity configured. The higher the periodicity, the higher the chance of inconsistency.

5.7. Filesystem based cache stores

A filesystem-based cache store is typically used when you want to have a cache with a cache store available locally which stores data that has overflowed from memory, having exceeded size and/or time restrictions.



Usage of filesystem-based cache stores on shared filesystems like NFS, Windows shares, etc. should be avoided as these do not implement proper file locking and can cause data corruption. File systems are inherently not transactional, so when attempting to use your cache in a transactional context, failures when writing to the file (which happens during the commit phase) cannot be recovered.

5.7.1. Single File Store

Starting with Infinispan 6.0, a new file cache store has been created called single file cache store. The old pre-6.0 file cache store has been completely removed, and it's no longer configurable.



Check [Data Migration section](#) for information on how to migrate old file based cache store data to the new single file cache store.

The new single file cache store keeps all data in a single file. The way it looks up data is by keeping an in-memory index of keys and the positions of their values in this file. This results in greater performance compared to old file cache store. There is one caveat though. Since the single file based cache store keeps keys in memory, it can lead to increased memory consumption, and hence it's not recommended for caches with big keys.

In certain use cases, this cache store suffers from fragmentation: if you store larger and larger values, the space is not reused and instead the entry is appended at the end of the file. The space (now empty) is reused only if you write another entry that can fit there. Also, when you remove all entries from the cache, the file won't shrink, and neither will be de-fragmented.

These are the available configuration options for the single file cache store:

- `path` where data will be stored. (e.g., `path="/tmp/myDataStore"`). By default, the location is `Infinispan-SingleFileStore`.
- `max-entries` specifies the maximum number of entries to keep in this file store. As mentioned before, in order to speed up lookups, the single file cache store keeps an index of keys and their corresponding position in the file. To avoid this index resulting in memory consumption problems, this cache store can be bounded by a maximum number of entries that it stores. If this limit is exceeded, entries are removed permanently using the LRU algorithm both from the in-memory index and the underlying file based cache store. So, setting a maximum limit only makes sense when Infinispan is used as a cache, whose contents can be recomputed or they can be retrieved from the authoritative data store. If this maximum limit is set when the Infinispan is used as an authoritative data store, it could lead to data loss, and hence it's not recommended for this use case. The default value is `-1` which means that the file store size is unlimited.

```
<persistence>
  <file-store path="/tmp/myDataStore" max-entries="5000"/>
</persistence>
```

```
ConfigurationBuilder b = new ConfigurationBuilder();
b.persistence()
  .addSingleFileStore()
  .location("/tmp/myDataStore")
  .maxEntries(5000);
```

5.7.2. Soft-Index File Store

In Infinispan 7.0 we have added a new experimental local file-based cache store - Soft-Index File Store. It is a pure Java implementation that tries to get around Single File Store's drawbacks by implementing a variant of B+ tree that is cached in-memory using Java's soft references - here's where the name Soft-Index File Store comes from. This B+ tree (called Index) is offloaded on filesystem to single file that does not need to be persisted - it is purged and rebuilt when the cache store restarts, its purpose is only offloading.

The data that should be persisted are stored in a set of files that are written in append-only way -

that means that if you store this on conventional magnetic disk, it does not have to seek when writing a burst of entries. It is not stored in single file but set of files. When the usage of any of these files drops below 50% (the entries from the file are overwritten to another file), the file starts to be collected, moving the live entries into different file and in the end removing that file from disk.

Most of the structures in Soft Index File Store are bounded, therefore you don't have to be afraid of OOMs. For example, you can configure the limits for concurrently open files as well.

Configuration

Here is an example of Soft-Index File Store configuration via XML:

```
<persistence>
  <soft-index-file-store xmlns="urn:infinispan:config:soft-index:7.0">
    <index path="/tmp/sifs/testCache/index" />
    <data path="/tmp/sifs/testCache/data" />
  </soft-index-file-store>
</persistence>
```

Programmatic configuration would look as follows:

```
ConfigurationBuilder b = new ConfigurationBuilder();
b.persistence()
  .addStore(SoftIndexFileStoreConfigurationBuilder.class)
  .indexLocation("/tmp/sifs/testCache/index");
  .dataLocation("/tmp/sifs/testCache/data")
```

Current limitations

Size of a node in the Index is limited, by default it is 4096 bytes, though it can be configured. This size also limits the key length (or rather the length of the serialized form): you can't use keys longer than size of the node - 15 bytes. Moreover, the key length is stored as 'short', limiting it to 32767 bytes. There's no way how you can use longer keys - SIFS throws an exception when the key is longer after serialization.

When entries are stored with expiration, SIFS cannot detect that some of those entries are expired. Therefore, such old file will not be compacted (method `AdvancedStore.purgeExpired()` is not implemented). This can lead to excessive file-system space usage.

For detailed description of all the parameters supported by the stores, please consult the [javadoc](#).

5.8. JDBC based cache loaders

Based on the type of keys to be persisted, there are three JDBC cache loaders:

- [JdbcBinaryStore](#) - can store any type of keys. It stores all the keys that have the same hash value (hashCode method on key) in the same table row/blob, having as primary key the hash value. While this offers great flexibility (can store any key type), it impacts concurrency/throughput. E.g. If storing k1,k2 and k3 keys, and keys had same hash code, then they'd persisted in the same table row. Now, if 3 threads try to concurrently update k1, k2 and k3 respectively, they would need to do it sequentially since these threads would be updating the same row.
- [JdbcStringBasedStore](#) - stores each key in its own row, increasing throughput under concurrent load. In order to store each key in its own column, it relies on a (pluggable) bijection that maps the each key to a String object. The bijection is defined by the Key2StringMapper interface. Infinispan ships a default implementation (smartly named [DefaultTwoWayKey2StringMapper](#)) that knows how to handle primitive types.
- [JdbcMixedStore](#) - it is a hybrid implementation that, based on the key type, delegates to either [JdbcBinaryStore](#) or [JdbcStringBasedStore](#).

5.8.1. Which JDBC cache loader should I use?

It is generally preferable to use [JdbcStringBasedStore](#) when you are in control of the key types, as it offers better throughput under heavy load. One scenario in which it is not possible to use it though, is when you can't write a [Key2StringMapper](#) to map the keys to string objects (e.g. when you don't have control over the types of the keys, for whatever reason). Then you should use either [JdbcBinaryStore](#) or [JdbcMixedStore](#) . The later is preferred to the former when the majority of the keys are handled by [JdbcStringBasedStore](#) , but you still have some keys you cannot convert through [DefaultTwoWayKey2StringMapper](#).

5.8.2. Connection management (pooling)

In order to obtain a connection to the database all the JDBC cache loaders rely on a [ConnectionFactory](#) implementation. The connection factory is specified programmatically using one of the `connectionPool()`, `dataSource()` or `simpleConnection()` methods on the `JdbcBinaryCacheStoreConfigurationBuilder` class or declaratively using one of the `<connectionPool />`, `<dataSource />` or `<simpleConnection />` elements. Infinispan ships with three `ConnectionFactory` implementations:

- [PooledConnectionFactory](#) is a factory based on `C3P0` . Refer to [javadoc](#) for details on configuring it.
- [ManagedConnectionFactory](#) is a connection factory that can be used within managed environments, such as application servers. It knows how to look into the JNDI tree at a certain location (configurable) and delegate connection management to the `DataSource`. Refer to [javadoc](#) [javadoc](#) for details on how this can be configured.
- [SimpleConnectionFactory](#) is a factory implementation that will create database connection on a per invocation basis. Not recommended in production.

The [PooledConnectionFactory](#) is generally recommended for stand-alone deployments (i.e. not running within AS or servlet container). [ManagedConnectionFactory](#) can be used when running in a managed environment where a `DataSource` is present, so that connection pooling is performed within the `DataSource`.

5.8.3. Sample configurations

Below is a sample configuration for the [JdbcBinaryStore](#) . For detailed description of all the parameters used refer to the [JdbcBinaryStore](#) . Please note the use of multiple XML schemas, since each store has its own schema.

```
<persistence>
  <binary-keyed-jdbc-store fetch-state="false" read-only="false" purge="false">
    <simple-connection connection-url=
"jdbc:h2:mem:infinispan_binary_based;DB_CLOSE_DELAY=-1" driver="org.h2.Driver"
username="sa"/>
    <binary-keyed-table prefix="ISPN_BUCKET_TABLE" drop-on-exit="true" create-on-
start="true">
      <id-column name="ID_COLUMN" type="VARCHAR(255)" />
      <data-column name="DATA_COLUMN" type="BINARY" />
      <timestamp-column name="TIMESTAMP_COLUMN" type="BIGINT" />
    </binary-keyed-table>
  </binary-keyed-jdbc-store>
</persistence>
```

```
ConfigurationBuilder builder = new ConfigurationBuilder();
builder.persistence()
  .addStore(JdbcBinaryStoreConfigurationBuilder.class)
  .fetchPersistentState(false)
  .ignoreModifications(false)
  .purgeOnStartup(false)
  .table()
  .dropOnExit(true)
  .createOnStart(true)
  .tableNamePrefix("ISPN_BUCKET_TABLE")
  .idColumnName("ID_COLUMN").idColumnType("VARCHAR(255)")
  .dataColumnName("DATA_COLUMN").dataColumnType("BINARY")
  .timestampColumnName("TIMESTAMP_COLUMN").timestampColumnType("BIGINT")
  .connectionPool()
    .connectionUrl("jdbc:h2:mem:infinispan_binary_based;DB_CLOSE_DELAY=-1")
    .username("sa")
    .driverClass("org.h2.Driver");
```

Below is a sample configuration for the [JdbcStringBasedStore](#) . For detailed description of all the parameters used refer to the [JdbcStringBasedStore](#) .

```

<persistence>
  <string-keyed-jdbc-store fetch-state="false" read-only="false" purge="false">
    <connection-pool connection-url=
"jdbc:h2:mem:infinispan_string_based;DB_CLOSE_DELAY=-1" username="sa" driver=
"org.h2.Driver"/>
    <string-keyed-table drop-on-exit="true" create-on-start="true" prefix=
"ISPN_STRING_TABLE">
      <id-column name="ID_COLUMN" type="VARCHAR(255)" />
      <data-column name="DATA_COLUMN" type="BINARY" />
      <timestamp-column name="TIMESTAMP_COLUMN" type="BIGINT" />
    </string-keyed-table>
  </string-keyed-jdbc-store>
</persistence>

```

```

ConfigurationBuilder builder = new ConfigurationBuilder();
builder.persistence().addStore(JdbcStringBasedStoreConfigurationBuilder.class)
    .fetchPersistentState(false)
    .ignoreModifications(false)
    .purgeOnStartup(false)
    .table()
        .dropOnExit(true)
        .createOnStart(true)
        .tableNamePrefix("ISPN_STRING_TABLE")
        .idColumnName("ID_COLUMN").idColumnType("VARCHAR(255)")
        .dataColumnName("DATA_COLUMN").dataColumnType("BINARY")
        .timestampColumnName("TIMESTAMP_COLUMN").timestampColumnType("BIGINT")
    .connectionPool()
        .connectionUrl("jdbc:h2:mem:infinispan_binary_based;DB_CLOSE_DELAY=-1")
        .username("sa")
        .driverClass("org.h2.Driver");

```

Below is a sample configuration for the [JdbcMixedStore](#) . For detailed description of all the parameters used refer to the [JdbcMixedStore](#) .

```

<persistence>
  <mixed-keyed-jdbc-store fetch-state="false" read-only="false" purge="false">
    <simple-connection connection-url=
"jdbc:h2:mem:infinispan_binary_based;DB_CLOSE_DELAY=-1" driver="org.h2.Driver"
username="sa"/>
    <string-keyed-table prefix="ISPN_MIXED_STR_TABLE" drop-on-exit="true" create-on-
start="true">
      <id-column name="ID_COLUMN" type="VARCHAR(255)" />
      <data-column name="DATA_COLUMN" type="BINARY" />
      <timestamp-column name="TIMESTAMP_COLUMN" type="BIGINT" />
    </string-keyed-table>
    <binary-keyed-table prefix="ISPN_MIXED_BINARY_TABLE" drop-on-exit="true" create-
on-start="true">
      <id-column name="ID_COLUMN" type="VARCHAR(255)" />
      <data-column name="DATA_COLUMN" type="BINARY" />
      <timestamp-column name="TIMESTAMP_COLUMN" type="BIGINT" />
    </binary-keyed-table>
  </mixed-keyed-jdbc-store>
</persistence>

```

```

ConfigurationBuilder builder = new ConfigurationBuilder();
builder.persistence().addStore(JdbcMixedStoreConfigurationBuilder.class)
  .fetchPersistentState(false).ignoreModifications(false).purgeOnStartup(false)
  .stringTable()
    .dropOnExit(true)
    .createOnStart(true)
    .tableNamePrefix("ISPN_MIXED_STR_TABLE")
    .idColumnName("ID_COLUMN").idColumnType("VARCHAR(255)")
    .dataColumnName("DATA_COLUMN").dataColumnType("BINARY")
    .timestampColumnName("TIMESTAMP_COLUMN").timestampColumnType("BIGINT")
  .binaryTable()
    .dropOnExit(true)
    .createOnStart(true)
    .tableNamePrefix("ISPN_MIXED_BINARY_TABLE")
    .idColumnName("ID_COLUMN").idColumnType("VARCHAR(255)")
    .dataColumnName("DATA_COLUMN").dataColumnType("BINARY")
    .timestampColumnName("TIMESTAMP_COLUMN").timestampColumnType("BIGINT")
  .connectionPool()
    .connectionUrl("jdbc:h2:mem:infinispan_binary_based;DB_CLOSE_DELAY=-1")
    .username("sa")
    .driverClass("org.h2.Driver");

```

Finally, below is an example of a JDBC cache store with a managed connection factory, which is chosen implicitly by specifying a datasource JNDI location:

```
<string-keyed-jdbc-store xmlns="urn:infinispan:config:store:jdbc:7.0" fetch-state=
"false" read-only="false" purge="false">
  <data-source jndi-url="java:/StringStoreWithManagedConnectionTest/DS" />
  <string-keyed-table drop-on-exit="true" create-on-start="true" prefix=
"ISPN_STRING_TABLE">
    <id-column name="ID_COLUMN" type="VARCHAR(255)" />
    <data-column name="DATA_COLUMN" type="BINARY" />
    <timestamp-column name="TIMESTAMP_COLUMN" type="BIGINT" />
  </string-keyed-table>
</string-keyed-jdbc-store>
```

```
ConfigurationBuilder builder = new ConfigurationBuilder();
builder.persistence().addStore(JdbcStringBasedStoreConfigurationBuilder.class)
    .fetchPersistentState(false).ignoreModifications(false).purgeOnStartup(false)
    .table()
        .dropOnExit(true)
        .createOnStart(true)
        .tableNamePrefix("ISPN_STRING_TABLE")
        .idColumnName("ID_COLUMN").idColumnType("VARCHAR(255)")
        .dataColumnName("DATA_COLUMN").dataColumnType("BINARY")
        .timestampColumnName("TIMESTAMP_COLUMN").timestampColumnType("BIGINT")
    .dataSource()
        .jndiUrl("java:/StringStoreWithManagedConnectionTest/DS");
```



Apache Derby users

If you're connecting to an Apache Derby database, make sure you set `dataColumnType` to `BLOB`: `<data-column name="DATA_COLUMN" type="BLOB"/>`

5.9. Remote store

The `RemoteStore` is a cache loader and writer implementation that stores data in a remote `infinispan` cluster. In order to communicate with the remote cluster, the `RemoteStore` uses the `HotRod` client/server architecture. `HotRod` bearing the load balancing and fault tolerance of calls and the possibility to fine-tune the connection between the `RemoteCacheStore` and the actual cluster. Please refer to `Hot Rod` for more information on the protocol, client and server configuration. For a list of `RemoteStore` configuration refer to the [javadoc](#) . Example:


```

<persistence>
  <remote-store xmlns="urn:infinispan:config:remote:7.0" cache="mycache" raw-values=
    "true">
    <remote-server host="one" port="12111" />
    <remote-server host="two" />
    <connection-pool max-active="10" exhausted-action="CREATE_NEW" />
    <write-behind />
  </remote-store>
</persistence>

```

```

ConfigurationBuilder b = new ConfigurationBuilder();
b.persistence().addStore(RemoteStoreConfigurationBuilder.class)
    .fetchPersistentState(false)
    .ignoreModifications(false)
    .purgeOnStartup(false)
    .remoteCacheName("mycache")
    .rawValues(true)
.addServer()
    .host("one").port(12111)
    .addServer()
    .host("two")
    .connectionPool()
    .maxActive(10)
    .exhaustedAction(ExhaustedAction.CREATE_NEW)
    .async().enable();

```

In this sample configuration, the remote cache store is configured to use the remote cache named "mycache" on servers "one" and "two". It also configures connection pooling and provides a custom transport executor. Additionally the cache store is asynchronous.

5.10. Cluster cache loader

The ClusterCacheLoader is a cache loader implementation that retrieves data from other cluster members.

It is a cache loader only as it doesn't persist anything (it is not a Store), therefore features like *fetchPersistentState* (and like) are not applicable.

A cluster cache loader can be used as a non-blocking (partial) alternative to *stateTransfer* : keys not already available in the local node are fetched on-demand from other nodes in the cluster. This is a kind of lazy-loading of the cache content.

```

<persistence>
  <cluster-loader remote-timeout="500"/>
</persistence>

```

```
ConfigurationBuilder b = new ConfigurationBuilder();
b.persistence()
    .addClusterLoader()
    .remoteCallTimeout(500);
```

For a list of ClusterCacheLoader configuration refer to the [javadoc](#).



The ClusterCacheLoader does not support preloading(preload=true). It also won't provide state if fetchPersistentSate=true.

5.11. Custom Cache Store deployment

A Custom Cache Store might be packaged into a separate JAR file and deployed in a HotRod server using the following steps:

1. Create a JAR file (or use a [Custom Cache Store Archetype](#)) and implement one of the interfaces within it:
 - `org.infinispan.persistence.spi.AdvancedCacheWriter`
 - `org.infinispan.persistence.spi.AdvancedCacheLoader`
 - `org.infinispan.persistence.spi.CacheLoader`
 - `org.infinispan.persistence.spi.CacheWriter`
 - `org.infinispan.persistence.spi.ExternalStore`
 - `org.infinispan.persistence.spi.AdvancedLoadWriteStore`
2. It is possible to create a Custom Cache Store configuration. This requires implementing `AbstractStoreConfiguration` and `AbstractStoreConfigurationBuilder`. Additionally, 2 annotations need to be added to the configuration - `@ConfigurationFor` and `@BuiltBy`. However this is an optional step.
3. Create a proper file in `META-INF/services/`, which reflects the implementation:
 - `/META-INF/services/org.infinispan.persistence.spi.AdvancedCacheWriter`
 - `/META-INF/services/org.infinispan.persistence.spi.AdvancedCacheLoader`
 - `/META-INF/services/org.infinispan.persistence.spi.CacheLoader`
 - `/META-INF/services/org.infinispan.persistence.spi.CacheWriter`
 - `/META-INF/services/org.infinispan.persistence.spi.ExternalStore`
 - `/META-INF/services/org.infinispan.persistence.spi.AdvancedLoadWriteStore` Write the fully qualified class name of the Custom Cache Store class implementation.
4. Deploy the JAR file in the Infinispan Server.

5.12. Command-Line Interface cache loader

The Command-Line Interface (CLI) cache loader is a cache loader implementation that retrieves data from another Infinispan node using the CLI. The node to which the CLI connects to could be a standalone node, or could be a node that it's part of a cluster. This cache loader is read-only, so it

will only be used to retrieve data, and hence, won't be used when persisting data.

The CLI cache loader is configured with a connection URL pointing to the Infinispan node to which connect to. Here is an example:



Details on the format of the URL and how to make sure a node can receive invocations via the CLI can be found in the [Command-Line Interface chapter](#).

```
<persistence>
  <cli-loader connection="jmx://1.2.3.4:4444/MyCacheManager/myCache" />
</persistence>
```

```
ConfigurationBuilder b = new ConfigurationBuilder();
b.persistence()
  .addStore(CLInterfaceLoaderConfigurationBuilder.class)
  .connectionString("jmx://1.2.3.4:4444/MyCacheManager/myCache");
```

5.13. LevelDB Cache Store

The Infinispan Community

5.13.1. Introduction

[LevelDB](#) is a fast key-value filesystem-based storage from Google. The LevelDB cache store can use both the native implementation (via a JNI bridge) or a [Java re-implementation](#).

Sample Usage

LevelDB cache store requires 2 filesystem directories to be configured - each directory for a LevelDB database. One location is used to store non-expired data, while the second location is used to store expired keys pending purge.

```
Configuration cacheConfig = new ConfigurationBuilder().persistence()
    .addStore(LevelDBStoreConfigurationBuilder.class)
    .build();
EmbeddedCacheManager cacheManager = new DefaultCacheManager(cacheConfig);

Cache<String, User> usersCache = cacheManager.getCache("usersCache");
usersCache.put("raysang", new User(...));
```

5.13.2. Configuration

Sample Programatic Configuration

```
Configuration cacheConfig = new ConfigurationBuilder().persistence()
    .addStore(LevelDBStoreConfigurationBuilder.class)
    .location("/tmp/leveldb/data")
    .expiredLocation("/tmp/leveldb/expired")
    .build();
```

Parameter	Description
location	Directory to use for LevelDB to store primary cache store data. Directory will be auto-created if it does not exist.
expiredLocation	Directory to use for LevelDB to store expiring data pending to be purged permanently. Directory will be auto-created if it does not exist.
expiryQueueSize	Size of the in-memory queue to hold expiring entries before it gets flushed into expired LevelDB store
clearThreshold	There are two methods to clear all entries in LevelDB. One method is to iterate through all entries and remove each entry individually. The other method is to delete the database and re-init. For smaller databases, deleting individual entries is faster than the latter method. This configuration sets the max number of entries allowed before using the latter method
compressionType	Configuration for LevelDB for data compression, see CompressionType enum for options
blockSize	Configuration for LevelDB - see documentation for performance tuning
cacheSize	Configuration for LevelDB - see documentation for performance tuning

Sample XML Configuration

infinispan.xml

```
<local-cache name="vehicleCache">
  <persistence>
    <leveldb-store path="/tmp/leveldb/data">
      <expiration path="/tmp/leveldb/expired"/>
    </leveldb-store>
  </persistence>
</local-cache>
```

5.13.3. Additional References

Refer to the [test case](#) for code samples in action.

Refer to [test configurations](#) for configuration samples.

5.14. REST Cache Store

The Infinispan Community

5.14.1. Introduction

TODO

5.14.2. Javadoc

TODO

5.14.3. Configuration

TODO

5.15. JPA Cache Store

The Infinispan Community

5.15.1. Introduction

The implementation depends on JPA 2.0 specification to access entity meta model.

In normal use cases, it's recommended to leverage Infinispan for JPA second level cache and/or query cache. However, if you'd like to use only Infinispan API and you want Infinispan to persist into a cache store using a common format (e.g., a database with well defined schema), then JPA Cache Store could be right for you.

Things to note

- When using JPA Cache Store, the key should be the ID of the entity, while the value should be the entity object.
- Only a single `@Id` or `@EmbeddedId` annotated property is allowed.
- Auto-generated ID is not supported.
- Lastly, all entries will be stored as immortal entries.

Sample Usage

For example, given a persistence unit "myPersistenceUnit", and a JPA entity User:

persistence.xml

```
<persistence-unit name="myPersistenceUnit">
    ...
</persistence-unit>
```

User entity class

User.java

```
@Entity
public class User implements Serializable {
    @Id
    private String username;
    private String firstName;
    private String lastName;

    ...
}
```

Then you can configure a cache "usersCache" to use JPA Cache Store, so that when you put data into the cache, the data would be persisted into the database based on JPA configuration.

```
EmbeddedCacheManager cacheManager = ...;

Configuration cacheConfig = new ConfigurationBuilder().persistence()
    .addStore(JpaStoreConfigurationBuilder.class)
    .persistenceUnitName("org.infinispan.loaders.jpa.configurationTest")
    .entityClass(User.class)
    .build();
cacheManager.defineCache("usersCache", cacheConfig);

Cache<String, User> usersCache = cacheManager.getCache("usersCache");
usersCache.put("raytsang", new User(...));
```

Normally a single Infinispan cache can store multiple types of key/value pairs, for example:

```
Cache<String, User> usersCache = cacheManager.getCache("myCache");
usersCache.put("raytsang", new User());
Cache<Integer, Teacher> teachersCache = cacheManager.getCache("myCache");
teachersCache.put(1, new Teacher());
```

It's important to note that, when a cache is configured to use a JPA Cache Store, that cache would only be able to store ONE type of data.

```
Cache<String, User> usersCache = cacheManager.getCache("myJPACache"); // configured
for User entity class
usersCache.put("raytsang", new User());
Cache<Integer, Teacher> teachersCache = cacheManager.getCache("myJPACache"); // cannot
do this when this cache is configured to use a JPA cache store
teachersCache.put(1, new Teacher());
```

Use of `@EmbeddedId` is supported so that you can also use composite keys.

```
@Entity
public class Vehicle implements Serializable {
    @EmbeddedId
    private VehicleId id;
    private String color;    ...
}

@Embeddable
public class VehicleId implements Serializable
{
    private String state;
    private String licensePlate;
    ...
}
```

Lastly, auto-generated IDs (e.g., `@GeneratedValue`) is not supported. When putting things into the cache with a JPA cache store, the key should be the ID value!

5.16. Configuration

5.16.1. Sample Programatic Configuration

```
Configuration cacheConfig = new ConfigurationBuilder().persistence()
    .addStore(JpaStoreConfigurationBuilder.class)
    .persistenceUnitName("org.infinispan.loaders.jpa.configurationTest")
    .entityClass(User.class)
    .build();
```

Parameter	Description
persistenceUnitName	JPA persistence unit name in JPA configuration (persistence.xml) that contains the JPA entity class
entityClass	JPA entity class that is expected to be stored in this cache. Only one class is allowed.

5.16.2. Sample XML Configuration

```
<local-cache name="vehicleCache">
  <persistence passivation="false">
    <jpa-store xmlns="urn:infinispan:config:store:jpa:7.0"
      persistence-unit="org.infinispan.persistence.jpa.configurationTest"
      entity-class="org.infinispan.persistence.jpa.entity.Vehicle">
    />
  </persistence>
</local-cache>
```

Parameter	Description
persistence-unit	JPA persistence unit name in JPA configuration (persistence.xml) that contains the JPA entity class
entity-class	Fully qualified JPA entity class name that is expected to be stored in this cache. Only one class is allowed.

5.16.3. Additional References

Refer to the [test case](#) for code samples in action.

Refer to [test configurations](#) for configuration samples.

5.16.4. Javadoc

TODO

5.17. More implementations

Many more cache loader and cache store implementations exist. Visit [this website](#) for more details.

Chapter 6. Clustering

Infinispan can be configured to be either local (standalone) or clustered. If in a cluster, the cache can be configured to replicate changes to all nodes, to invalidate changes across nodes and finally to be used in distributed mode - state changes are replicated to a small subset of nodes enough to be fault tolerant but not too many nodes to prevent scalability.

6.1. Local Mode

While Infinispan is particularly interesting in clustered mode, it also offers a very capable local mode. In this mode, it acts as a simple, in-memory data cache similar to JBoss Cache and EHCache.

But why would one use a local cache rather than a map? Caches offer a lot of features over and above a simple map, including write-through and write-behind caching to persist data, eviction of entries to prevent running out of memory, and support for expirable entries. Infinispan, specifically, is built around a high-performance, read-biased data container which uses modern techniques similar to [read-copy-update](#) — which buys you non-blocking, thread-safe reads even when concurrent writes are taking place. Infinispan also makes heavy use of compare-and-swap and other lock-free algorithms, making it ideal for high-throughput, multi-CPU/multi-core environments. Further, Infinispan's Cache API extends the JDK's `ConcurrentMap` - making migration from a map to Infinispan trivial.

Creating a local-only cache-manager is trivial: just use the *no-argument* `DefaultCacheManager` constructor, or supply the following XML configuration file

```
<infinispan/>
```

You can also create local caches in a clustering-capable `CacheManager`.

6.1.1. Simple Cache

Traditional local caches use the same architecture as clustered caches, i.e. they use the interceptor stack. That way a lot of the implementation can be reused. However, if the advanced features are not needed and performance is more important, the interceptor stack can be stripped away and simple cache can be used.

So, which features are stripped away? From the configuration perspective, simple cache does not support:

- transactions and invocation batching
- persistence (cache stores and loaders)
- custom interceptors (there's no interceptor stack!)
- indexing
- compatibility (embedded/server mode)
- store as binary (which is hardly useful for local caches)

From the API perspective these features throw an exception:

- adding custom interceptors
- Distributed Executors Framework

So, what's left?

- basic map-like API
- cache listeners (local ones)
- expiration
- eviction
- security
- JMX access
- statistics (though for max performance it is recommended to switch this off using `statistics-available=false`)

Declarative configuration

```
<local-cache name="mySimpleCache" simple-cache="true">  
  <!-- expiration, eviction, security... -->  
</local-cache>
```

Programmatic configuration

```
CacheManager cm = getCacheManager();  
ConfigurationBuilder builder = new ConfigurationBuilder().simpleCache(true);  
cm.defineConfiguration("mySimpleCache", builder.build());  
Cache cache = cm.getCache("mySimpleCache");
```

Simple cache checks against features it does not support, if you configure it to use e.g. transactions, configuration validation will throw an exception.

6.2. Replicated Mode

Replication is a simple clustered mode where cache instances automatically discover neighboring instances on other JVMs on the same local network, and form a cluster. Entries added to any of these cache instances will be replicated to all other cache instances in the cluster, and can be retrieved locally from any instance. This clustered mode provides a quick and easy way to share state across a cluster, however replication practically only performs well in small clusters (under 10 nodes), due to the number of replication messages that need to happen - as the cluster size increases. Infinispan can be configured to use UDP multicast which mitigates this problem to some degree.

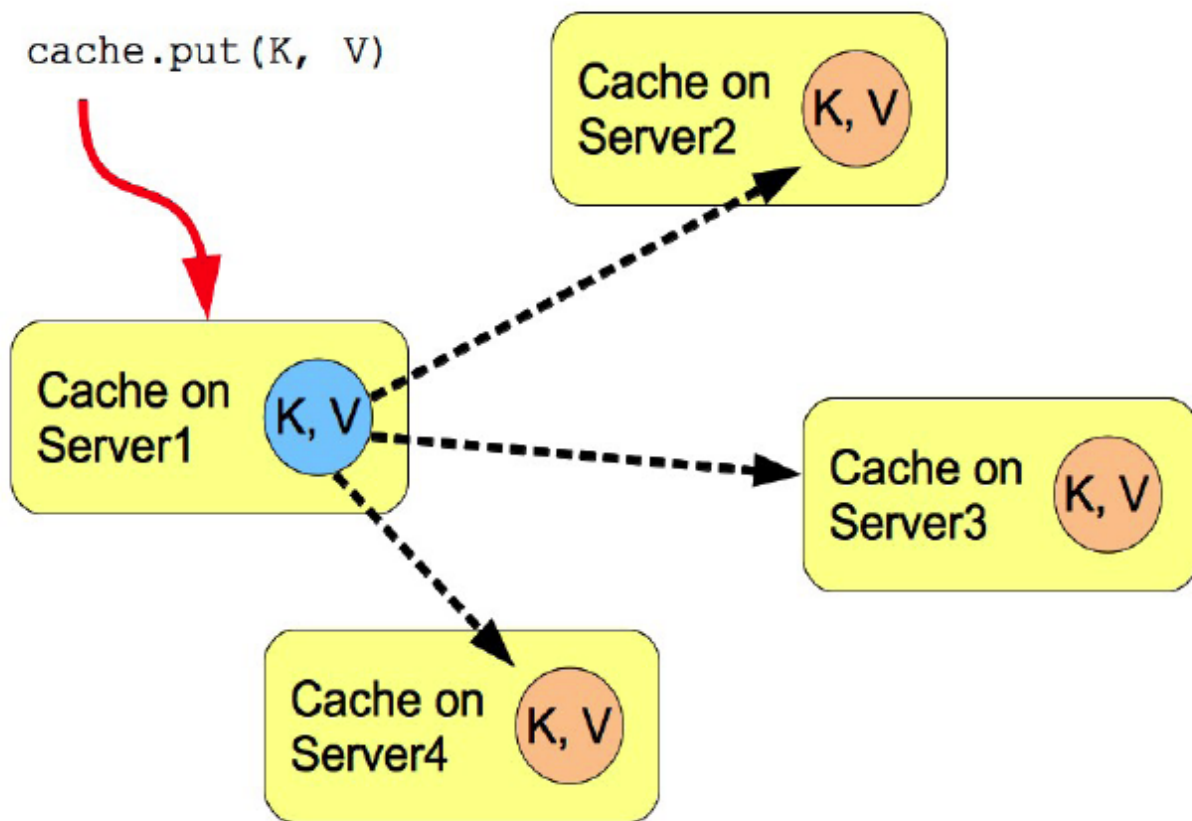


Figure 2. Replication mode

Replication can be synchronous or asynchronous. Use of either one of the options is application dependent. Synchronous replication blocks the caller (e.g. on a `put()`) until the modifications have been replicated successfully to all nodes in a cluster. Asynchronous replication performs replication in the background (the `put()` returns immediately). Infinispan offers a replication queue, where modifications are replicated periodically (i.e. interval-based), or when the queue size exceeds a number of elements, or a combination thereof. A replication queue can therefore offer much higher performance as the actual replication is performed by a background thread.

Asynchronous replication is faster (no caller blocking), because synchronous replication requires acknowledgments from all nodes in a cluster that they received and applied the modification successfully (round-trip time). However, when a synchronous replication returns successfully, the caller knows for sure that all modifications have been applied to all cache instances, whereas this is not be the case with asynchronous replication. With asynchronous replication, errors are simply written to a log. Even when using transactions, a transaction may succeed but replication may not succeed on all cache instances.

6.3. Invalidation Mode

Invalidation is a clustered mode that does not actually share any data at all, but simply aims to remove data that may be stale from remote caches. This cache mode only makes sense if you have another, permanent store for your data such as a database and are only using Infinispan as an optimization in a read-heavy system, to prevent hitting the database every time you need some state. If a cache is configured for invalidation rather than replication, every time data is changed in a cache other caches in the cluster receive a message informing them that their data is now stale

and should be evicted from memory.

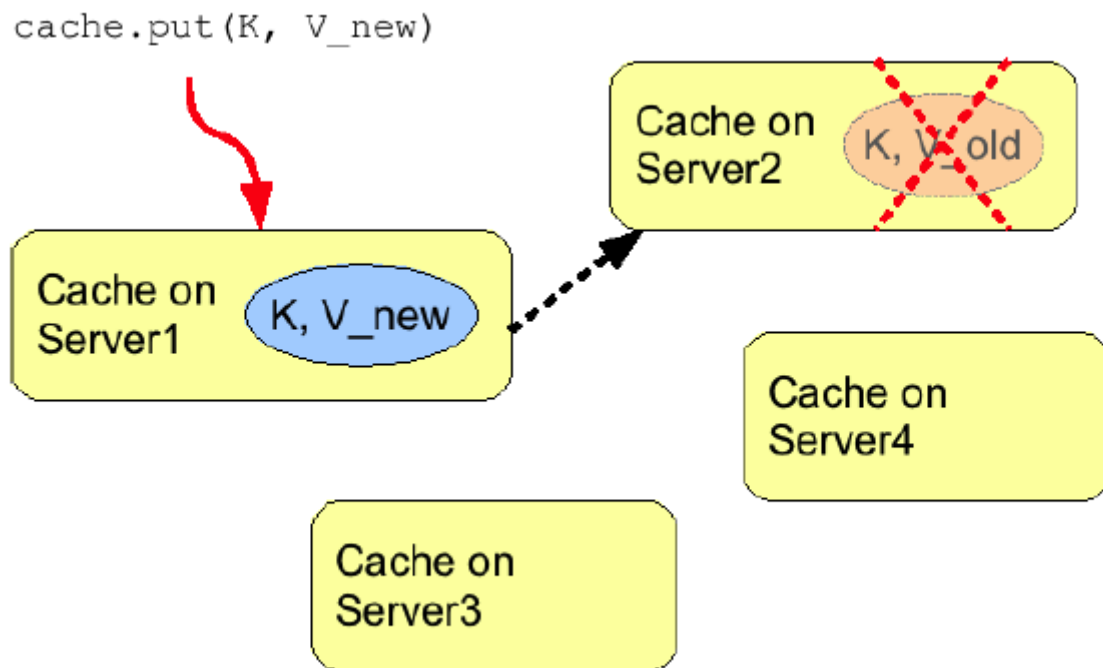


Figure 3. Invalidation mode

Invalidation, when used with a shared cache loader would cause remote caches to refer to the shared cache loader to retrieve modified data. The benefit of this is twofold: network traffic is minimized as invalidation messages are very small compared to replicating updated data, and also that other caches in the cluster look up modified data in a lazy manner, only when needed.

Invalidation messages are sent after each modification (no transactions or batches), or at the end of a transaction or batch, upon successful commit. This is usually more efficient as invalidation messages can be optimized for the transaction as a whole rather than on a per-modification basis.

Invalidation too can be synchronous or asynchronous, and just as in the case of replication, synchronous invalidation blocks until all caches in the cluster receive invalidation messages and have evicted stale data while asynchronous invalidation works in a 'fire-and-forget' mode, where invalidation messages are broadcast but doesn't block and wait for responses.

6.4. Distribution Mode

Distribution is a powerful clustering mode which allows Infinispan to scale linearly as more nodes are added to the cluster. Distribution makes use of a hash algorithm to determine on which node(s) entries should be stored. The number of copies that should be maintained in the cluster for each cache entry is configurable (**numOwners**). The number of copies represents the trade-off between performance and durability of data. The more copies you maintain, the lower performance will be, but also the lower the risk of losing data due to server outages. Regardless of how many copies are maintained, distribution still scales linearly and this is key to Infinispan's scalability.

Another feature of the hash algorithm is that it is deterministic in locating entries without resorting to multicast requests or maintaining expensive metadata. Doing a GET anywhere will result in at

most *numOwners* remote calls. The remote GET requests are staggered: we request the value from the primary owner, but if it doesn't respond in a reasonable amount of time, we request the value from the backup owners as well. (The `{{infinispan.stagger.delay}}` system property, in milliseconds, controls the delay between requests.) A GET may also result in 0 remote calls if the key is present in the local cache. Doing a PUT can result in more remote calls, depending on the cache configuration (e.g. whether the cache is transactional).

6.4.1. Read consistency

Since GETs are sent to all data owners in parallel and the first returning result is used, this can lead to data inconsistency when using an *asynchronous* transport. If an updating thread modifies the primary data owner, but updates are only sent to backup nodes asynchronously, a concurrent read from the same thread may read a stale value for a short period of time until the asynchronous replication completes.

Note that this is *only* if the transport is *asynchronous*. If using a *synchronous* transport this behavior is not exhibited.

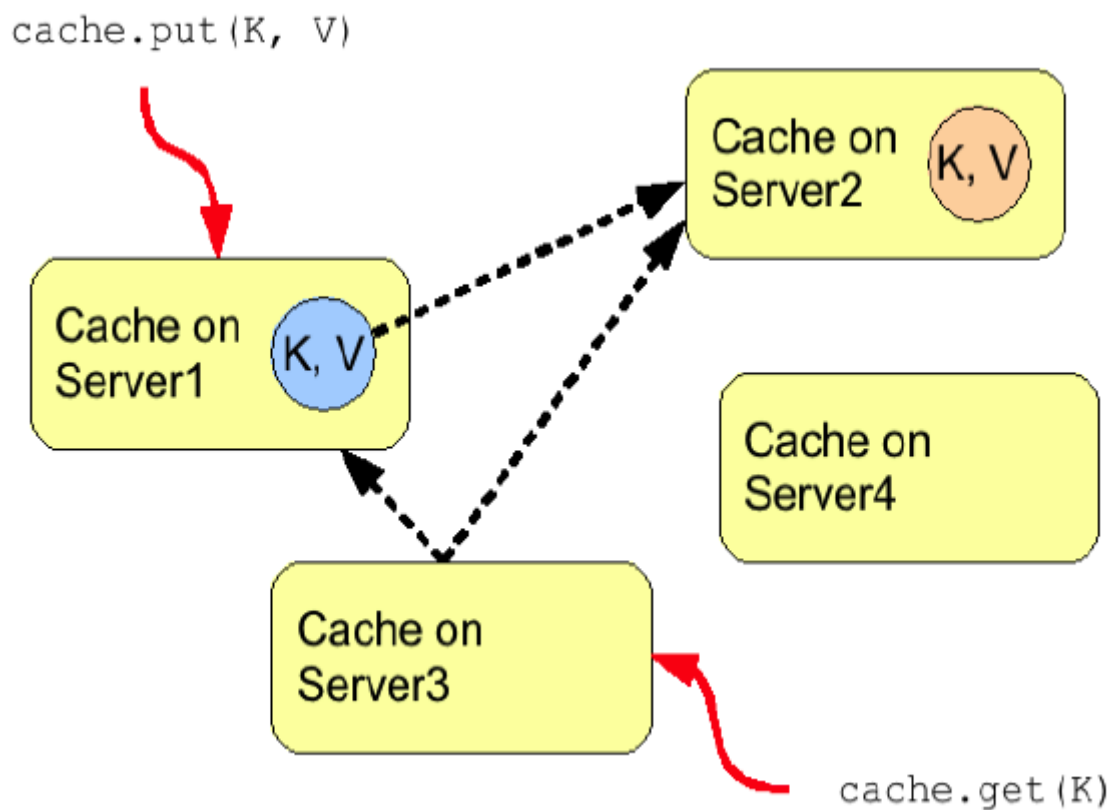


Figure 4. Distribution mode

6.4.2. Hashing Algorithms

The hashing algorithm in Infinispan is based on [consistent hashing](#), and even though our implementation has diverged a bit, we still use the term **consistent hash**.

Unlike in consistent hashing, we split the key space into fixed **segments**. The number of segments is configurable (**numSegments**), and it cannot be changed without restarting the cluster. The

mapping of keys to segments is also fixed — a key should map to the same segment, regardless of how the topology of the cluster changes.

Each hash segment is mapped to a list of nodes called **owners**. The order matters, because the first owner, also known as the **primary owner**, has a special role in many cache operations (e.g. locking). The other owners are called **backup owners**. There is no hard rule on how the segments are mapped to owners, although the hashing algorithms generally try to balance the number of segments allocated to each node and at the same time minimize the number of segments that have to move after a node joins or leaves the cluster.

The hashing algorithm in Infinispan is customizable, and in fact there are five implementations that ship with Infinispan by default:

org.infinispan.distribution.ch.DefaultConsistentHashFactory

The default hashing algorithm. It achieves a pretty even distribution, but it has one disadvantage: the mapping of segments to nodes depends on the order in which caches joined the cluster, so a key's owners are not guaranteed to be the same in all the caches running in a cluster.

org.infinispan.distribution.ch.TopologyAwareConsistentHashFactory

Selected automatically when [Server Hinting](#) is enabled. Similar to the default algorithm, but also tries to spread each segment's copies across as many sites, racks, or machines as possible.

org.infinispan.distribution.ch.SyncConsistentHashFactory

An alternative algorithm, closer to consistent hashing (but still not exactly the same). It addresses the weakness of the default algorithm, and always assigns a key to the same node in every cache as long as the cluster is symmetric. It does have some weaknesses of itself, though: the load distribution is less even, and it also moves more segments than necessary on a join or leave.

org.infinispan.distribution.ch.TopologyAwareSyncConsistentHashFactory

Similar to *SyncConsistentHashFactory*, but adapted for [Server Hinting](#).

org.infinispan.distribution.ch.ReplicatedConsistentHashFactory

This algorithm is used internally to implement replicated caches. Users should never select this explicitly in a distributed cache.

Capacity Factors

The nodes in a cluster are not always identical. It is possible to have "non-standard" nodes that take 2x as much load as a regular node, or 0.5x as much load as a regular node, using the **capacityFactor** setting. The capacity factor can be any non-negative number, and the hashing algorithm will try to assign to each node a load weighted by its capacity factor (both as a primary owner and as a backup owner).



Capacity factors support is new in Infinispan 6.0.

One interesting use case is nodes with a capacity factor of 0. This could be useful when some nodes are too short-lived to be useful as data owners, but they can't use HotRod (or other remote

protocols) because they need transactions. With cross-site replication as well, the "site master" should only deal with forwarding commands between sites and shouldn't handle user requests, so it makes sense to configure it with a capacity factor of 0.

Hashing Configuration

This is how you configure hashing declaratively, via XML:

```
<distributed-cache name="distributedCache" owners="2" segments="100" capacity-  
factor="2" />
```

And this is how you can configure it programmatically, in Java:

```
Configuration c = new ConfigurationBuilder()  
    .clustering()  
        .cacheMode(CacheMode.DIST_SYNC)  
        .hash()  
            .numOwners(2)  
            .numSegments(100)  
            .capacityFactor(2)  
    .build();
```

6.4.3. Initial cluster size

Infinispan's very dynamic nature in handling topology changes (i.e. nodes being added / removed at runtime) means that, normally, a node doesn't wait for the presence of other nodes before starting. While this is very flexible, it might not be suitable for applications which require a specific number of nodes to join the cluster before caches are started. For this reason, you can specify how many nodes should have joined the cluster before proceeding with cache initialization. To do this, use the *initialClusterSize* and *initialClusterTimeout* transport properties. The declarative XML configuration:

```
<transport initial-cluster-size="4" initial-cluster-timeout="30000" />
```

The programmatic Java configuration:

```
GlobalConfiguration global = new GlobalConfigurationBuilder()  
    .transport()  
        .initialClusterSize(4)  
        .initialClusterTimeout(30000)  
    .build();
```

The above configuration will wait for 4 nodes to join the cluster before initialization. If the initial nodes do not appear within the specified timeout, the cache manager will fail to start.

6.4.4. L1 Caching

To prevent repeated remote calls when doing multiple GETs, L1 caching can be enabled. L1 caching places remotely received values in a near cache for a short period of time (configurable) so repeated lookups would not result in remote calls. In the above diagram, if L1 was enabled, a subsequent GET for the same key on Server3 would not result in any remote calls.

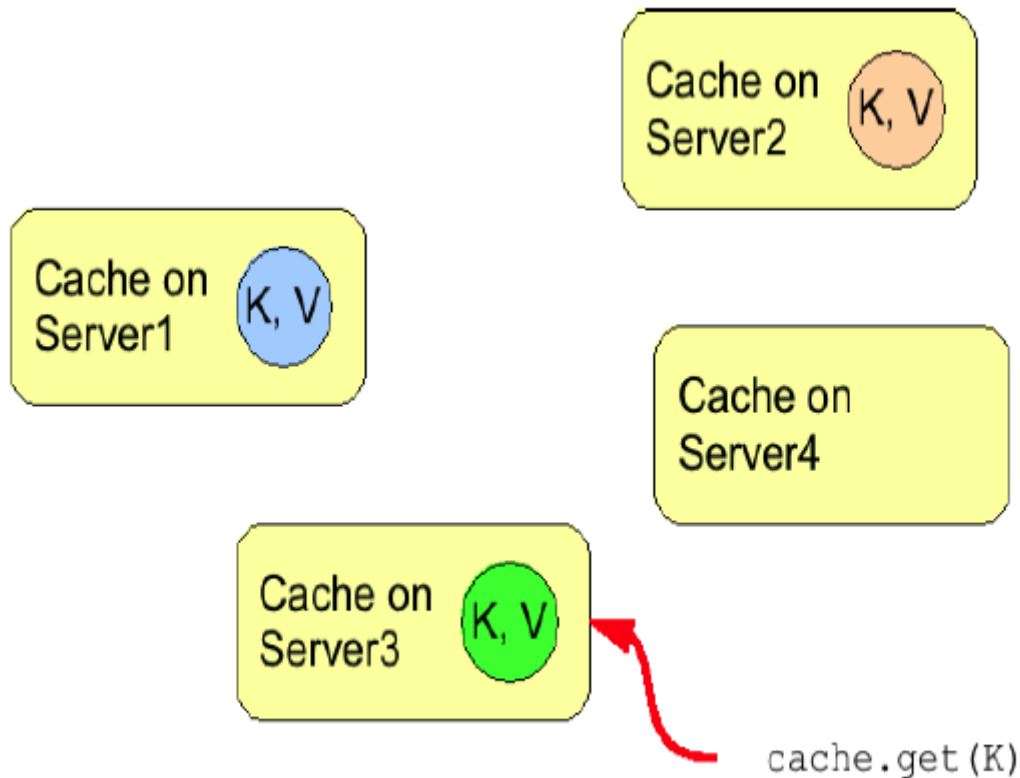


Figure 5. L1 caching

L1 caching is not free though. Enabling it comes at a cost, and this cost is that every time a key is updated, an invalidation message needs to be multicast to ensure nodes with the entry in L1 invalidates the entry. L1 caching causes the requesting node to cache the retrieved entry locally and listen for changes to the key on the wire. L1-cached entries are given an internal expiry to control memory usage. Enabling L1 will improve performance for repeated reads of non-local keys, but will increase memory consumption to some degree. It offers a nice tradeoff between the "read-mostly" performance of an invalidated data grid with the scalability of a distributed one. Is L1 caching right for you? The correct approach is to benchmark your application with and without L1 enabled and see what works best for your access pattern.



Looking for Buddy Replication? Buddy Replication - from JBoss Cache - does not exist in Infinispan. See this blog article which discusses the reasons why Buddy Replication was not implemented in Infinispan, and how the same effects can be achieved using Infinispan: <http://infinispan.blogspot.com/2009/08/distribution-instead-of-buddy.html>

6.4.5. Server Hinting

The motivations behind this feature is to ensure when using distribution, backups are not picked to reside on the same physical server, rack or data centre. For obvious reasons it doesn't work with total replication.

Configuration

The hints are configured at transport level:

```
<transport
  cluster = "MyCluster"
  machine = "LinuxServer01"
  rack = "Rack01"
  site = "US-WestCoast" />
```

The following topology hints can be specified:

machine

This is probably the most useful, to disambiguate between multiple JVM instances on the same node, or even multiple virtual hosts on the same physical host.

rack

In larger clusters with nodes occupying more than a single rack, this setting would help prevent backups being stored on the same rack.

site

To differentiate between nodes in different data centres replicating to each other. Note that [Cross site replication](#) is another alternative for clusters that need to span two or more data centres.

All of the above are optional, and if not provided, the distribution algorithms provide no guarantees that backups will not be stored in instances on the same machine/rack/site.

6.4.6. Key affinity service

The key affinity service solves the following problem: for a distributed Infinispan cluster one wants to make sure that a value is placed in a certain node. Based on a supplied cluster [address](#) identifying the node, the service returns a key that will be hashed to that particular node.

API

Following code snippet depicts how a reference to this service can be obtained and used.

```
// 1. Obtain a reference to a cache manager
EmbeddedCacheManager cacheManager = getCacheManager();//obtain a reference to a cache
manager
Cache cache = cacheManager.getCache();

// 2. Create the affinity service
KeyAffinityService keyAffinityService = KeyAffinityServiceFactory
.newLocalKeyAffinityService(
    cache,
    new RndKeyGenerator(),
    Executors.newSingleThreadExecutor(),
    100);

// 3. Obtain a key to be mapped to a certain address
Object localKey = keyAffinityService.getKeyForAddress(cacheManager.getAddress());

// 4. This put makes sure that the key resigns on the local node (as obtained
cacheManager.getAddress())
cache.put(localKey, "yourValue");
```

The service is started at step 2: after this point it uses the supplied *Executor* to generate and queue keys. At step 3, we obtain a key for this service, and use it at step 4, with that guarantee that it is distributed on the node identified by `cacheManager.getAddress()`.

Lifecycle

KeyAffinityService extends *Lifecycle*, which allows stopping and (re)starting it:

```
public interface Lifecycle {
    void start();
    void stop();
}
```

The service is instantiated through *KeyAffinityServiceFactory*. All the factory methods have an *Executor* parameter, that is used for asynchronous key generation (so that it won't happen in the caller's thread). It is the user's responsibility to handle the shutdown of this *Executor*.

The *KeyAffinityService*, once started, needs to be explicitly stopped. This stops the background key generation and releases other held resources.

The only situation in which *KeyAffinityService* stops by itself is when the cache manager with which it was registered is shutdown.

Topology changes

When a topology change takes place the key ownership from the *KeyAffinityService* might change. The key affinity service keep tracks of these topology changes and updates and doesn't return stale keys, i.e. keys that would currently map to a different node than the one specified. However, this

does not guarantee that at the time the key is used its node affinity hasn't changed, e.g.:

- Thread **T1** reads a key **k1** that maps to node **A**.
- A topology change happens which makes **k1** map to node **B**.
- **T1** uses **k1** to add something to the cache. At this point **k1** maps to **B**, a different node than the one requested at the time of read.

Whilst this is not ideal, it should be a supported behaviour for the application as all the already in-use keys might be moved over during cluster change. The *KeyAffinityService* provides an access proximity optimisation for stable clusters which doesn't apply during the instability of topology changes.

6.4.7. The Grouping API

Complementary to [Key affinity service](#) and similar to [AtomicMap](#), the grouping API allows you to co-locate a group of entries on the same nodes, but without being able to select the actual nodes.

How does it work?

Normally, when you store an entry, Infinispan will take a hash code of the key, map the hash to a hash segment, and store the entry on the nodes which own that segment. Infinispan always uses an algorithm to locate a key, never allowing the nodes on which the entry is stored to be specified manually. This scheme allows any node to know which nodes owns a key, without having to distribute such ownership information. This reduces the overhead of Infinispan, but more importantly improves redundancy as there is no need to replicate the ownership information in case of node failure.

If you use the grouping API, then Infinispan will ignore the hash of the key when deciding which *node* to store the entry on, and instead use a hash of the group. Infinispan still uses the hash of the key in its internal data structures, so using the grouping API will not slow things down. When the group API is in use, it is important that every node can still compute, using an algorithm, the owners of every key. For this reason, the group cannot be specified manually. The group can either be intrinsic to the entry (generated by the key class) or extrinsic (generated by an external function).

How do I use the grouping API?

First, you must enable groups. If you are configuring Infinispan programmatically, then call:

```
Configuration c = new ConfigurationBuilder()
    .clustering().hash().groups().enabled()
    .build();
```

Or, if you are using XML:

```
<distributed-cache>
  <groups enabled="true"/>
</distributed-cache>
```

If you have control of the key class (you can alter the class definition, it's not part of an unmodifiable library), and the determination of the group is not an orthogonal concern to the key class, then we recommend you use an intrinsic group. The intrinsic group can be specified using the `@Group` annotation placed on the method. Let's take a look at an example:

```
class User {
    ...
    String office;
    ...

    public int hashCode() {
        // Defines the hash for the key, normally used to determine location
        ...
    }

    // Override the location by specifying a group, all keys in the same
    // group end up with the same owner
    @Group
    public String getOffice() {
        return office;
    }
}
```



The group must be a `String`

If you don't have control over the key class, or the determination of the group is an orthogonal concern to the key class, we recommend you use an extrinsic group. An extrinsic group is specified by implementing the *Grouper* interface, which has a single method `computeGroup`, which should return the group. *Grouper* acts as an interceptor, passing the previously computed value in. The group passed to the first *Grouper* will be that determined by `@Group` (if `@Group` is defined). This allows you even greater control over the group when using an intrinsic group. For a grouper to be used when determining the group for a key, its *keyType* must be assignable from the key being grouped.

Let's take a look at an example of a *Grouper*:

```

public class KXGrouper implements Grouper<String> {

    // A pattern that can extract from a "kX" (e.g. k1, k2) style key
    // The pattern requires a String key, of length 2, where the first character is
    // "k" and the second character is a digit. We take that digit, and perform
    // modular arithmetic on it to assign it to group "1" or group "2".
    private static Pattern kPattern = Pattern.compile("(^k)(<a>\\d</a>)$");

    public String computeGroup(String key, String group) {
        Matcher matcher = kPattern.matcher(key);
        if (matcher.matches()) {
            String g = Integer.parseInt(matcher.group(2)) % 2 + "";
            return g;
        } else
            return null;
    }

    public Class<String> getKeyType() {
        return String.class;
    }
}

```

Here we determine a simple grouper that can take the key class and extract from the group from the key using a pattern. We ignore any group information specified on the key class.

You must register every grouper you wish to have used. If you are configuring Infinispan programmatically:

```

Configuration c = new ConfigurationBuilder()
    .clustering().hash().groups().enabled().addGrouper(new KXGrouper())
    .build();

```

Or, if you are using XML:

```

<distributed-cache>
  <groups enabled="true">
    <grouper class="com.acme.KXGrouper" />
  </groups>
</distributed-cache>

```

Advanced Interface



This interface is available since Infinispan 7.0.0.

AdvancedCache allows to interact with the keys belonging to a group. It is possible to return the Set of keys belonging to a group and remove all the keys of the group. Below is the interface available:

```

/**
 * It fetches all the keys which belong to the group.
 * <p/>
 * Semantically, it iterates over all the keys in memory and persistence, and performs
 a read operation in the keys
 * found. Multiple invocations inside a transaction ensures that all the keys previous
 read are returned and it may
 * return newly added keys to the group from other committed transactions (also known
 as phantom reads).
 * <p/>
 * The {@code map} returned is immutable and represents the group at the time of the
 invocation. If you want to add
 * or remove keys from a group use {@link #put(Object, Object)} and {@link
 #remove(Object)}. To remove all the keys
 * in the group use {@link #removeGroup(String)}.
 * <p/>
 * To improve performance you may use the {@code flag} {@link
 org.infinispan.context.Flag#SKIP_CACHE_LOAD} to avoid
 * fetching the key/value from persistence. However, you will get an inconsistent
 snapshot of the group.
 *
 * @param groupName the group name.
 * @return an immutable {@link java.util.Map} with the key/value pairs.
 */
Map<K, V> getGroup(String groupName);

/**
 * It removes all the key which belongs to a group.
 * <p/>
 * Semantically, it fetches the most recent group keys/values and removes them.
 * <p/>
 * Note that, concurrent addition perform by other transactions/threads to the group
 may not be removed.
 *
 * @param groupName the group name.
 */
void removeGroup(String groupName);

```

6.5. Asynchronous Options

When Infinispan instances are clustered, regardless of the cluster mode, data can be propagated to other nodes in a synchronous or asynchronous way. When synchronous, the sender waits for replies from the receivers and when asynchronous, the sender sends the data and does not wait for replies from other nodes in the cluster.

With asynchronous modes, speed is more important than consistency and this is particularly advantageous in use cases such as HTTP session replication with sticky sessions enabled. In these

scenarios, data, or in this case a particular session, is always accessed on the same cluster node and only in case of failure is data accessed in a different node. This type of architectures allow consistency to be relaxed in favour of increased performance.

In order to choose the asynchronous configuration that best suits your application, it's important to understand the following configuration settings:

6.5.1. Asynchronous Communications

Whenever you add `<replicated-cache mode="ASYNC">` or `<distributed-cache mode="ASYNC">` or `<invalidation-cache mode="ASYNC">` element, you're telling the underlying JGroups layer in Infinispan to use asynchronous communication. What this means is that JGroups will send any replication/distribution/invalidation request to the wire but will not wait for a reply from the receiver.

6.5.2. Replication Queue

The aim of the replication queue is to batch the individual cache operations and send them as one, as opposed to sending each cache operation individually. As a result, replication queue enabled configurations perform generally better compared to those that have it switched off because less RPC messages are sent, fewer envelopes are used...etc. The only real trade off to the replication queue is that the queue is flushed periodically (based on time or queue size) and hence it might take longer for the replication/distribution/invalidation to be realised across the cluster. When replication queue is turned off, data is placed directly on the wire and hence it takes less for data to arrive to other nodes.

6.5.3. Asynchronous API

Finally, the [Asynchronous API](#) can be used to emulate non-blocking APIs, whereby calls are handed over to a different thread and asynchronous API calls return to the client immediately. Using this API can lead to reordering, so you should avoid calling modifying asynchronous methods on the same keys.

6.5.4. Return Values

Regardless of the asynchronous option used, the return values of cache operations are reliable. If talking about return values of cache operations that return previous value, the correctness of these returns are guaranteed as well regardless of the clustering mode. With replication, the previous value is already available locally, and with distribution, regardless of whether it's asynchronous or synchronous, Infinispan sends a synchronous request to get the previous value if not present locally. If on the other hand the asynchronous API is used, client code needs to get hold of the [NotifyingFuture](#) returned by the async operation in order to be able to query the previous value.

6.6. Partition handling

An Infinispan cluster is built out of a number of nodes where data is stored. In order not to lose data in the presence of node failures, Infinispan copies the same data - cache entry in Infinispan parlance - over multiple nodes. This level of data redundancy is configured through the

numOwners configuration attribute and ensures that as long as fewer than **numOwners** nodes crash simultaneously, Infinispan has a copy of the data available.

However there might be catastrophic situations in which more than **numOwners** nodes disappear from the cluster:

- **split brain**. Caused e.g. by a router crash, this splits the cluster in two or more partitions, or sub-clusters that operate independently. In these circumstances, multiple clients reading/writing from different partitions see different versions of the same cache entry, which for many application is problematic. Note there are ways to alleviate the possibility for the split brain to happen, such as redundant networks or [IP bonding](#). These only reduce the window of time for the problem to occur, though.
- **numOwners** nodes crash in sequence. When at least **numOwners** nodes crash in rapid sequence and Infinispan does not have the time to properly rebalance its state between crashes, the result is partial data lost.

The partition handling functionality discussed in this section allows the user to be informed when data has been lost, temporarily or permanently, and wait for the cluster to heal. The goal is to avoid situations in which wrong data is returned to the user as a result of either split brain or multiple nodes crashing in rapid sequence. In terms of Brewer's [CAP theorem](#), enabling partition handling in Infinispan preserves data consistency but sacrifices availability in the presence of partitions.

Enabling partition handling is critical for applications that have high consistency requirements: when the data read from the system must be accurate. On the other hand, if Infinispan is used as a best-effort cache, partitions are perfectly tolerable.

The following sections describe the way Infinispan handles [split brain](#) and [successive failures](#) when partition handling is enabled, followed by a section on [configuring the partition handling functionality](#).

6.6.1. Split brain

In a split brain situation, each network partition will install its own JGroups view, removing the nodes from the other partition(s). We don't have a direct way of determining whether the has been split into two or more partitions, since the partitions are unaware of each other. Instead, we assume the cluster has split when one or more nodes disappear from the JGroups cluster without sending an explicit leave message.

With partition handling disabled, each such partition would continue to function as an independent cluster. Each partition may only see a part of the data, and each partition could write conflicting updates in the cache.

With partition handling enabled, if we detect a split, each partition does not start a rebalance immediately, but first it checks whether it should enter degraded mode instead:

- If at least one segment has lost all its owners (meaning at least *numOwners* nodes left since the last rebalance ended), the partition enters degraded mode.
- If the partition does not contain a simple majority of the nodes ($\text{floor}(\text{numNodes}/2) + 1$) in the *latest stable topology*, the partition also enters degraded mode.

- Otherwise the partition keeps functioning normally, and it starts a rebalance.

The *stable topology* is updated every time a rebalance operation ends and the coordinator determines that another rebalance is not necessary.

These rules ensures that at most one partition stays in available mode, and the other partitions enter degraded mode.

When a partition is in degraded mode, it only allows access to the keys that are wholly owned:

- Requests (reads and writes) for entries that have all the copies on nodes within this partition are honoured.
- Requests for entries that are partially or totally owned by nodes that disappeared are rejected with an `AvailabilityException`.

This guarantees that partitions cannot write different values for the same key (cache is consistent), and also that one partition can not read keys that have been updated in the other partitions (no stale data).

To exemplify, consider the initial cluster $M = \{A, B, C, D\}$, configured in distributed mode with `numOwners = 2`. Further on, consider three keys $k1$, $k2$ and $k3$ (that might exist in the cache or not) such that `owners(k1) = {A,B}`, `owners(k2) = {B,C}` and `owners(k3) = {C,D}`. Then the network splits in two partitions, $N1 = \{A, B\}$ and $N2 = \{C, D\}$, they enter degraded mode and behave like this:

- on $N1$, $k1$ is available for read/write, $k2$ (partially owned) and $k3$ (not owned) are not available and accessing them results in an `AvailabilityException`
- on $N2$, $k1$ and $k2$ are not available for read/write, $k3$ is available

A relevant aspect of the partition handling process is the fact that when a split brain happens, the resulting partitions rely on the original consistent hash function (the one that existed before the split brain) in order to calculate key ownership. So it doesn't matter if $k1$, $k2$, or $k3$ already existed cache or not, their availability is the same.

If at a further point in time the network heals and $N1$ and $N2$ partitions merge back together into the initial cluster M , then M exits the degraded mode and becomes fully available again.

As another example, the cluster could split in two partitions $O1 = \{A, B, C\}$ and $O2 = \{D\}$, partition $O1$ will stay fully available (rebalancing cache entries on the remaining members). Partition $O2$, however, will detect a split and enter the degraded mode. Since it doesn't have any fully owned keys, it will reject any read or write operation with an `AvailabilityException`.

If afterwards partitions $O1$ and $O2$ merge back into M , then the cache entries on D will be wiped (since they could be stale). D will be fully available, but it will not hold any data until the cache is rebalanced.

Current limitations

Two partitions could start up isolated, and as long as they don't merge they can read and write inconsistent data. In the future, we will allow custom availability strategies (e.g. check that a certain node is part of the cluster, or check that an external machine is accessible) that could handle that

situation as well.

6.6.2. Successive nodes stopped

As mentioned in the previous section, Infinispan can't detect whether a node left the JGroups view because of a process/machine crash, or because of a network failure: whenever a node leaves the JGroups cluster abruptly, it is assumed to be because of a network problem.

If the configured number of copies (*numOwners*) is greater than 1, the cluster can remain available and will try to make new replicas of the data on the crashed node. However, other nodes might crash during the rebalance process. If more than *numOwners* nodes crash in a short interval of time, there is a chance that some cache entries have disappeared from the cluster altogether. In this case, with partition handling functionality enabled, Infinispan assumes (incorrectly) that there is a split brain and enters degraded mode as described in the split-brain section.

The administrator can also shut down more than **numOwners** nodes in rapid succession, causing the loss of the data stored only on those nodes. When the administrator shuts down a node gracefully, Infinispan knows that the node can't come back. However, the cluster doesn't keep track of how each node left, and the cache still enters *degraded* mode as if those nodes had crashed.

At this stage there is no way for the cluster to recover its state, except stopping it and repopulating it on restart with the data from an external source. Clusters are expected to be configured with an appropriate **numOwners** in order to avoid **numOwners** successive node failures, so this situation should be pretty rare. If the application can handle losing some of the data in the cache, the administrator can force the availability mode back to AVAILABLE [via JMX](#).

6.6.3. Configuring partition handling

At this stage the partition handling is disabled by default. We will revisit this decision in the future, based on user feedback. In order to enable partition handling within the XML configuration:

```
<distributed-cache name="the-default-cache">
  <partition-handling enabled="true"/>
</distributed-cache>
```

Unless the cache is distributed or replicated, the configuration is ignored.

The same can be achieved programmatically:

```
ConfigurationBuilder dcc = new ConfigurationBuilder();
dcc.clustering().partitionHandling().enabled(true);
```

6.6.4. Monitoring and administration

The availability mode of a cache is exposed in JMX as an attribute in the [Cache MBean](#). The attribute is writable, allowing an administrator to forcefully migrate a cache from degraded state back to available (at the cost of consistency).

The availability mode is also accessible via the [AdvancedCache](#) interface:

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

// Read the availability
boolean available = ac.getAvailability() == AvailabilityMode.AVAILABLE;

// Change the availability
if (!available) {
    ac.setAvailability(AvailabilityMode.AVAILABLE);
}
```

Chapter 7. Marshalling

Marshalling is the process of converting Java POJOs into something that can be written in a format that can be transferred over the wire. Unmarshalling is the reverse process whereby data read from a wire format is transformed back into Java POJOs. Infinispan uses marshalling/unmarshalling in order to:

- Transform data so that it can be send over to other Infinispan nodes in a cluster.
- Transform data so that it can be stored in underlying cache stores.
- Store data in Infinispan in a wire format to provide lazy deserialization capabilities.

7.1. The Role Of JBoss Marshalling

Since performance is a very important factor in this process, Infinispan uses JBoss Marshalling framework instead of standard Java Serialization in order to marshall/unmarshall Java POJOs. Amongst other things, this framework enables Infinispan to provide highly efficient ways to marshall internal Infinispan Java POJOs that are constantly used. Apart from providing more efficient ways to marshall Java POJOs, including internal Java classes, JBoss Marshalling uses highly performant `java.io.ObjectOutput` and `java.io.ObjectInput` implementations compared to standard `java.io.ObjectOutputStream` and `java.io.ObjectInputStream`.

7.2. Support For Non-Serializable Objects

From a users perspective, a very common concern is whether Infinispan supports storing non-Serializable objects. In 4.0, an Infinispan cache instance can only store non-Serializable key or value objects if, and only if:

- cache is configured to be a local cache *and...*
- cache is not configured with lazy serialization *and...*
- cache is not configured with any write-behind cache store

If either of these options is true, key/value pairs in the cache will need to be marshalled and currently they require to either to extend `java.io.Serializable` or `java.io.Externalizable`.



Since Infinispan 5.0, marshalling non-Serializable key/value objects is supported as long as users can to provide meaningful Externalizer implementations for these non-Seralizable objects. [This section](#) has more details.

If you're unable to retrofit Serializable or Externalizable into the classes whose instances are stored in Infinispan, you could alternatively use something like [XStream](#) to convert your Non-Serializable objects into a String that can be stored into Infinispan. You can find an example on how to use XStream [here](#) . The one caveat about using XStream is that it slows down the process of storing key/value objects due to the XML transformation that it needs to do.

7.2.1. Store As Binary

Store as binary enables data to be stored in its serialized form. This can be useful to achieve lazy deserialization, which is the mechanism by which Infinispan by which serialization and deserialization of objects is deferred till the point in time in which they are used and needed. This typically means that any deserialization happens using the thread context class loader of the invocation that requires deserialization, and is an effective mechanism to provide classloader isolation. By default lazy deserialization is disabled but if you want to enable it, you can do it like this:

- Via XML at the Cache level, either under `<*-cache />` element:

```
<store-as-binary />
```

- Programmatically:

```
ConfigurationBuilder builder = ...  
builder.storeAsBinary().enable();
```

Equality Considerations

When using lazy deserialization/storing as binary, keys and values are wrapped as [MarshaledValues](#). It is this wrapper class that transparently takes care of serialization and deserialization on demand, and internally may have a reference to the object itself being wrapped, or the serialized, byte array representation of this object.

This has a particular effect on the behavior of equality. The `equals()` method of this class will either compare binary representations (byte arrays) or delegate to the wrapped object instance's `equals()` method, depending on whether both instances being compared are in serialized or deserialized form at the time of comparison. If one of the instances being compared is in one form and the other in another form, then one instance is either serialized or deserialized. The preference will be to compare object representations, unless the cache is [compacted](#), in which case byte array comparison is favored.

This will affect the way keys stored in the cache will work, when `storeAsBinary` is used, since comparisons happen on the key which will be wrapped by a `MarshaledValue`. Implementers of `equals()` methods on their keys need to be aware of the behavior of equality comparison, when a key is wrapped as a `MarshaledValue`, as detailed above.

Store-by-value via defensive copying

The configuration `storeAsBinary` offers the possibility to enable defensive copying, which allows for store-by-value like behaviour.

Infinispan marshalls objects the moment they're stored, hence changes made to object references are not stored in the cache, not even for local caches. This provides store-by-value like behaviour. Enabling `storeAsBinary` can be achieved:

- Via XML at the Cache level, either under `<*-cache />` or `<default />` elements:

```
<store-as-binary keys="true" values="true"/>
```

- Programmatically:

```
ConfigurationBuilder builder = ...  
builder.storeAsBinary().enable().storeKeysAsBinary(true).storeValuesAsBinary(true);
```

7.3. Advanced Configuration

Internally, Infinispan uses an implementation of [this Marshaller interface](#) in order to marshall/unmarshall Java objects so that they're sent other nodes in the grid, or so that they're stored in a cache store, or even so to transform them into byte arrays for lazy deserialization.

By default, Infinispan uses the [VersionAwareMarshaller](#) which, as the name suggests, adds a version short to the start of any stream when writing, enabling similar VersionAwareMarshaller instances to read the version short and know which specific marshaller implementation to delegate the call to. Using a VersionAwareMarshaller helps achieve wire protocol compatibility between minor releases but still affords us the flexibility to tweak and improve the wire protocol between minor or micro releases. Optionally, Infinispan users to optionally provide their own marshaller, for example:

- Via XML at the CacheManager level, under `<cache-manager />` element:

```
<serialization marshaller="com.acme.MyMarshaller"/>
```

- Programmatically:

```
GlobalConfigurationBuilder builder = ...  
builder.serialization().marshaller(myMarshaller); // needs an instance of the  
marshaller
```

7.3.1. Troubleshooting

Sometimes it might happen that the Infinispan marshalling layer, and in particular JBoss Marshalling, might have issues marshalling/unmarshalling some user object. In Infinispan 4.0, marshalling exceptions will contain further information on the objects that were being marshalled. Example:

```

java.io.NotSerializableException: java.lang.Object
at org.jboss.marshalling.river.RiverMarshaller.doWriteObject(RiverMarshaller.java:857)
at org.jboss.marshalling.AbstractMarshaller.writeObject(AbstractMarshaller.java:407)
at
org.infinispan.marshall.exts.ReplicableCommandExternalizer.writeObject(ReplicableCommandExternalizer.java:54)
at
org.infinispan.marshall.jboss.ConstantObjectTable$ExternalizerAdapter.writeObject(ConstantObjectTable.java:267)
at org.jboss.marshalling.river.RiverMarshaller.doWriteObject(RiverMarshaller.java:143)
at org.jboss.marshalling.AbstractMarshaller.writeObject(AbstractMarshaller.java:407)
at
org.infinispan.marshall.jboss.JBossMarshaller.objectToObjectStream(JBossMarshaller.java:167)
at
org.infinispan.marshall.VersionAwareMarshaller.objectToBuffer(VersionAwareMarshaller.java:92)
at
org.infinispan.marshall.VersionAwareMarshaller.objectToByteBuffer(VersionAwareMarshaller.java:170)
at
org.infinispan.marshall.VersionAwareMarshallerTest.testNestedNonSerializable(VersionAwareMarshallerTest.java:415)
Caused by: an exception which occurred:
in object java.lang.Object@b40ec4
in object org.infinispan.commands.write.PutKeyValueCommand@df661da7
... Removed 22 stack frames

```

The way the "in object" messages are read is the same in which stacktraces are read. The highest "in object" being the most inner one and the lowest "in object" message being the most outer one. So, the above example indicates that a `java.lang.Object` instance contained in an instance of `org.infinispan.commands.write.PutKeyValueCommand` could not be serialized because `java.lang.Object@b40ec4` is not serializable.

This is not all though! If you enable DEBUG or TRACE logging levels, marshalling exceptions will contain show the `toString()` representations of objects in the stacktrace. For example:

```

java.io.NotSerializableException: java.lang.Object
...
Caused by: an exception which occurred:
in object java.lang.Object@b40ec4
-> toString = java.lang.Object@b40ec4
in object org.infinispan.commands.write.PutKeyValueCommand@df661da7
-> toString = PutKeyValueCommand{key=k, value=java.lang.Object@b40ec4,
putIfAbsent=false, lifespanMillis=0, maxIdleTimeMillis=0}

```

With regards to unmarshalling exceptions, showing such level of information it's a lot more complicated but where possible. Infinispan will provide class type information. For example:

```
java.io.IOException: Injected failure!
at
org.infinispan.marshall.VersionAwareMarshallerTest$1.readExternal(VersionAwareMarshallerTest.java:426)
at
org.jboss.marshalling.river.RiverUnmarshaller.doReadNewObject(RiverUnmarshaller.java:172)
at
org.jboss.marshalling.river.RiverUnmarshaller.doReadObject(RiverUnmarshaller.java:273)
at
org.jboss.marshalling.river.RiverUnmarshaller.doReadObject(RiverUnmarshaller.java:210)
at org.jboss.marshalling.AbstractUnmarshaller.readObject(AbstractUnmarshaller.java:85)
at
org.infinispan.marshall.jboss.JBossMarshaller.objectFromObjectStream(JBossMarshaller.java:210)
at
org.infinispan.marshall.VersionAwareMarshaller.objectFromByteBuffer(VersionAwareMarshaller.java:104)
at
org.infinispan.marshall.VersionAwareMarshaller.objectFromByteBuffer(VersionAwareMarshaller.java:177)
at
org.infinispan.marshall.VersionAwareMarshallerTest.testErrorUnmarshalling(VersionAwareMarshallerTest.java:431)
Caused by: an exception which occurred:
in object of type org.infinispan.marshall.VersionAwareMarshallerTest$1
```

In this example, an `IOException` was thrown when trying to unmarshall a instance of the inner class `org.infinispan.marshall.VersionAwareMarshallerTest$1`. In similar fashion to marshalling exceptions, when `DEBUG` or `TRACE` logging levels are enabled, classloader information of the class type is provided. For example:


```

java.io.IOException: Injected failure!
...
Caused by: an exception which occurred:
in object of type org.infinispan.marshall.VersionAwareMarshallerTest$1
-> classloader hierarchy:
-> type classloader = sun.misc.Launcher$AppClassLoader@198dfaf
->...file:/opt/eclipse/configuration/org.eclipse.osgi/bundles/285/1/.cp/eclipse
-testng.jar
->...file:/opt/eclipse/configuration/org.eclipse.osgi/bundles/285/1/.cp/lib/testng
-jdk15.jar
->...file:/home/galder/jboss/infinispan/code/trunk/core/target/test-classes/
->...file:/home/galder/jboss/infinispan/code/trunk/core/target/classes/
->...file:/home/galder/.m2/repository/org/testng/testng/5.9/testng-5.9-jdk15.jar
->...file:/home/galder/.m2/repository/net/jcip/jcip-annotations/1.0/jcip-annotations
-1.0.jar
->...file:/home/galder/.m2/repository/org/easymock/easymockclassexension/2.4/easymock
classexension-2.4.jar
->...file:/home/galder/.m2/repository/org/easymock/easymock/2.4/easymock-2.4.jar
->...file:/home/galder/.m2/repository/cglib/cglib-nodep/2.1_3/cglib-nodep-2.1_3.jar
->...file:/home/galder/.m2/repository/javax/xml/bind/jaxb-api/2.1/jaxb-api-2.1.jar
->...file:/home/galder/.m2/repository/javax/xml/stream/stax-api/1.0-2/stax-api-1.0
-2.jar
->...file:/home/galder/.m2/repository/javax/activation/activation/1.1/activation
-1.1.jar
->...file:/home/galder/.m2/repository/jgroups/jgroups/2.8.0.CR1/jgroups-2.8.0.CR1.jar
->...file:/home/galder/.m2/repository/org/jboss/javaee/jboss-transaction
-api/1.0.1.GA/jboss-transaction-api-1.0.1.GA.jar
->...file:/home/galder/.m2/repository/org/jboss/marshalling/river/1.2.0.CR4
-SNAPSHOT/river-1.2.0.CR4-SNAPSHOT.jar
->...file:/home/galder/.m2/repository/org/jboss/marshalling/marshalling-api/1.2.0.CR4
-SNAPSHOT/marshalling-api-1.2.0.CR4-SNAPSHOT.jar
->...file:/home/galder/.m2/repository/org/jboss/jboss-common-core/2.2.14.GA/jboss
-common-core-2.2.14.GA.jar
->...file:/home/galder/.m2/repository/org/jboss/logging/jboss-logging
-spi/2.0.5.GA/jboss-logging-spi-2.0.5.GA.jar
->...file:/home/galder/.m2/repository/log4j/log4j/1.2.14/log4j-1.2.14.jar
->...file:/home/galder/.m2/repository/com/thoughtworks/xstream/xstream/1.2/xstream
-1.2.jar
->...file:/home/galder/.m2/repository/xpp3/xpp3_min/1.1.3.4.0/xpp3_min-1.1.3.4.0.jar
->...file:/home/galder/.m2/repository/com/sun/xml/bind/jaxb-impl/2.1.3/jaxb-impl
-2.1.3.jar
-> parent classloader = sun.misc.Launcher$ExtClassLoader@1858610
->...file:/usr/java/jdk1.5.0_19/jre/lib/ext/localedata.jar
->...file:/usr/java/jdk1.5.0_19/jre/lib/ext/sunpkcs11.jar
->...file:/usr/java/jdk1.5.0_19/jre/lib/ext/sunjce_provider.jar
->...file:/usr/java/jdk1.5.0_19/jre/lib/ext/dnsns.jar
... Removed 22 stack frames
</code>

```

Finding the root cause of marshalling/unmarshalling exceptions can sometimes be really daunting

but we hope that the above improvements would help get to the bottom of those in a more quicker and efficient manner.

7.4. User Defined Externalizers

One of the key aspects of Infinispan is that it often needs to marshal/unmarshal objects in order to provide some of its functionality. For example, if it needs to store objects in a write-through or write-behind cache store, the stored objects need marshalling. If a cluster of Infinispan nodes is formed, objects shipped around need marshalling. Even if you enable lazy deserialization, objects need to be marshalled so that they can be lazily unmarshalled with the correct classloader.

Using standard JDK serialization is slow and produces payloads that are too big and can affect bandwidth usage. On top of that, JDK serialization does not work well with objects that are supposed to be immutable. In order to avoid these issues, Infinispan uses [JBoss Marshalling](#) for marshalling/unmarshalling objects. JBoss Marshalling is fast, produces very space efficient payloads, and on top of that during unmarshalling, it enables users to have full control over how to construct objects, hence allowing objects to carry on being immutable.

Starting with 5.0, users of Infinispan can now benefit from this marshalling framework as well, and they can provide their own externalizer implementations, but before finding out how to provide externalizers, let's look at the benefits they bring.

7.4.1. Benefits of Externalizers

The JDK provides a simple way to serialize objects which, in its simplest form, is just a matter of extending [java.io.Serializable](#), but as it's well known, this is known to be slow and it generates payloads that are far too big. An alternative way to do serialization, still relying on JDK serialization, is for your objects to extend [java.io.Externalizable](#). This allows for users to provide their own ways to marshal/unmarshal classes, but has some serious issues because, on top of relying on slow JDK serialization, it forces the class that you want to serialize to extend this interface, which has two side effects: The first is that you're forced to modify the source code of the class that you want to marshal/unmarshal which you might not be able to do because you either, don't own the source, or you don't even have it. Secondly, since Externalizable implementations do not control object creation, you're forced to add set methods in order to restore the state, hence potentially forcing your immutable objects to become mutable.

Instead of relying on JDK serialization, Infinispan uses JBoss Marshalling to serialize objects and requires any classes to be serialized to be associated with an [Externalizer](#) interface implementation that knows how to transform an object of a particular class into a serialized form and how to read an object of that class from a given input. Infinispan does not force the objects to be serialized to implement Externalizer. In fact, it is recommended that a separate class is used to implement the Externalizer interface because, contrary to JDK serialization, Externalizer implementations control how objects of a particular class are created when trying to read an object from a stream. This means that `readObject()` implementations are responsible of creating object instances of the target class, hence giving users a lot of flexibility on how to create these instances (whether direct instantiation, via factory or reflection), and more importantly, allows target classes to carry on being immutable. This type of externalizer architecture promotes good OOP designs principles, such as the principle of [single responsibility](#).

It's quite common, and in general recommended, that Externalizer implementations are stored as inner static public classes within classes that they externalize. The advantages of doing this is that related code stays together, making it easier to maintain. In Infinispan, there are two ways in which Infinispan can be plugged with user defined externalizers:

7.4.2. User Friendly Externalizers

In the simplest possible form, users just need to provide an [Externalizer](#) implementation for the type that they want to marshall/unmarshall, and then annotate the marshalled type class with `{@link SerializeWith}` annotation indicating the externalizer class to use. For example:

```
import org.infinispan.commons.marshall.Externalizer;
import org.infinispan.commons.marshall.SerializeWith;

@SerializeWith(Person.PersonExternalizer.class)
public class Person {

    final String name;
    final int age;

    public Person(String name, int age) {
        this.name = name;
        this.age = age;
    }

    public static class PersonExternalizer implements Externalizer<Person> {
        @Override
        public void writeObject(ObjectOutput output, Person person)
            throws IOException {
            output.writeObject(person.name);
            output.writeInt(person.age);
        }

        @Override
        public Person readObject(ObjectInput input)
            throws IOException, ClassNotFoundException {
            return new Person((String) input.readObject(), input.readInt());
        }
    }
}
```

At runtime JBoss Marshalling will inspect the object and discover that it's marshallable (thanks to the annotation) and so marshall it using the externalizer class passed. To make externalizer implementations easier to code and more typesafe, make sure you define type `<T>` as the type of object that's being marshalled/unmarshalled.

Even though this way of defining externalizers is very user friendly, it has some disadvantages:

- Due to several constraints of the model, such as support for different versions of the same class

or the need to marshall the Externalizer class, the payload sizes generated via this method are not the most efficient.

- This model requires that the marshalled class be annotated with `{@link SerializeWith}` but a user might need to provide an Externalizer for a class for which source code is not available, or for any other constraints, it cannot be modified.
- The use of annotations by this model might be limiting for framework developers or service providers that try to abstract lower level details, such as the marshalling layer, away from the user.

If you're affected by any of these disadvantages, an alternative method to provide externalizers is available via more advanced externalizers:

7.4.3. Advanced Externalizers

[AdvancedExternalizer](#) provides an alternative way to provide externalizers for marshalling/unmarshalling user defined classes that overcome the deficiencies of the more user-friendly externalizer definition model explained in Externalizer. For example:

```

import org.infinispan.marshall.AdvancedExternalizer;

public class Person {

    final String name;
    final int age;

    public Person(String name, int age) {
        this.name = name;
        this.age = age;
    }

    public static class PersonExternalizer implements AdvancedExternalizer<Person> {
        @Override
        public void writeObject(ObjectOutput output, Person person)
            throws IOException {
            output.writeObject(person.name);
            output.writeInt(person.age);
        }

        @Override
        public Person readObject(ObjectInput input)
            throws IOException, ClassNotFoundException {
            return new Person((String) input.readObject(), input.readInt());
        }

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

        @Override
        public Integer getId() {
            return 2345;
        }
    }
}

```

The first noticeable difference is that this method does not require user classes to be annotated in anyway, so it can be used with classes for which source code is not available or that cannot be modified. The bound between the externalizer and the classes that are marshalled/unmarshalled is set by providing an implementation for `getTypeClasses()` which should return the list of classes that this externalizer can marshal:

Linking Externalizers with Marshaller Classes

Once the Externalizer's `readObject()` and `writeObject()` methods have been implemented, it's time to link them up together with the type classes that they externalize. To do so, the Externalizer implementation must provide a `getTypeClasses()` implementation. For example:

```

import org.infinispan.util.Util;
...
@Override
public Set<Class<? extends ReplicableCommand>> getTypeClasses() {
    return Util.asSet(LockControlCommand.class, RehashControlCommand.class,
        StateTransferControlCommand.class, GetKeyValueCommand.class,
        ClusteredGetCommand.class,
        SingleRpcCommand.class, CommitCommand.class,
        PrepareCommand.class, RollbackCommand.class,
        ClearCommand.class, EvictCommand.class,
        InvalidateCommand.class, InvalidateL1Command.class,
        PutKeyValueCommand.class, PutMapCommand.class,
        RemoveCommand.class, ReplaceCommand.class);
}

```

In the code above, `ReplicableCommandExternalizer` indicates that it can externalize several type of commands. In fact, it marshalls all commands that extend `ReplicableCommand` interface, but currently the framework only supports class equality comparison and so, it's not possible to indicate that the classes to be marshalled are all children of a particular class/interface.

However there might sometimes when the classes to be externalized are private and hence it's not possible to reference the actual class instance. In this situations, users can attempt to look up the class with the given fully qualified class name and pass that back. For example:

```

@Override
public Set<Class<? extends List>> getTypeClasses() {
    return Util.<Class<? extends List>>asSet(
        Util.loadClass("java.util.Collections$SingletonList"));
}

```

Externalizer Identifier

Secondly, in order to save the maximum amount of space possible in the payloads generated, advanced externalizers require externalizer implementations to provide a positive identifier via `getId()` implementations or via XML/programmatic configuration that identifies the externalizer when unmarshalling a payload. In order for this to work however, advanced externalizers require externalizers to be registered on cache manager creation time via XML or programmatic configuration which will be explained in next section. On the contrary, externalizers based on `Externalizer` and `SerializeWith` require no pre-registration whatsoever. Internally, Infinispan uses this advanced externalizer mechanism in order to marshal/unmarshal internal classes.

So, `getId()` should return a positive integer that allows the externalizer to be identified at read time to figure out which Externalizer should read the contents of the incoming buffer, or it can return null. If `getId()` returns null, it is indicating that the id of this advanced externalizer will be defined via XML/programmatic configuration, which will be explained in next section.

Regardless of the source of the the id, using a positive integer allows for very efficient variable length encoding of numbers, and it's much more efficient than shipping externalizer

implementation class information or class name around. Infinispan users can use any positive integer as long as it does not clash with any other identifier in the system. It's important to understand that a user defined externalizer can even use the same numbers as the externalizers in the Infinispan Core project because the internal Infinispan Core externalizers are special and they use a different number space to the user defined externalizers. On the contrary, users should avoid using numbers that are within the pre-assigned identifier ranges which can be found at the end of this article. Infinispan checks for id duplicates on startup, and if any are found, startup is halted with an error.

When it comes to maintaining which ids are in use, it's highly recommended that this is done in a centralized way. For example, `getId()` implementations could reference a set of statically defined identifiers in a separate class or interface. Such class/interface would give a global view of the identifiers in use and so can make it easier to assign new ids.

Registering Advanced Externalizers

The following example shows the type of configuration required to register an advanced externalizer implementation for Person object shown earlier stored as a static inner class within it:

infinispan.xml

```
<infinispan>
  <cache-container>
    <serialization>
      <advanced-externalizer class="Person$PersonExternalizer"/>
    </serialization>
  </cache-container>
  ...
</infinispan>
```

Programmatically:

```
GlobalConfigurationBuilder builder = ...
builder.serialization()
    .addAdvancedExternalizer(new Person.PersonExternalizer());
```

As mentioned earlier, when listing these externalizer implementations, users can optionally provide the identifier of the externalizer via XML or programmatically instead of via `getId()` implementation. Again, this offers a centralized way to maintain the identifiers but it's important that the rules are clear: An `AdvancedExternalizer` implementation, either via XML/programmatic configuration or via annotation, needs to be associated with an identifier. If it isn't, Infinispan will throw an error and abort startup. If a particular `AdvancedExternalizer` implementation defines an id both via XML/programmatic configuration and annotation, the value defined via XML/programmatically is the one that will be used. Here's an example of an externalizer whose id is defined at registration time:

```

<infinispan>
  <cache-container>
    <serialization>
      <advanced-externalizer id="123"
                             class="Person$PersonExternalizer"/>
    </serialization>
  </cache-container>
  ...
</infinispan>

```

Programmatically:

```

GlobalConfigurationBuilder builder = ...
builder.serialization()
  .addAdvancedExternalizer(123, new Person.PersonExternalizer());

```

Finally, a couple of notes about the programmatic configuration. `GlobalConfiguration.addExternalizer()` takes varargs, so it means that it is possible to register multiple externalizers in just one go, assuming that their ids have already been defined via `@Marshall`s annotation. For example:

```

builder.serialization()
  .addAdvancedExternalizer(new Person.PersonExternalizer(),
                           new Address.AddressExternalizer());

```

Preassigned Externalizer Id Ranges

This is the list of Externalizer identifiers that are used by Infinispan based modules or frameworks. Infinispan users should avoid using ids within these ranges.

Infinispan Tree Module:	1000 - 1099
Infinispan Server Modules:	1100 - 1199
Hibernate Infinispan Second Level Cache:	1200 - 1299
Infinispan Lucene Directory:	1300 - 1399
Hibernate OGM:	1400 - 1499
Hibernate Search:	1500 - 1599
Infinispan Query Module:	1600 - 1699
Infinispan Remote Query Module:	1700 - 1799
Infinispan Scripting Module:	1800 - 1849
Infinispan Server Event Logger Module:	1850 - 1899

Infinispan Remote Store:	1900 - 1999
--------------------------	-------------

Chapter 8. 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

- [DummyTransactionManagerLookup](#) : This provides with a dummy transaction manager which should only be used for testing. Being a dummy, this is not recommended for production use as it has some severe limitations to do with concurrent transactions and recovery.
- [JBossStandaloneJTAManagerLookup](#) : If you're running Infinispan in a standalone environment, 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 dummy transaction manager.
- [GenericTransactionManagerLookup](#) : This is a lookup class that locates transaction managers in the most popular Java EE application servers. If no transaction manager can be found, it defaults on the dummy transaction manager.

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();
```

8.1. Configuring transactions

Transactions are being configured at cache level.

```
<transaction
  transaction-manager-lookup=
"org.infinispan.transaction.lookup.GenericTransactionManagerLookup"
  mode="FULL_XA"
  locking="OPTIMISTIC"/>
```

- transactionManagerLookupClass fully qualified class name of a class that looks up a reference to a javax.transaction.TransactionManager
- mode - configures whether the cache is transaction mode, the available options are:
 - **NONE** - non transactional cache
 - **FULL_XA** - XA transactional cache with recovery enabled.
 - **NON_DURABLE_XA** - XA transactional cache with recovery disabled.
 - **NON_XA** - Transactional cache with intergration via Synchronization instead of XA.
- locking - configures whether the cache uses optimistic or pessimistic locking.

For more details on how two phase commit (2PC) is implemented in Infinispan and how locks are being acquired see the section below. All possible transactional settings are available in [Configuration reference](#)

8.2. Transaction modes

Starting with Infinispan 5.1 release a cache can accessed either transactionally or non-transactionally. The mixed access mode that existed in Infinispan 4 and 5.0 is no longer supported. There are several reasons for going this path, but one of them most important is a cleaner semantic on how concurrency is managed between multiple requestors for the same cache entry.

By default, all Infinispan caches are non-transactional. A cache can be made transactional by changing the **mode** attribute:

```
<local-cache name="transactional">
  <transaction mode="NON_XA"/>
</local-cache>
```

One can configure a transactional cache programatically as well, the equivalent is:

```
Configuration c = new ConfigurationBuilder().transaction().transactionMode
(TransactionMode.TRANSACTIONAL).build();
assert c.transaction().transactionalCache();
```



Do not forget to configure a TransactionManagerLookup for transactional caches.

Supported transaction models are optimistic and pessimistic. Optimistic model is an improvement over the old transaction model as it completely defers lock acquisition to transaction prepare time.

New approach reduces lock acquisition duration and increases throughput which in turn avoids deadlocks significantly. In pessimistic model, cluster wide-locks are acquired on each write operation only being released after the transaction completed.

8.2.1. Optimistic Transactions

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.

Optimistic transactions can be enabled in the configuration file:

```
<local-cache name="transactional">
  <transaction mode="NON_XA" locking="OPTIMISTIC"/>
</local-cache>
```

or programatically:

```
Configuration c = new ConfigurationBuilder().transaction().lockingMode(LockingMode
.OPTIMISTIC).build();
assert c.transaction().lockingMode() == LockingMode.OPTIMISTIC;
```



By default, a transactional cache is optimistic.

8.2.2. Pessimistic Transactions

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

```
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).

Pessimistic transactions can be enabled in the configuration file:

```
<local-cache name="transactional">
  <transaction mode="NON_XA" locking="PESSIMISTIC"/>
</local-cache>
```

or programmatically:

```
Configuration c = new ConfigurationBuilder().transaction().lockingMode(LockingMode
.PESSIMISTIC).build();
assert c.transaction().lockingMode() == LockingMode.PESSIMISTIC;
```

8.2.3. Backward compatibility

The `autoCommit` attribute was added in order to assure backward compatibility with Infinispan 4. If a cache is transactional and `autoCommit` is enabled (defaults to true) then any call that is performed outside of a transaction's scope is transparently wrapped within a transaction. In other words Infinispan adds the logic for starting a transaction before the call and committing it after the call.

Therefore if your code accesses a cache both transactionally and non-transactionally all you have to do when migrating to Infinispan 5.1 is mark the cache as transactional and enable `autoCommit` (that's actually enabled by default)

The `autoCommit` feature can be managed through configuration:

```
<local-cache name="transactional">
  <transaction mode="NON_XA" auto-commit="true"/>
</local-cache>
```

8.2.4. 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 (`writeSkewCheck`).

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.

8.3. Deadlock detection

Deadlocks can significantly (up to one order of magnitude, see benchmarks) reduce the throughput of a system, especially when multiple transactions are operating against the same key set. Deadlock detection is disabled by default, but can be enabled/configured per cache (i.e. under `*-cache` config element) by adding the following:

```
<local-cache deadlock-detection-spin="1000"/>
```

Some clues on when to enable deadlock detection. A high number of transaction rolling back due to `TimeoutException` is an indicator that this functionality might help. `TimeoutException` might be

caused by other causes as well, but deadlocks will always result in this exception being thrown. Generally, when you have a high contention on a set of keys, deadlock detection may help. But the best way is not to guess the performance improvement but to benchmark and monitor it: you can have access to statistics (e.g. number of deadlocks detected) through JMX, as it is exposed via the `DeadlockDetectingLockManager` MBean. For more details on how deadlock detection works, benchmarks and design details refer to [this](#) article.

Note: deadlock detection only runs on an a per cache basis: deadlocks that spread over two or more caches won't be detected.

8.4. 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.

8.5. 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.

Starting with 5.0 release, Infinispan allows transaction enlistment through [Synchronisation](#) . To enable it just use `NON_XA` transaction mode:

```
<transaction mode="NON_XA"/>
```

[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 an [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 [Synchronisation](#) makes the `TransactionManager` skip writing the log to the disk (performance improvement).

8.6. 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.

8.6.1. Configuring batching

To use batching, you need to enable invocation batching in your cache configuration, either on the Configuration object:

```
Configuration.setInvocationBatchingEnabled(true);
```

or in your XML file:

```
<local-cache>
  <transaction mode="BATCH"/>
</local-cache>
```

By default, invocation batching is disabled.

Note that you *do not* have to have a transaction manager defined to use batching.

8.6.2. 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

```

8.6.3. 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:

```
<transaction mode="NON_XA" />
```

8.7. 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.

8.7.1. 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.

8.7.2. 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 [Reconciliate state](#) section.

8.7.3. 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. In order to enable recovery through xml configuration:

```
<transaction mode="FULL_XA" recovery-cache="noRecovery"/>
```



the *recovery-cache* attribute is not mandatory.

Alternatively you can enable it through the fluent configuration API as follows:

```
//simply calling .recovery() enables it
configuration.transaction().recovery();

//then you can disable it
configuration.transaction().recovery().disable();

//or just check its status
boolean isRecoveryEnabled = configuration.isTransactionRecoveryEnabled();
```

Recovery can be enabled/disabled on a per cache level: e.g it is possible to have a transaction spanning a cache that has it enabled and another one that doesn't.



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. More about enabling JMX [here](#).

8.7.4. 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 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 "recoveryInfoCacheName" 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 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.

8.7.5. Integration with the transaction manager

Even though this is transaction manager specific, generally a transaction manager would need a reference to an 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. At the moment it is not possible to do this with infinispan: the recovery must be run from the same process where the infinispan instance exists. This limitation will be dropped once [transactions over HotRod](#) are available.

8.7.6. 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.

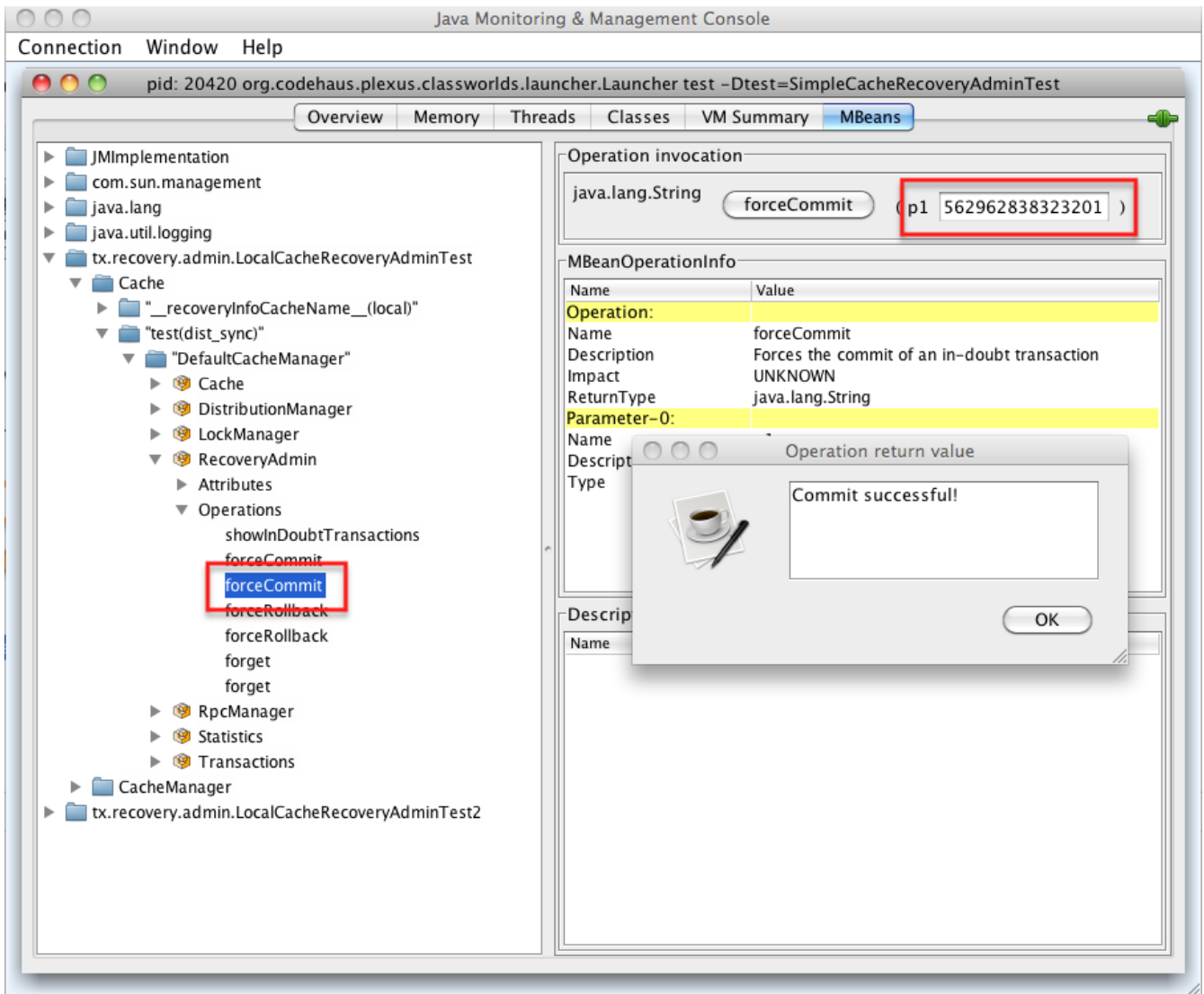


Figure 7. Force commit



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.

8.8. Total Order based commit protocol

The Total Order based protocol is a multi-master scheme (in this context, multi-master scheme means that all nodes can update all the data) as the (optimistic/pessimist) locking model implemented in Infinispan. This commit protocol relies on the concept of totally ordered delivery of messages which, informally, implies that each node which delivers a set of messages, delivers them in the same order.

This protocol comes with this advantages.

1. transactions can be committed in one phase, as they are delivered in the same order by the nodes that receive them.
2. it mitigates distributed deadlocks.

The weaknesses of this approach are the fact that its implementation relies on a single thread per node which delivers the transaction and its modification, and the slightly higher number of messages exchanged by JGroups.

Thus, this protocol delivers best performance in scenarios of *high contention* , in which it can benefit from the single-phase commit and the deliver thread is not the bottleneck.

Currently, the Total Order based protocol is available only in *transactional* caches for *replicated* and *distributed* modes.

8.8.1. Overview

The Total Order based commit protocol only affects how transactions are committed and it depends of the isolation level configured, more precisely the *write skew check* . Note that it only provides the *same isolation levels* as the locking model, i.e. *read-committed* and *repeatable-read* . If the write skew check is not enabled, then all the transaction are committed in one phase (independently if Infinispan is enlisted as *Synchronization* or *XaResource*). In this case, the isolation level is not violated because it is ensured during the transaction execution. Also the transactions always commit successfully because they do not need to perform any validation in prepare phase.

On other hand, when write skew check is enabled, the protocol adapts using one phase commit when it is safe. However, if Infinispan is enlisted as *Synchronization* , it always commit in two phases, because the *Transaction Manager* does not provide any information if Infinispan is the only resource enlisted or not. In *XaResource* enlistment, we can use one phase if the *Transaction Manager* request a commit in one phase (i.e. one-phase optimization, usually used when the transaction has a single *XaResource* registered, see [XaResource.commit\(\)](#)) and the Infinispan cache is configured in replicated mode or in distributed mode (the last one, when the *writeSkew==false*). This optimization is not safe in distributed mode when *writeSkew==true* because each node performs the validation in different keys subset.

Commit in one phase

When the transaction ends, Infinispan sends the transaction (and its modification) in total order. This ensures all the transactions are deliver in the same order in all the involved Infinispan nodes. As a result, when a transaction is delivered, it performs a deterministic validation over the same state, leading to the same outcome (transaction commit or rollback). Also, if the transactional mode is configured with *syncCommitPhase==false* , the node that sent the transaction still needs to wait for the self-deliver of the transaction because it needs to know the transaction outcome. In other hand, it does not need to wait for the replies from other nodes because they will reply with the same outcome. Although, if *syncCommitPhase==true* , it needs to wait for the replies in order to respect the semantic of the flag.

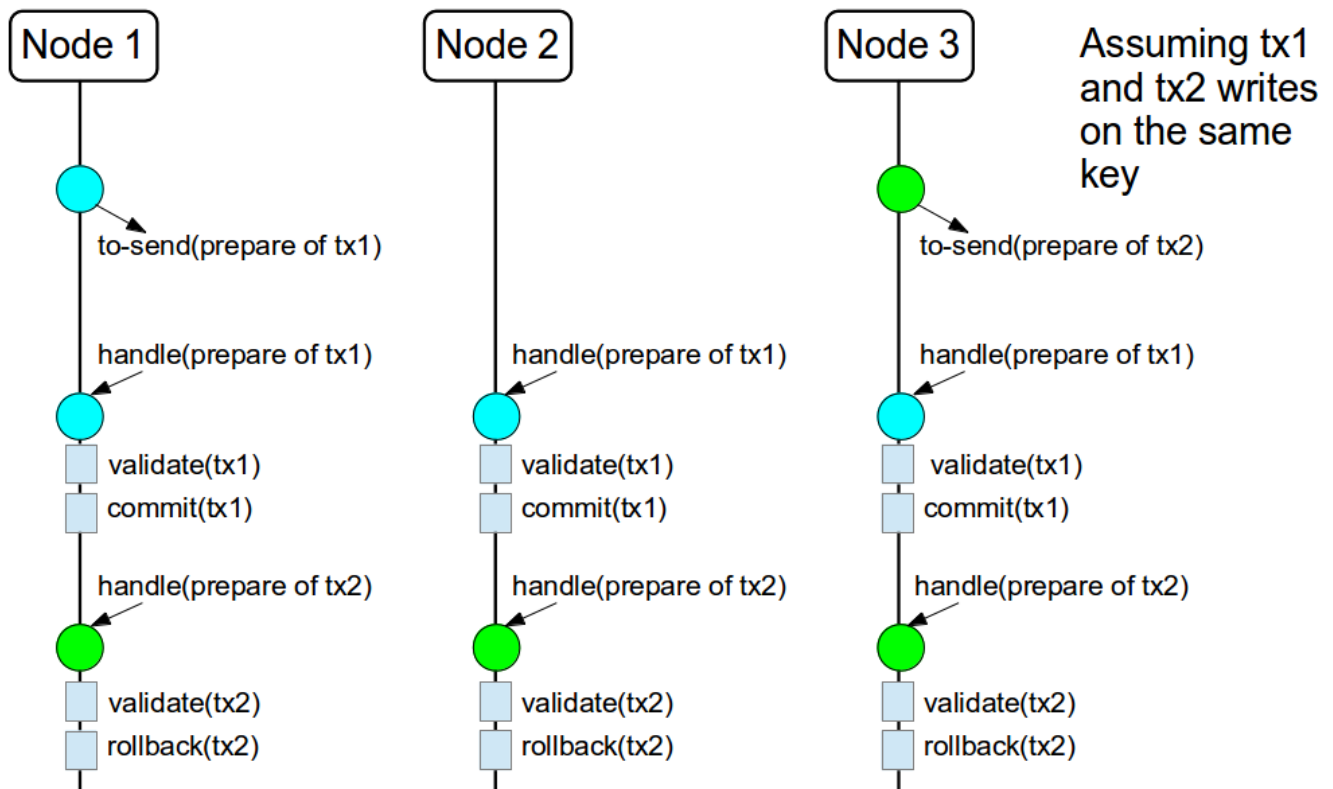


Figure 8. 1-phase commit

The figure above demonstrates a high level example with 3 nodes. *Node1* and *Node3* are running one transaction each and lets assume that both transaction writes on the same key. To make it more interesting, lets assume that both nodes tries to commit at the same time, represented by the first colored circle in the figure. The *blue* circle represents the transaction *tx1* and the *green* the transaction *tx2* . Both nodes do a remote invocation in total order (*to-send*) with the transaction's modifications. At this moment, all the nodes will agree in the same deliver order, for example, *tx1* followed by *tx2* . Then, each node delivers *tx1* , perform the validation and commits the modifications. The same steps are performed for *tx2* but, in this case, the validation will fail and the transaction is rollback in all the involved nodes.

Commit in two phases

The first phase is the same as described above except that the nodes will not apply the modifications after the validation, including the modifications sent in total order and the same scheme to wait for the replies. As soon as it has the confirmation that all keys are successfully validated, it give a positive response to the *Transaction Manager* (remember that the *Transaction Manager* is responsive to invoke the *prepare()* of the transaction). On other hand, if it receives a negative reply, it returns a negative response to the *Transaction Manager* . Finally, the transaction is committed or aborted in the second phase depending of the *Transaction Manager* .

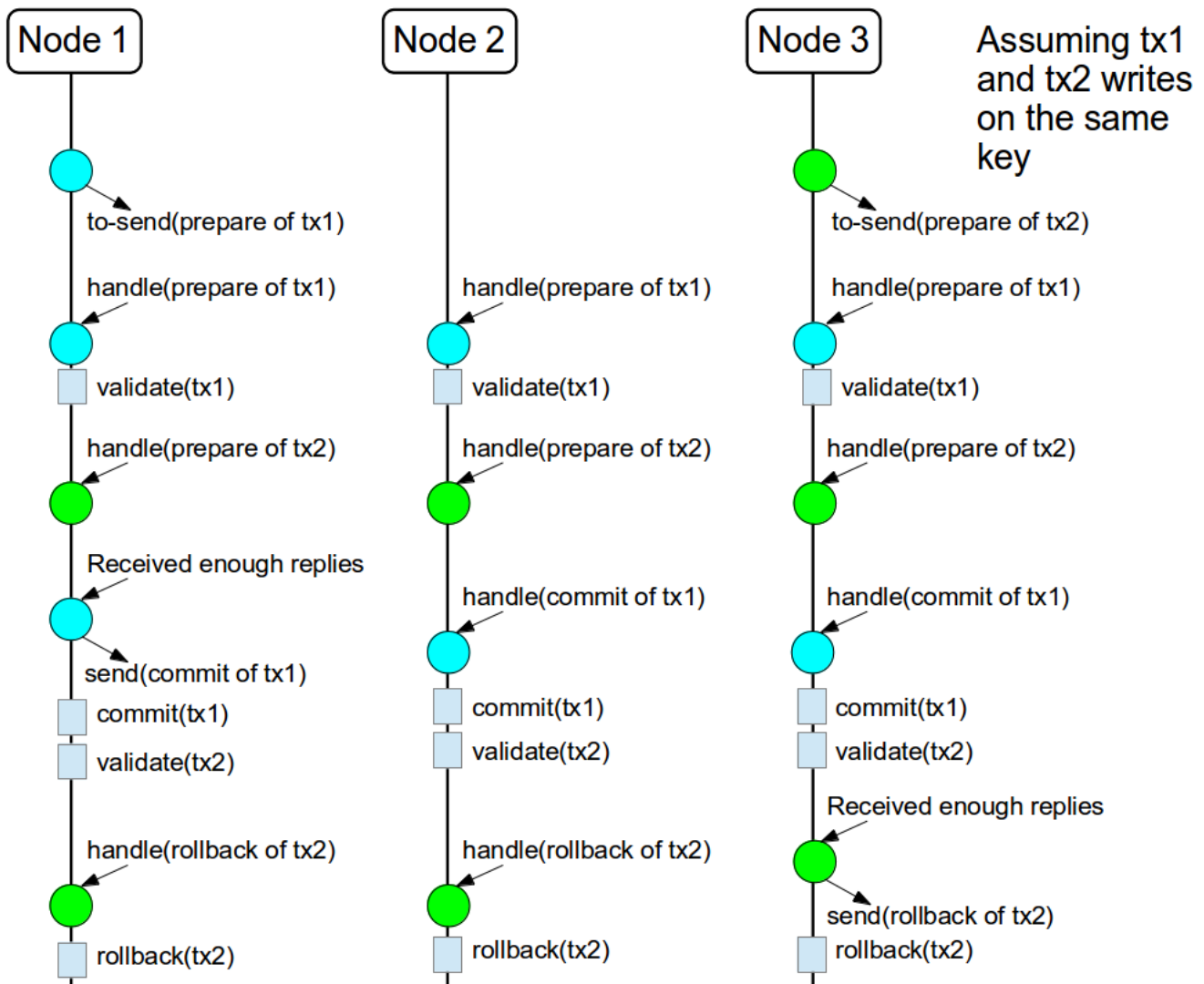


Figure 9. 2-phase commit

The figure above shows the scenario described in the first figure but now committing the transactions using two phases. When *tx1* is deliver, it performs the validation and it replies to the *Transaction Manager*. Next, lets assume that *tx2* is deliver before the *Transaction Manager* request the second phase for *tx1*. In this case, *tx2* will be enqueued and it will be validated only when *tx1* is completed. Eventually, the *Transaction Manager* for *tx1* will request the second phase (the commit) and all the nodes are free to perform the validation of *tx2*.

Transaction Recovery

[Transaction recovery](#) is currently not available for Total Order based commit protocol

Total order executor service

Since 9.0, total order protocol uses the *remote-command-executor*.

State Transfer

For simplicity reasons, the total order based commit protocol uses a blocking version of the current state transfer. The main differences are:

1. enqueue the transaction deliver while the state transfer is in progress;

- the state transfer control messages (*CacheTopologyControlCommand*) are sent in total order.

This way, it provides a synchronization between the state transfer and the transactions deliver that is the same all the nodes. Although, the transactions caught in the middle of state transfer (i.e. sent before the state transfer start and deliver after it) needs to be re-sent to find a new total order involving the new joiners.

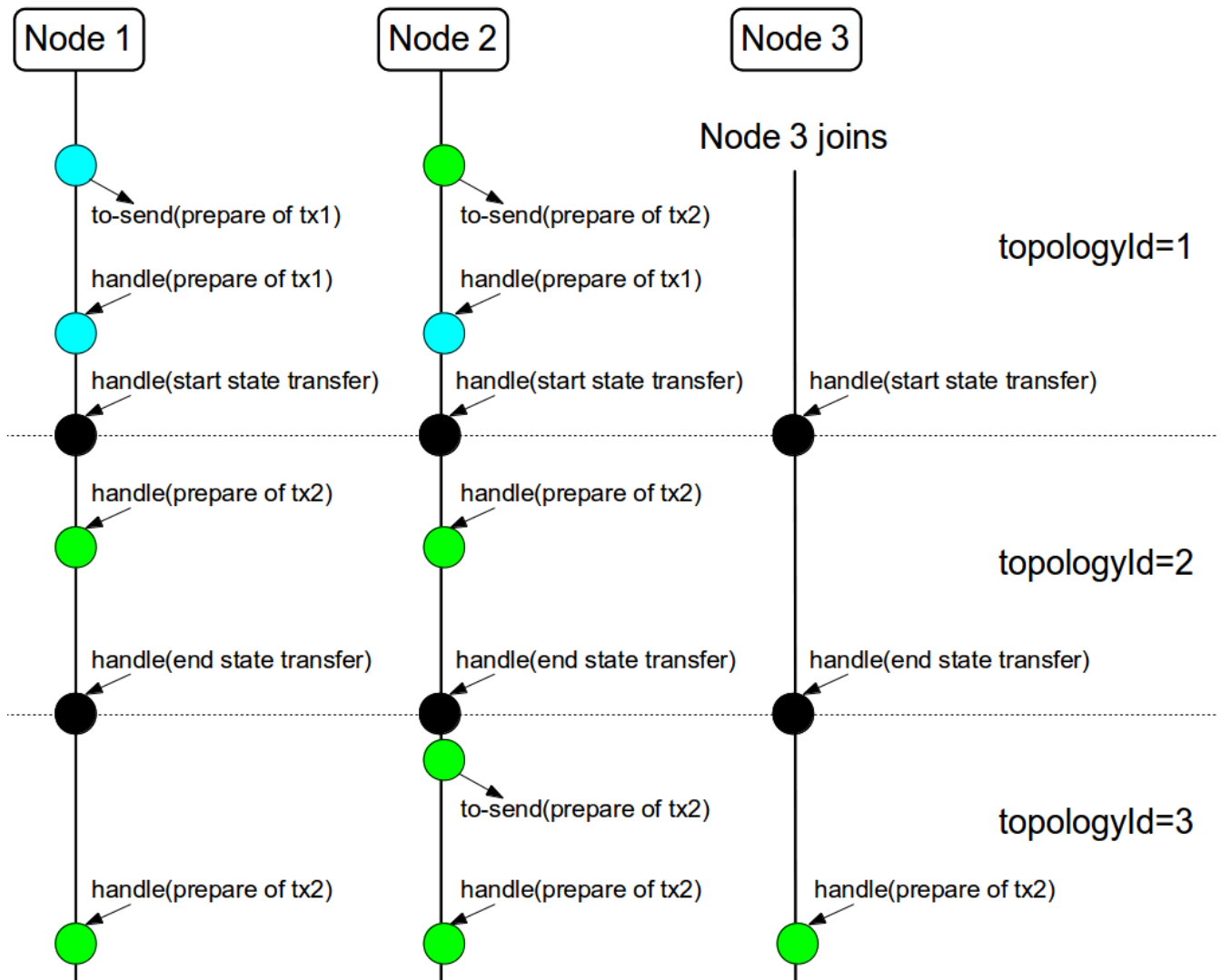


Figure 10. Node joining during transaction

The figure above describes a node joining. In the scenario, the *tx2* is sent in *topologyId=1* but when it is received, it is in *topologyId=2*. So, the transaction is re-sent involving the new nodes.

8.8.2. Configuration

To use Total Order based commit protocol in your Infinispan cache, you need to configure a couple of thing:

- add the total order protocols in JGroups configuration file:

jgroups.xml

```
<SEQUENCER />
<tom.TOA />
```

Check the JGroups manual for more detail in here: [JGroups Manual](#)

- configure the Infinispan cache as a transactional cache and set the transaction protocol to total order:

infinispan.xml

```
<local-cache>
  <transaction mode="NON_XA" protocol="TOTAL_ORDER" />
</local-cache>
```

You can build the same configuration programmatically in the following way:

```
ConfigurationBuilder cb = new ConfigurationBuilder();
cb.transaction().transactionMode(TransactionMode.TRANSACTIONAL).transactionProtocol(Tr
ansactionProtocol.TOTAL_ORDER);
```

Optionally, you can configure the total order executor to use your own executor services. By default, it creates an executor service with *coreThreads=1* and *maxThreads=32* . It can be configured in the following way:

infinispan.xml

```
<infinispan>
  <threads>
    <blocking-bounded-queue-thread-pool name="custom-totalorder"
      core-threads="1" max-threads="32"/>
  </threads>
  <cache-container>
    <transport total-order-executor="custom-totalorder" />
  </cache-container>
</infinispan>
```

or programmatically:

```
GlobalConfigurationBuilder gcb = new GlobalConfigurationBuilder();
gcb.transport().totalOrderThreadPool().threadPoolFactory(
  new BlockingThreadPoolExecutorFactory(32, 1, 10000, 60000));
```

Beside the *coreThreads* and the *maxThreads* , the *DefaultExecutorFactory* also accepts as properties as the *queueSize* , *keepAliveTime* (in milliseconds), *threadPriority* , *threadNamePrefix* and *threadNameSuffix* . Note that, this parameters are used by the *ExecutorService* . The total order

executor uses an unbounded queue. Also, when you provide an *ExecutorService* , make sure that it will no reject tasks , otherwise your data can became *inconsistent* .

8.8.3. Total Order support in JGroups.

SEQUENCER

The *SEQUENCER* protocol ensures total order involving all the members in the cluster. It is a sequencer-based implementation in which the sender forwards the messages to a sequencer (the current cluster coordinator), and the sequencer sends it back to the cluster on behalf of the original sender. Because it is always the same sender (whose messages are delivered in FIFO order), a global (or total) order is established.

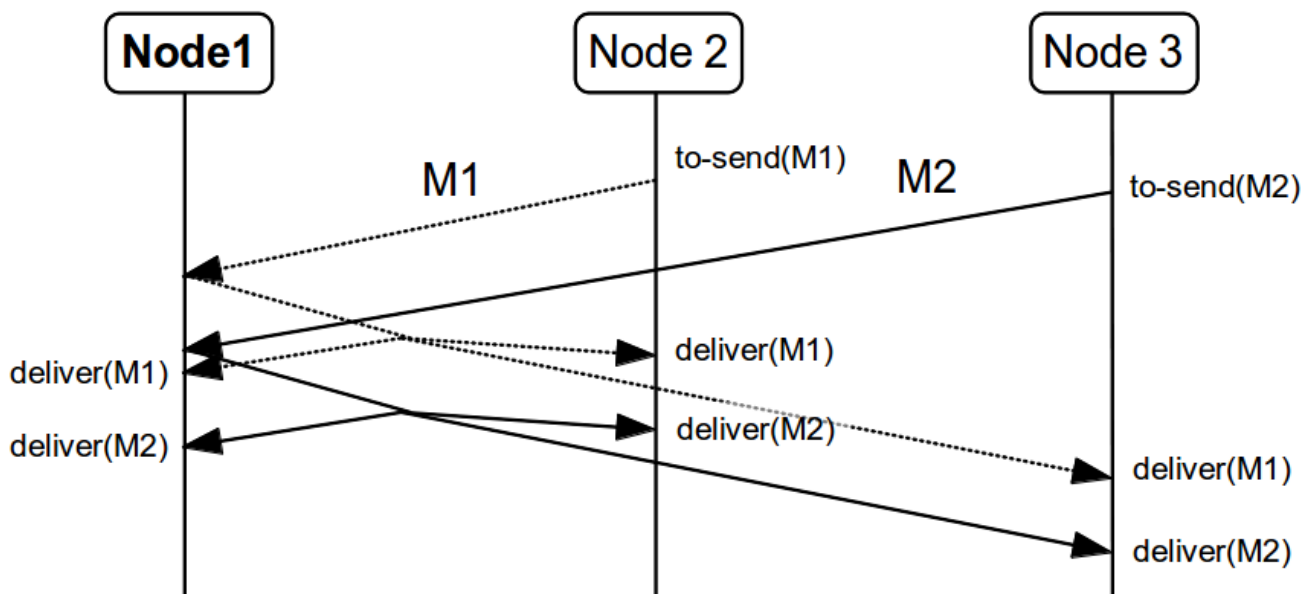


Figure 11. Total-order broadcast

The figure above shows the the communication steps to total-order broadcast two messages *M1* and *M2* from different senders. Below, the figure shows the communication steps needed to commit a single transaction, when two phase are used. The dotted line represents the communications steps performed by the *SEQUENCER* . As it is possible to see, ensure total order is not a cheap operation and it has a cost of an extra communication step comparing with the lock based implementation.

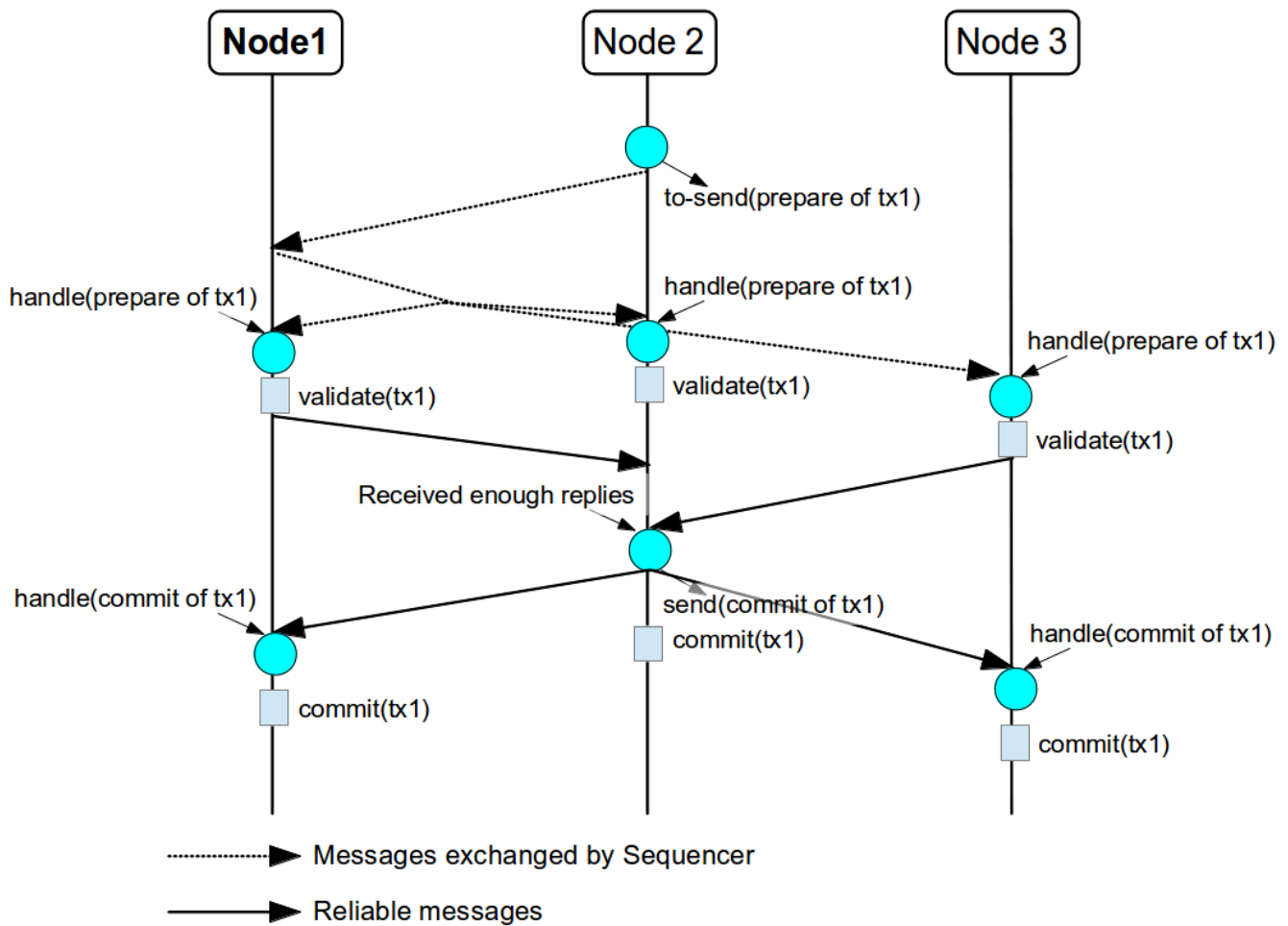


Figure 12. Total-order tx commit

More information about the *SEQUENCER* in JGroups manual: [SEQUENCER - JGroups Manual page](#)

TOA - Total Order Anycast

The *TOA* protocol is implemented based on the Skeen Algorithm. Each node has an ordered (by the message logical clock) queue with the messages and a local logical clock and it works in a centralized way. The sender sends N unicast messages with the data to all destination nodes. When the message is received, each replica increments its logical clock and it sends back the value to the sender. Meanwhile, the message is put on the queue with the value of logical clock and marked as *temporary*. The sender collects all values and calculates the maximum value of them. Finally it sends other N unicast message with the final value of the message. This number indicates the final order number of deliver for the message. Each replica updates its logical clock, if the value is lower than the final value received, and updates the message in the queue, re-ordered if necessary. Then the message is marked as *final*. The messages are delivered when it is on the top of the queue and is *final*. The figure below explains in a graphical way how it is done.

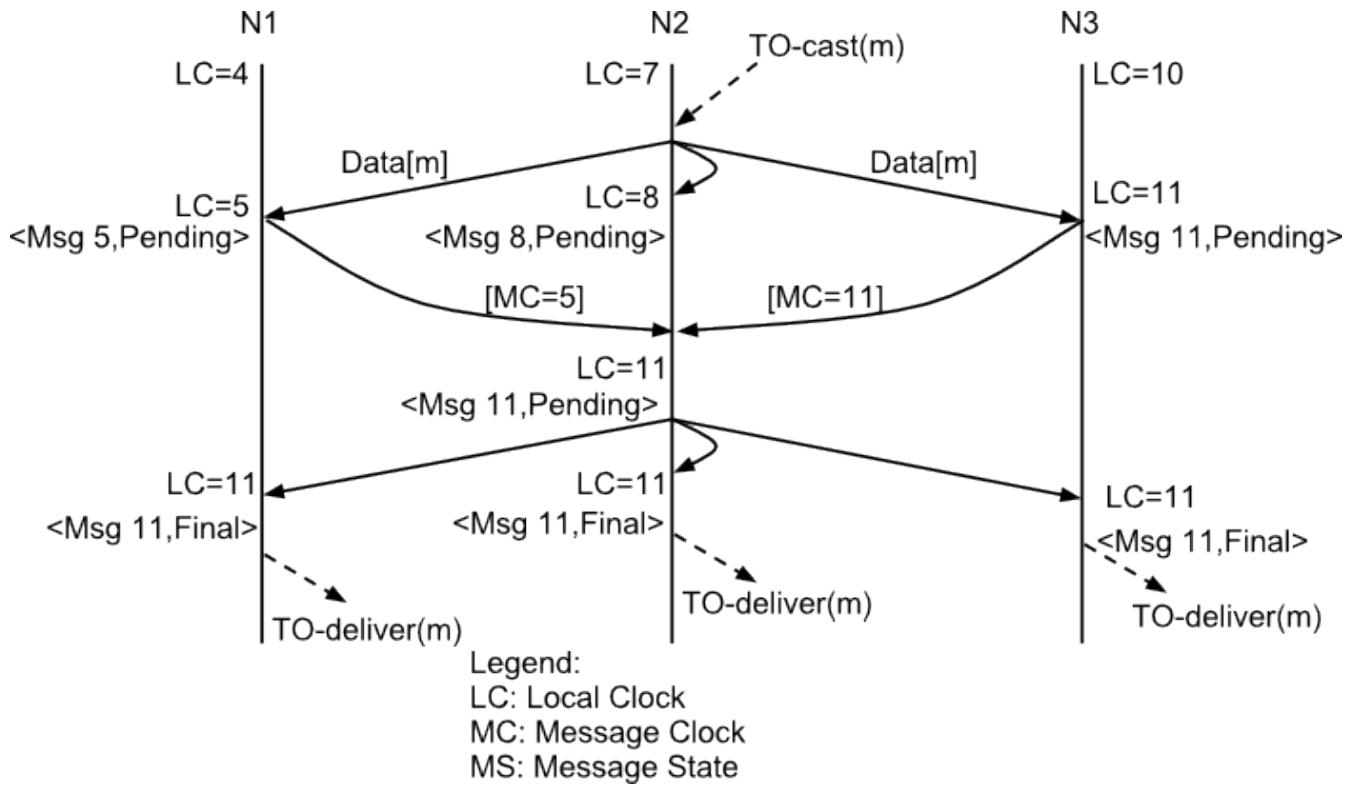


Figure 13. Total-order Anycast

The next figure show one transaction to be committed in detail, including all the communication steps. The dotted line represents the messages exchanged by *TOA* and the solid lines a single unicast message. This figure shows that the total order protocol has 2 more communications steps than the lock based implementation.

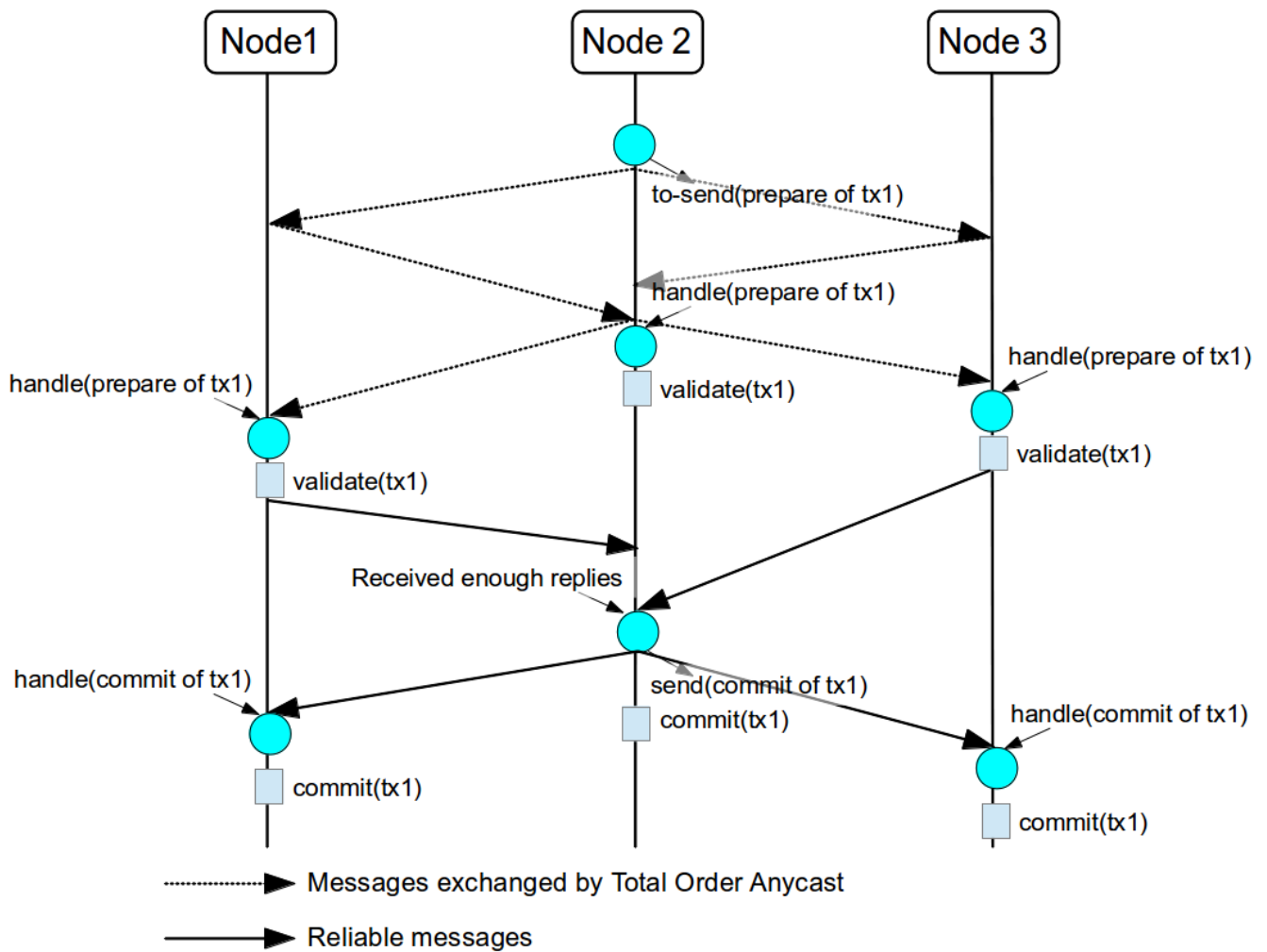


Figure 14. Transaction commit detail

More information about the Total Order Anycast in JGroups manual: [TOA - JGroups Manual page](#)

8.8.4. Benchmark results

In order to compare the performance of total order with the locking model, [RadarGun](#) was used to perform a benchmark evaluation in two different scenarios: a *no contention* scenario and a *contention* scenario.

The Infinispan configuration used is:

```
<infinispan>
  <jgroups>
    <stack-file name="external" path="jgroups/jgroups.xml"/>
  </jgroups>
  <cache-container default-cache="default">
    <transport cluster="x" stack="external">
      <replicated-cache name="default" mode="SYNC" remote-timeout="10000">
        <transaction transaction-manager-lookup=
"org.infinispan.transaction.lookup.GenericTransactionManagerLookup"
          mode="NON_XA" protocol="TOTAL_ORDER" />
        <locking concurrency-level="1000" striping="false"
          isolation="REPEATABLE_READ" write-skew="true"/> <!-- write-
skew="false" for the no write skew experiments -->
        <state-transfer enabled="false"/>
      </replicated-cache>
      <replicated-cache name="testCache"/>
    </cache-container>
  </infinispan>
```

and the benchmark configuration, using [Radar Gun](#), is:

```

...
    <benchmark initSize="2" maxSize="{10:slaves}" increment="2">
        <DestroyWrapper runOnAllSlaves="true"/>
        <StartCluster staggerSlaveStartup="true" delayAfterFirstSlaveStarts="5000"
delayBetweenStartingSlaves="500"/>
        <ClusterValidation partialReplication="false"/>
        <StressTestWarmup duration="1m" opsCountStatusLog="5000" numThreads="8"
transactionSize="10"
                        useTransactions="true" writePercentage="50" numEntries="
1000" sharedKeys="false"/>
        <StressTest duration="5m" opsCountStatusLog="5000" numThreads="8"
transactionSize="10"
                        useTransactions="true" writePercentage="50" numEntries="1000"
sharedKeys="false"/>
        <CsvReportGeneration targetDir="no_contention"/>
        <ClearCluster/>
        <StressTestWarmup duration="1m" opsCountStatusLog="5000" numThreads="8"
transactionSize="10"
                        useTransactions="true" writePercentage="50" numEntries="
1000" sharedKeys="true"/>
        <StressTest duration="5m" opsCountStatusLog="5000" numThreads="8"
transactionSize="10"
                        useTransactions="true" writePercentage="50" numEntries="1000"
sharedKeys="true"/>
        <CsvReportGeneration targetDir="contention"/>
    </benchmark>
...

```

The difference between the contention and no contention is the pool of key. In the first case the pool of keys are shared among all the threads (and nodes) and in the last case each threads has it own private pool of keys.

The first group of plots shows the performance in the *contented* scenario:

Contention Scenario

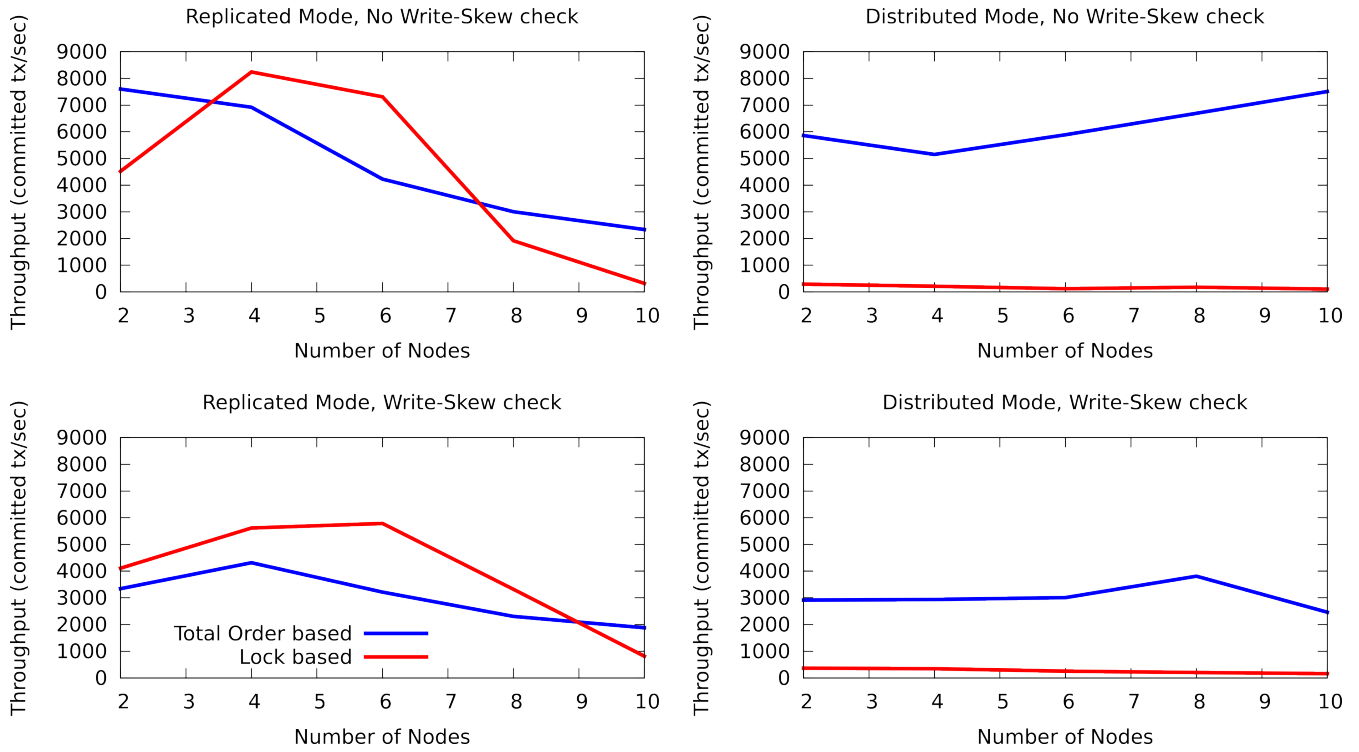


Figure 15. Tx contention scenario

and the next group of plots the *no contended* scenario:

No Contention Scenario

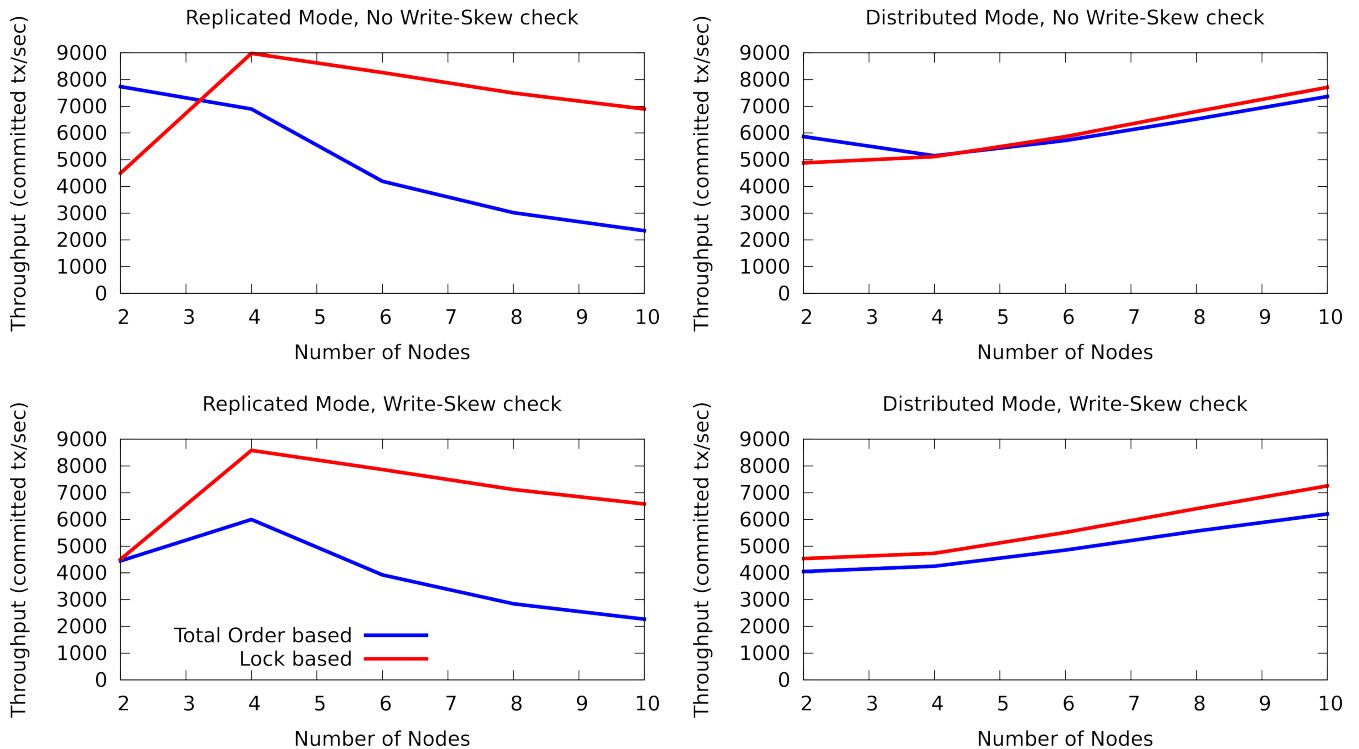


Figure 16. Tx no-contention scenario

8.8.5. Want to know more?

The [recovery design document](#) describes in more detail the insides of transaction recovery implementation.

Chapter 9. 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

9.1. 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.

9.1.1. How it works in clustered caches?

In clustered caches, each key has a node responsible to lock the key. This node is called primary owner.

Non Transactional caches

1. The write operation is sent to the primary owner of the key.
2. The primary owner tries to lock the key.
 - a. If it succeeds, it forwards the operation to the other owners;
 - b. Otherwise, an exception is thrown.



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



If the operation is executed locally in the primary owner, the first step is skipped.

Pessimistic transactional cache

In pessimist transactional caches, the locks are acquired during write/lock operations.

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.



For conditional operations and write skew check (if enabled), the validation is performed in the originator.

Optimistic transactional cache

In optimistic transactional caches, the locks are acquired during transaction 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.



For conditional commands, the validation still happens on the originator. In addition to that, the write skew check is done in the primary owner.

9.1.2. Isolation levels

Infinispan offers two isolation levels - [READ_COMMITTED](#) (the default) and [REPEATABLE_READ](#), configurable via the `<locking />` configuration element.

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 will return the new updated value:

1. Thread1: tx.begin()
2. Thread1: cache.get(k) returns v
3. Thread2: tx.begin()
4. Thread2: cache.get(k) returns v
5. Thread2: cache.put(k, v2)

6. Thread2: tx.commit()
7. Thread1: cache.get(k) returns v2!

With REPEATABLE_READ, step 7 will still return v. So, if you're going to retrieve the same key multiple times within a transaction, you should use REPEATABLE_READ.

9.1.3. 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.

9.1.4. 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

From Infinispan 5.0, 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. Previously, in Infinispan 4.x lock striping used to be enabled by default.

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

9.1.5. 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.

9.1.6. 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.

9.2. Data Versioning

Infinispan will offer three forms of data versioning, including simple, partition aware and external. Each case is described in detail below.

9.2.1. Simple versioning

The purpose of simple versioning is to provide a reliable mechanism of write skew checks when using optimistic transactions, `REPEATABLE_READ` and a clustered cache. Write skew checks are performed at prepare-time to ensure a concurrent transaction hasn't modified an entry while it was read and potentially updated based on the value read.

When operating in `LOCAL` mode, write skew checks rely on Java object references to compare differences and this is adequate to provide a reliable write-skew check, however this technique is useless in a cluster and a more reliable form of versioning is necessary to provide reliable write skew checks.

Simple versioning is an implementation of the proposed `EntryVersion` interface, backed by a long that is incremented each time the entry is updated.

9.2.2. Partition-aware versioning

This versioning scheme makes use of [vector clocks](#) to provide a network partition resilient form of versioning.

Unlike simple versioning, which is maintained per entry, a vector clock's node counter is maintained per-node.

9.2.3. External versioning

This scheme 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.

9.2.4. Tombstones

To deal with deletions of entries, tombstones will be maintained as null entries that have been deleted, so that version information of the deleted entry can be maintained and write skews can still be detected. However this is an expensive thing to do, and as such, is a configuration option, disabled by default. Further, tombstones will follow a strict lifespan and will be cleared from the system after a specific amount of time.

9.2.5. Configuration

By default versioning will be *disabled*. This will mean write skew checks when using transactions and *REPEATABLE_READ* as an isolation level will be unreliable when used in a cluster. Note that this doesn't affect single-node, LOCAL mode usage.

```
<versioning scheme="SIMPLE|NONE" />
```

Or

```
new ConfigurationBuilder().versioning().scheme(SIMPLE);
```

Chapter 10. Streams

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.

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.

10.1. Common stream operations

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

10.1.1. 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.

10.1.2. 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.

10.2. 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`, compatibility mode, and a cache loader).

10.2.1. 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));
```

10.3. Distribution/Replication

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.

10.3.1. 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.

10.3.2. Serialization

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

The simplest way is to cast your lambdas as `Serializable` as below.

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, you can use the newly provided `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. You can read more details about how the collector performs in a distributed fashion at [distributed execution](#).

```
Map<Object, String> jbossValues = cache.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 way is to use an `AdvancedExternalizer` as this provides the smallest payload.

10.3.3. 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.

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`. Note that currently intermediate operations return a `Stream` instance so you must make sure to invoke these methods before calling another intermediate operation.

10.3.4. 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<Object, String> stream = cache.entrySet().stream();
stream.timeout(1, TimeUnit.MINUTES);
```

For more information about this, please check the java doc in [timeout](#) javadoc.

10.3.5. 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.

10.3.6. 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`.

10.3.7. Key based rehash aware operators

The `iterator`, `spliterator` 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` & `spliterator`) or at least once behavior (`forEach`) even under cluster membership changes.

The `iterator` and `spliterator` 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 a replication cache

Currently if you are using a replicated cache the `iterator` or `splititerator` terminal operations will not perform any of the operations remotely and will instead perform everything on the local node. This is for performance as doing a remote iteration process is very costly.

10.3.8. 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.

Peek

An artificial iterator is implanted up to the intermediate peek operation. Only up to the number of peeked elements is returned a remote node. Then results are brought locally so it can peek at only the amount desired.

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.

10.4. Examples

Word count is a classic, if overused, example of map/reduce paradigm. Assume we have a mapping of key → 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, Integer> wordCountMap = c1.entrySet().parallelStream()
            .map((Serializable & Function<Map.Entry<String, String>, String[]>) e -> e
                .getValue().split("\\s"))
            .flatMap((Serializable & Function<String[], Stream<String>>) Arrays::stream)
            .collect(CacheCollectors.serializableCollector(() -> 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((Serializable & Function<Map.Entry<String, String>, String[]>) e -> e
                .getValue().split("\\s"))
            .flatMap((Serializable & Function<String[], Stream<String>>) Arrays::stream)
            .collect(CacheCollectors.serializableCollector(() -> 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((Serializable & Function<Map.Entry<String, String>, String[]>) e ->
                e.getValue().split("\\s"))
            .flatMap((Serializable & Function<String[], Stream<String>>) Arrays::stream)
            .collect(CacheCollectors.serializableCollector(() -> 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.

Also remember that **Streams** are a JRE tool now and there are a multitude of examples that can be found all over. Just remember that your operations need to be Serializable in some fashion!

Chapter 11. Distributed Execution

Infinispan provides distributed execution through a standard JDK [ExecutorService](#) interface. Tasks submitted for execution, instead of being executed in a local JVM, are executed on an entire cluster of Infinispan nodes. Every `DistributedExecutorService` is bound to one particular cache. Tasks submitted will have access to key/value pairs from that particular cache if and only if the task submitted is an instance of `DistributedCallable`. Also note that there is nothing preventing users from submitting a familiar `Runnable` or `Callable` just like to any other `ExecutorService`. However, `DistributedExecutorService`, as its name implies, will likely migrate submitted `Callable` or `Runnable` to another JVM in Infinispan cluster, execute it and return a result to task invoker. Due to a potential task migration to other nodes every `Callable`, `Runnable` and/or `DistributedCallable` submitted must be either `Serializable` or `Externalizable`. Also the value returned from a callable must be `Serializable` or `Externalizable` as well. If the value returned is not serializable a `NotSerializableException` will be thrown.

Infinispan's distributed task executors use data from Infinispan cache nodes as input for execution tasks. Most other distributed frameworks do not have that leverage and users have to specify input for distributed tasks from some well known location. Furthermore, users of Infinispan distributed execution framework do not have to configure store for intermediate and final results thus removing another layer of complexity and maintenance.

Our distributed execution framework capitalizes on the fact input data in Infinispan data grid is already load balanced (in case of DIST mode). Since input data is already balanced execution tasks will be automatically balanced as well; users do not have to explicitly assign work tasks to specific Infinispan nodes. However, our framework accommodates users to specify arbitrary subset of cache keys as input for distributed execution tasks.

11.1. DistributedCallable API

In case users need access to Infinispan cache data for an execution of a task we recommend that you encapsulate task in [DistributedCallable](#) interface. `DistributedCallable` is a subtype of the existing `Callable` from `java.util.concurrent` package; `DistributedCallable` can be executed in a remote JVM and receive input from Infinispan cache. Task's main algorithm could essentially remain unchanged, only the input source is changed. Existing `Callable` implementations most likely get its input in a form of some Java object/primitive while `DistributedCallable` gets its input from Infinispan cache. Therefore, users who have already implemented `Callable` interface to describe their task units would simply extend `DistributedCallable` and use keys from Infinispan execution environment as input for the task. Implementation of `DistributedCallable` can in fact continue to support implementation of an already existing `Callable` while simultaneously be ready for distributed execution by extending `DistributedCallable`.

```

public interface DistributedCallable<K, V, T> extends Callable<T> {

    /**
     * Invoked by execution environment after DistributedCallable
     * has been migrated for execution to a specific Infinispan node.
     *
     * @param cache
     *         cache whose keys are used as input data for this
     *         DistributedCallable task
     * @param inputKeys
     *         keys used as input for this DistributedCallable task
     */
    public void setEnvironment(Cache<K, V> cache, Set<K> inputKeys);

}

```

11.2. Callable and CDI

Users that do not want or can not implement `DistributedCallable` yet need a reference to input cache used in `DistributedExecutorService` have an option of the input cache being injected by CDI mechanism. Upon arrival of user's `Callable` to an Infinispan executing node, Infinispan CDI mechanism will provide appropriate cache reference and inject it to executing `Callable`. All one has to do is to declare a `Cache` field in `Callable` and annotate it with `org.infinispan.cdi.Input` annotation along with mandatory `@Inject` annotation.

```

public class CallableWithInjectedCache implements Callable<Integer>, Serializable {

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

    @Override
    public Integer call() throws Exception {
        //use injected cache reference
        return 1;
    }

}

```

11.3. DistributedExecutorService, DistributedTaskBuilder and DistributedTask API

`DistributedExecutorService` is a simple extension of a familiar `ExecutorService` from `java.util.concurrent` package. However, advantages of `DistributedExecutorService` are not to be overlooked. Existing `Callable` tasks, instead of being executed in JDK's `ExecutorService`, are also eligible for execution on Infinispan cluster. Infinispan execution environment would migrate a task

to execution node(s), run the task and return the result(s) to the calling node. Of course, not all Callable tasks would benefit from parallel distributed execution. Excellent candidates are long running and computationally intensive tasks that can run concurrently and/or tasks using input data that can be processed concurrently. For more details about good candidates for parallel execution and parallel algorithms in general refer to [Introduction to Parallel Computing](#) .

The second advantage of the DistributedExecutorService is that it allows a quick and simple implementation of tasks that take input from Infinispan cache nodes, execute certain computation and return results to the caller. Users would specify which keys to use as input for specified DistributedCallable and submit that callable for execution on Infinispan cluster. Infinispan runtime would locate the appropriate keys, migrate DistributedCallable to target execution node(s) and finally return a list of results for each executed Callable. Of course, users can omit specifying input keys in which case Infinispan would execute DistributedCallable on all keys for a specified cache.

Lets see how we can use DistributedExecutorService If you already have Callable/Runnable tasks defined! Well, simply submit them to an instance of DefaultExecutorService for execution!

```
ExecutorService des = new DefaultExecutorService(cache);
Future<Boolean> future = des.submit(new SomeCallable());
Boolean r = future.get();
```

In case you need to specify more task parameters like task timeout, custom failover policy or execution policy use [DistributedTaskBuilder](#) and [DistributedTask](#) API.

```
DistributedExecutorService des = new DefaultExecutorService(cache);
DistributedTaskBuilder<Boolean> taskBuilder = des.createDistributedTaskBuilder(new
SomeCallable());
taskBuilder.timeout(10, TimeUnit.SECONDS);
...
...
DistributedTask<Boolean> distributedTask = taskBuilder.build();
Future<Boolean> future = des.submit(distributedTask);
Boolean r = future.get();
```

11.4. Distributed task failover

Distributed execution framework supports task failover. By default no failover policy is installed and task's Runnable/Callable/DistributedCallable will simply fail. Failover mechanism is invoked in the following cases:

- a) Failover due to a node failure where task is executing
- b) Failover due to a task failure (e.g. Callable task throws Exception).

Infinispan provides random node failover policy which will attempt execution of a part of distributed task on another random node, if such node is available. However, users that have a need to implement a more sophisticated failover policy can implement

[DistributedTaskFailoverPolicy](#) interface. For example, users might want to use consistent hashing (CH) mechanism for failover of uncompleted tasks. CH based failover might for example migrate failed task T to cluster node(s) having a backup of input data that was executed on a failed node F.

```
/**
 * DistributedTaskFailoverPolicy allows pluggable fail over target selection for a
 * failed remotely
 * executed distributed task.
 *
 */
public interface DistributedTaskFailoverPolicy {

    /**
     * As parts of distributively executed task can fail due to the task itself
     * throwing an exception
     * or it can be an Infinispan system caused failure (e.g node failed or left
     * cluster during task
     * execution etc).
     *
     * @param failoverContext
     *         the FailoverContext of the failed execution
     * @return result the Address of the Infinispan node selected for fail over
     * execution
     */
    Address failover(FailoverContext context);

    /**
     * Maximum number of fail over attempts permitted by this
     * DistributedTaskFailoverPolicy
     *
     * @return max number of fail over attempts
     */
    int maxFailoverAttempts();
}
```

Therefore one could for example specify random failover execution policy simply by:

```
DistributedExecutorService des = new DefaultExecutorService(cache);
DistributedTaskBuilder<Boolean> taskBuilder = des.createDistributedTaskBuilder(new
SomeCallable());
taskBuilder.failoverPolicy(DefaultExecutorService.RANDOM_NODE_FAILOVER);
DistributedTask<Boolean> distributedTask = taskBuilder.build();
Future<Boolean> future = des.submit(distributedTask);
Boolean r = future.get();
```

11.5. Distributed task execution policy

`DistributedTaskExecutionPolicy` is an enum that allows tasks to specify its custom task execution policy across Infinispan cluster. `DistributedTaskExecutionPolicy` effectively scopes execution of tasks to a subset of nodes. For example, someone might want to exclusively execute tasks on a local network site instead of a backup remote network centre as well. Others might, for example, use only a dedicated subset of a certain Infinispan rack nodes for specific task execution. `DistributedTaskExecutionPolicy` is set per instance of `DistributedTask`.

```
DistributedExecutorService des = new DefaultExecutorService(cache);
DistributedTaskBuilder<Boolean> taskBuilder = des.createDistributedTaskBuilder(new
SomeCallable());
taskBuilder.executionPolicy(DistributedTaskExecutionPolicy.SAME_RACK);
DistributedTask<Boolean> distributedTask = taskBuilder.build();
Future<Boolean> future = des.submit(distributedTask);
Boolean r = future.get();
```

11.6. Examples

Pi approximation can greatly benefit from parallel distributed execution in `DistributedExecutorService`. 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 π . The more darts we shoot the better approximation we get. In the example below we shoot 10 million darts but instead of "shooting" them serially we parallelize work of dart shooting across entire Infinispan cluster.

```
public class PiAppx {

    public static void main (String [] arg){
        List<Cache> caches = ...;
        Cache cache = ...;

        int numPoints = 10000000;
        int numServers = caches.size();
        int numberPerWorker = numPoints / numServers;

        DistributedExecutorService des = new DefaultExecutorService(cache);
        long start = System.currentTimeMillis();
        CircleTest ct = new CircleTest(numberPerWorker);
        List<Future<Integer>> results = des.submitEverywhere(ct);
        int countCircle = 0;
        for (Future<Integer> f : results) {
            countCircle += f.get();
        }
        double appxPi = 4.0 * countCircle / numPoints;
```

```

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

    private static class CircleTest implements Callable<Integer>, Serializable {

        /** The serialVersionUID */
        private static final long serialVersionUID = 3496135215525904755L;

        private final int loopCount;

        public CircleTest(int loopCount) {
            this.loopCount = loopCount;
        }

        @Override
        public Integer call() throws Exception {
            int insideCircleCount = 0;
            for (int i = 0; i < loopCount; i++) {
                double x = Math.random();
                double y = Math.random();
                if (insideCircle(x, y))
                    insideCircleCount++;
            }
            return insideCircleCount;
        }

        private 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. Querying

Infinispan supports indexing and searching of Java objects stored in the grid using powerful search APIs which complement its main Map-like API. Historically, searching was first available in Infinispan via [Apache Lucene](#)'s API but since version 6.0 Infinispan provides its own [query API](#) based on a simple and expressive internal DSL. Searching with the new API is available for both embedded and remote clients while the Lucene based API is only available to embedded clients. The remote querying capability is further described in the [Hot Rod client chapter](#).

12.1. The infinispan-query module

This module adds indexing and querying capabilities to Infinispan. It uses [Hibernate Search](#) and [Apache Lucene](#) to index and search objects in the cache. It allows users to obtain objects within the cache without needing to know the keys to each object that they want to obtain. You can search your objects based on some of its properties. For example to retrieve all red cars (exact metadata match), or all books about a specific topic (full text search and relevance scoring).

The queries can be expressed as Lucene queries, built directly using the Lucene Query API or built with the help of Hibernate Search Query DSL. Alternatively, you can also use Infinispan's own query DSL which most users might find easier to use than the one based on Lucene at the cost of not being able to access some of the powerful capabilities which are specific to the underlying Lucene implementation.

12.1.1. Configuration

Indexing must be enabled in the configuration (as explained in [XML Configuration](#) or [Programmatic configuration](#)). This will trigger automatic indexing of objects stored in the cache; there are several different ways to specify how these objects need to be indexed explained in the following paragraphs. To run queries you use the *SearchManager* which exposes all necessary methods to get started.

12.2. Simple example

We're going to store *Book* instances in Infinispan; 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.

```
// example values stored in the cache and indexed:
import org.hibernate.search.annotations.*;

//Values you want to index need to be annotated with @Indexed, then you pick which
fields and how they are to be indexed:
@Indexed
public class Book {
    @Field String title;
    @Field String description;
    @Field @DateBridge(resolution=Resolution.YEAR) Date publicationYear;
    @IndexedEmbedded Set<Author> authors = new HashSet<Author>();
}

public class Author {
    @Field String name;
    @Field String surname;
    // hashCode() and equals() omitted
}
```

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 search manager from the cache:
SearchManager searchManager = org.infinispan.query.Search.getSearchManager(cache);

// create any standard Lucene query, via Lucene's QueryParser or any other means:
org.apache.lucene.search.Query fullTextQuery = //any Apache Lucene Query

// convert the Lucene query to a CacheQuery:
CacheQuery cacheQuery = searchManager.getQuery( fullTextQuery );

// get the results:
List<Object> found = cacheQuery.list();
```

A Lucene Query is often created by parsing a query in text format such as "title:infinispan AND authors.name:sanne", or by using the query builder provided by Hibernate Search.

```
// get the search manager from the cache:
SearchManager searchManager = org.infinispan.query.Search.getSearchManager( cache );

// you could make the queries via Lucene APIs, or use some helpers:
QueryBuilder queryBuilder = searchManager.buildQueryBuilderForClass(Book.class).get();

// the queryBuilder has a nice fluent API which guides you through all options.
// this has some knowledge about your object, for example which Analyzers
// need to be applied, but the output is a fairly standard Lucene Query.
org.apache.lucene.search.Query luceneQuery = queryBuilder.phrase()
    .onField("description")
    .andField("title")
    .sentence("a book on highly scalable query engines")
    .createQuery();

// the query API itself accepts any Lucene Query, and on top of that
// you can restrict the result to selected class types:
CacheQuery query = searchManager.getQuery(luceneQuery, Book.class);

// and there are your results!
List objectList = query.list();

for (Object book : objectList) {
    System.out.println(book);
}
```

A part from *list()* you have the option for streaming results, or use pagination.

This barely scratches the surface of all what is possible to do: see the [Hibernate Search reference documentation](#) to learn about sorting, numeric fields, declarative filters, caching filters, complex object graph indexing, custom types and the powerful faceting search API.

12.2.1. Notable differences with Hibernate Search

Using *@DocumentId* to mark a field as identifier does not apply to Infinispan values; in Infinispan Query 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.

12.2.2. Requirements for the Key: *@Transformable*

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 Transformer via annotations

You can annotate your key type with *org.infinispan.query.Transformable* :

```

@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 Transformer programmatically

Using this technique, you don't have to annotated your custom key type:

```

org.infinispan.query.SearchManager.registerKeyTransformer(Class<?>, Class<? extends
Transformer>)

```

12.3. Configuration

12.3.1. Configuration via XML

To enable indexing via XML, you need to add the `<indexing />` element to your cache configuration, and optionally pass additional properties to the embedded Hibernate Search engine:

```

<infinispan>
  <cache-container default-cache="default">
    <local-cache name="default">
      <indexing index="LOCAL">
        <property name="default.directory_provider">ram</property>
      </indexing>
    </local-cache>
  </cache-container>
</infinispan>

```

In this example the index is stored in memory, so when this nodes is shutdown the index is lost: good for a quick demo, but in real world cases you'll want to use the default (store on filesystem) or store the index in Infinispan as well. For the complete reference of properties to define, refer to the

12.3.2. Automatic configuration

```
<local-cache name="default">
  <indexing index="LOCAL" auto-config="true">
    </indexing>
  </local-cache>
```

The attribute `auto-config` provides a simple way of configuring indexing based on the cache type. For replicated and local caches, the indexing is configured to be persisted on disk and not shared with any other processes. Also, it is configured so that minimum delay exists between the moment an object is indexed and the moment it is available for searches (near real time).



it is possible to redefine any property added via `auto-config`, and also add new properties, allowing for advanced tuning.

The auto config adds the following properties for replicated and local caches:

Property name	value	description
<code>hibernate.search.default.directory_provider</code>	<code>filesystem</code>	Filesystem based index. More details at Hibernate Search documentation
<code>hibernate.search.default.exclusive_index_use</code>	<code>true</code>	indexing operation in exclusive mode, allowing Hibernate Search to optimize writes

Property name	value	description
hibernate.search.default.indexmanager	near-real-time	make use of Lucene near real time feature, meaning indexed objects are promptly available to searches
hibernate.search.default.reader.strategy	shared	Reuse index reader across several queries, thus avoiding reopening it

For distributed caches, the auto-config configure indexes in infinispan itself, internally handled as a master-slave mechanism where indexing operations are sent to a single node which is responsible to write to the index.

The auto config properties for distributed caches are:

Property name	value	description
hibernate.search.default.directory_provider	infinispan	Indexes stored in Infinispan. More details at Hibernate Search documentation
hibernate.search.default.exclusive_index_use	true	indexing operation in exclusive mode, allowing Hibernate Search to optimize writes

Property name	value	description
hibernate.search.default.indexmanager	org.infinispan.query.indexmanager.InfinispanIndexManager	Delegates index writing to a single node in the Infinispan cluster
hibernate.search.default.reader.strategy	shared	Reuse index reader across several queries, avoiding reopening it

12.3.3. Lucene Directory

Infinispan Query isn't aware of where you store the indexes, it just passes the configuration of which *Lucene Directory* implementation you want to use to the Hibernate Search engine. There are several *Lucene Directory* implementations bundled, and you can plug your own or add third party implementations: the Directory is the IO API for Lucene to store the indexes.

The most common *Lucene Directory* implementations used with *Infinispan Query* are:

- Ram - stores the index in a local map to the node. This index can't be shared.
- Filesystem - stores the index in a locally mounted filesystem. This could be a network shared FS, but sharing this way is generally not recommended.
- Infinispan - stores the index in a different dedicated Infinispan cache. This cache can be configured as replicated or distributed, to share the index among nodes. See also the dedicated chapter on the Lucene Directory in this guide.

Of course having a shared index vs. an independent index on each node directly affects behaviour of the Query module; some combinations might not make much sense.

12.3.4. Using programmatic configuration and index mapping

In the following example we start Infinispan programmatically, avoiding XML configuration files, and also map an object *Author* which is to be stored in the grid and made searchable on two properties but without annotating the class.

```

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

Configuration infinispansConfiguration = new ConfigurationBuilder()
    .indexing()
        .enable()
        .indexLocalOnly(true)
        .withProperties(properties)
    .build();

DefaultCacheManager cacheManager = new DefaultCacheManager(infinispansConfiguration);

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.assertEquals(cq.getResultSize(), 1);

```

12.4. Cache modes and managing indexes

Index management is currently controlled by the *Configuration.setIndexLocalOnly()* setter, or the `<indexing index="LOCAL" />` XML element. If you set this to true, only modifications made locally on each node are considered in indexing. Otherwise, remote changes are considered too.

Regarding actually configuring a Lucene directory, refer to the [Hibernate Search documentation](#) on how to pass in the appropriate Lucene configuration via the Properties object passed to QueryHelper.

12.4.1. LOCAL

In local mode, you may use any Lucene Directory implementation. Also the option *indexLocalOnly* isn't meaningful.

12.4.2. REPLICATION

In replication mode, each node can have its own local copy of the index. So indexes can either be stored locally on each node (RAMDirectory, FSDirectory, etc) but you need to set *indexLocalOnly* to

false , so that each node will apply needed updates it receives from other nodes in addition to the updates started locally. Any Directory implementation can be used, but you have to make sure that when a new node is started it receives an up to date copy of the index; typically rsync is well suited for this task, but being an external operation you might end up with a slightly out-of-sync index, especially if updates are very frequent.

Alternately, if you use some form of shared storage for indexes (see *Sharing the Index*), you then have to set *indexLocalOnly* to *true* so that each node will apply only the changes originated locally; in this case there's no risk in having an out-of-sync index, but to avoid write contention on the index you should make sure that a single node is "in charge" of updating the index. Again, the Hibernate Search reference documentation describes means to use a [JMS queue](#) or [JGroups](#) to send indexing tasks to a master node.

The diagram below shows a replicated deployment, in which each node has a local index.

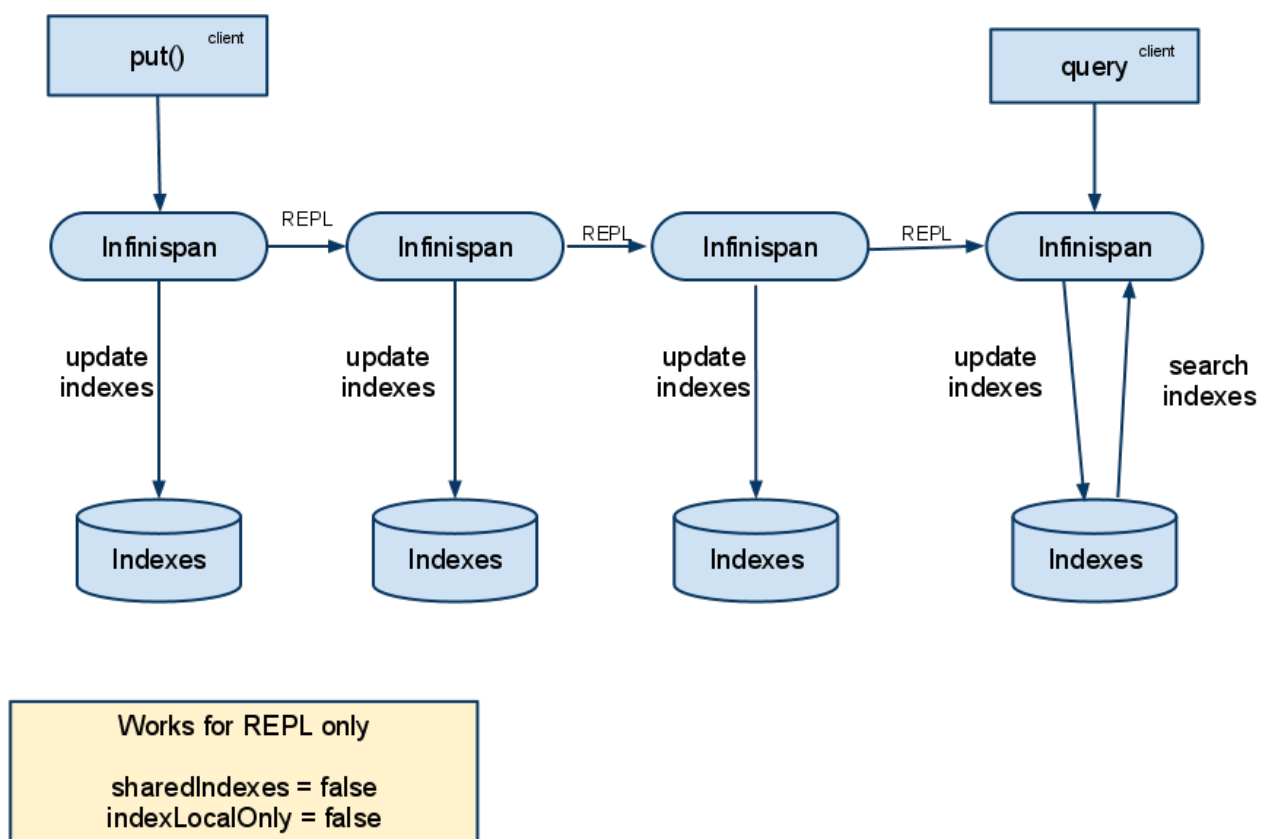


Figure 17. Indexes in replicated mode

12.4.3. DISTRIBUTION

For these 2 cache modes, you *need* to use a shared index and set *indexLocalOnly* to *true*.

The diagram below shows a deployment with a shared index. Note that while not mandatory, a shared index can be used for replicated (vs. distributed) caches as well.

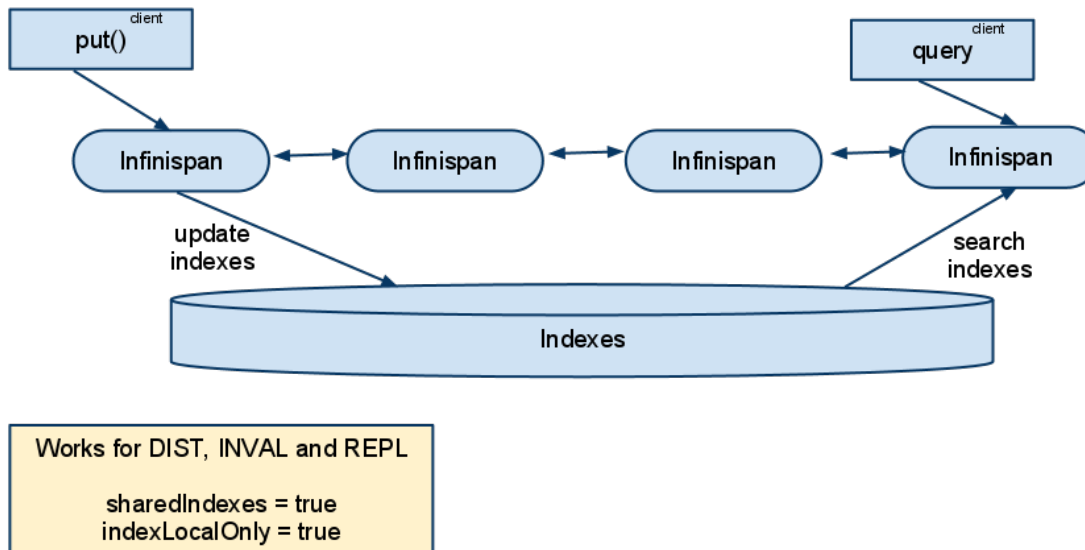


Figure 18. Shared indexes

12.4.4. INVALIDATION

Indexing or searching of elements under INVALIDATION mode is not supported.

12.5. Sharing the Index

The most simple way to share an index is to use some form of shared storage for the indexes, like an *FSDirectory* on a shared disk; however this form is problematic as the *FSDirectory* relies on specific locking semantics which are often incompletely implemented on network filesystems, or not reliable enough; if you go for this approach make sure to search for potential problems on the Lucene mailing lists for other experiences and workarounds. Good luck, test well.

There are many alternative Directory implementations you can find, one of the most suited approaches when working with Infinispan is of course to store the index in an Infinispan cache: have a look at the [InfinispanDirectoryProvider](#), as all Infinispan based layers it can be combined with persistent CacheLoaders to keep the index on a shared filesystem without the locking issues, or alternatively in a database, cloud storage, or any other CacheLoader implementation; you could backup the index in the same store used to backup your values.

For full documentation on clustering the Lucene engine, refer to the [Hibernate Search documentation](#) to properly configure it clustered.

12.6. Clustering the Index in Infinispan

Again the configuration details are in the Hibernate Search reference, in particular in the [infinispan-directories](#) section. This backend will by default start a secondary Infinispan CacheManager, and optionally take another Infinispan configuration file: don't reuse the same configuration or you will start grids recursively! It is currently not possible to share the same CacheManager.

12.7. Rebuilding the Index

Occasionally you might need to rebuild the Lucene index by reconstructing it from the data stored in the Cache. You need to rebuild the index if you change the definition of what is indexed on your types, or if you change for example some *Analyzer* parameter, as Analyzers affect how the index is defined. Also, you might need to rebuild the index if you had it destroyed by some system administration mistake. To rebuild the index just get a reference to the `MassIndexer` and start it; beware if might take some time as it needs to reprocess all data in the grid!

```
SearchManager searchManager = Search.getSearchManager(cache);
searchManager.getMassIndexer().start();
```



This is also available as a `start` JMX operation on the `MassIndexer` MBean registered under the name `org.infinispan:type=Query,manager="{name-of-cache-manager}",cache="{name-of-cache}",component=MassIndexer`.

12.8. Obtaining query statistics

Query *Statistics* can be obtained from the *SearchManager*, as demonstrated in the following code snippet.

```
SearchManager searchManager = Search.getSearchManager(cache);
org.hibernate.search.stat.Statistics statistics = searchManager.getStatistics();
```



This data is also available via JMX through the `Hibernate Search StatisticsInfoMBean` registered under the name `org.infinispan:type=Query,manager="{name-of-cache-manager}",cache="{name-of-cache}",component=Statistics`. Please note this MBean is always registered by Infinispan but the statistics are collected only if `statistics collection is enabled` at cache level.



Hibernate Search has its own configuration properties `hibernate.search.jmx_enabled` and `hibernate.search.generate_statistics` for JMX statistics as explained [here](#). Using them with Infinispan Query is forbidden as it will only lead to duplicated MBeans and unpredictable results.

12.9. Infinispan's Query DSL



This is a new API undergoing refinements and changes that might break compatibility in future releases.

Starting with 6.0 Infinispan provides its own query DSL, independent of Lucene and Hibernate Search. Decoupling the query API from the underlying query and indexing mechanism makes it possible to introduce new alternative engines in the future, besides Lucene, and still being able to

use the same uniform query API. The current implementation of indexing and searching is still based on Hibernate Search and Lucene so all indexing related aspects presented in this chapter still apply.

The new API simplifies the writing of queries by not exposing the user to the low level details of constructing Lucene query objects and also has the advantage of being available to [remote Hot Rod clients](#). But before delving into further details, let's examine first a simple example of writing a query for the *Book* entity from [previous example](#).

Query example using Infinispan's query DSL

```
import org.infinispan.query.dsl.*;

// get the DSL query factory from the cache, to be used for constructing the Query
// object:
QueryFactory qf = org.infinispan.query.Search.getQueryFactory(cache);

// create a query for all the books that have a title which contains the word
// "engine":
org.infinispan.query.dsl.Query query = qf.from(Book.class)
    .having("title").like("%engine%")
    .toBuilder().build();

// get the results:
List<Book> list = query.list();
```

The API is located in the *org.infinispan.query.dsl* package. A query is created with the help of the *QueryFactory* instance which is obtained from the per-cache *SearchManager*. Each *QueryFactory* instance is bound to the same *Cache* instance as the *SearchManager*, but it is otherwise a stateless and thread-safe object that can be used for creating multiple queries in parallel.

Query creation starts with the invocation of the *from(Class entityType)* method which returns a *QueryBuilder* object that is further responsible for creating queries targeted to the specified entity class from the given cache.



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.

The *QueryBuilder* accumulates search criteria and configuration specified through the invocation of its DSL methods and is ultimately used to build a *Query* object by the invocation of the *QueryBuilder.build()* method that completes the construction. Being a stateful object, it cannot be used for constructing multiple queries at the same time (except for [nested queries](#)) but can be reused afterwards.



This *QueryBuilder* is different from the one from Hibernate Search but has a somewhat similar purpose, hence the same name. We are considering renaming it in near future to prevent ambiguity.

Executing the query and fetching the results is as simple as invoking the `list()` method of the *Query* object. Once executed the *Query* object is not reusable. If you need to re-execute it in order to obtain fresh results then a new instance must be obtained by calling `QueryBuilder.build()`.

12.10. Filtering operators

Constructing a query is a hierarchical process of composing multiple criteria and is best explained following this hierarchy.

The simplest possible form of a query criteria is a restriction on the values of an entity attribute according to a filtering operator that accepts zero or more arguments. The entity attribute is specified by invoking the `having(String attributePath)` method of the query builder which returns an intermediate context object (*FilterConditionEndContext*) that exposes all the available operators. Each of the methods defined by *FilterConditionEndContext* is an operator that accepts an argument, except for `between` which has two arguments and `isNull` which has no arguments. The arguments are statically evaluated at the time the query is constructed, so if you're looking for a feature similar to SQL's correlated sub-queries, that is not currently available.

```
// a single query criterion
QueryBuilder qb = ...
qb.having("title").eq("Infinispan Data Grid Platform");
```

Table 5. *FilterConditionEndContext* exposes the following filtering operators:

Filter	Arguments	Description
<code>in</code>	Collection values	Checks that the left operand is equal to one of the elements from the Collection of values given as argument.
<code>in</code>	Object... values	Checks that the left operand is equal to one of the (fixed) list of values given as argument.
<code>contains</code>	Object value	Checks that the left argument (which is expected to be an array or a Collection) contains the given element.
<code>containsAll</code>	Collection values	Checks that the left argument (which is expected to be an array or a Collection) contains all the elements of the given collection, in any order.
<code>containsAll</code>	Object... values	Checks that the left argument (which is expected to be an array or a Collection) contains all of the the given elements, in any order.
<code>containsAny</code>	Collection values	Checks that the left argument (which is expected to be an array or a Collection) contains any of the elements of the given collection.
<code>containsAny</code>	Object... values	Checks that the left argument (which is expected to be an array or a Collection) contains any of the the given elements.
<code>isNull</code>		Checks that the left argument is null.

Filter	Arguments	Description
like	String pattern	Checks that the left argument (which is expected to be a String) matches a wildcard pattern that follows the JPA rules.
eq	Object value	Checks that the left argument is equal to the given value.
equal	Object value	Alias for eq.
gt	Object value	Checks that the left argument is greater than the given value.
gte	Object value	Checks that the left argument is greater than or equal to the given value.
lt	Object value	Checks that the left argument is less than the given value.
lte	Object value	Checks that the left argument is less than or equal to the given value.
between	Object from, Object to	Checks that the left argument is between the given range limits.

It's important to note that query construction requires a multi-step chaining of method invocation that must be done in the proper sequence, must be properly completed exactly *once* and must not be done twice, or it will result in an error. The following examples are invalid, and depending on each case they lead to criteria being ignored (in benign cases) or an exception being thrown (in more serious ones).

```
// Incomplete construction. This query does not have any filter on "title" attribute yet,
// although the author may have intended to add one.
QueryBuilder qb1 = ...
qb1.having("title");
Query q1 = qb1.build(); // consequently, this query matches all Book instances regardless of title!

// Duplicated completion. This results in an exception at run-time.
// Maybe the author intended to connect two conditions with a boolean operator,
// but this does NOT actually happen here.
QueryBuilder qb2 = ...
qb2.having("title").like("%Infinispan%");
qb2.having("description").like("%clustering%"); // will throw
java.lang.IllegalStateException: Sentence already started. Cannot use 'having(..)' again.
Query q2 = qb2.build();
```

12.10.1. Filtering based on attributes of embedded entities

The `having` method also accepts dot separated attribute paths for referring to *embedded entity* attributes, so the following is a valid query:

```
// match all books that have an author named "Manik"
Query query = queryFactory.from(Book.class)
    .having("author.name").eq("Manik")
    .toBuilder().build();
```

Each part of the attribute path must refer to an existing indexed attribute in the corresponding entity or embedded entity class respectively. It's possible to have multiple levels of embedding.

12.11. 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 DSL method invocations during construction is irrelevant. Here **and** operator still has higher priority than **or** even though **or** was invoked first.

```
// match all books that have the word "Infinispan" in their title
// or have an author named "Manik" and their description contains the word
// "clustering"
Query query = queryFactory.from(Book.class)
    .having("title").like("%Infinispan%")
    .or().having("author.name").eq("Manik")
    .and().having("description").like("%clustering%")
    .toBuilder().build();
```

Boolean negation is achieved with the **not** operator, which has highest precedence among logical operators and applies only to the next simple attribute condition.

```
// match all books that do not have the word "Infinispan" in their title and are
// authored by "Manik"
Query query = queryFactory.from(Book.class)
    .not().having("title").like("%Infinispan%")
    .and().having("author.name").eq("Manik")
    .toBuilder().build();
```

12.12. Nested conditions

Changing the precedence of logical operators is achieved with nested filter conditions. Logical operators can be used to connect two simple attribute conditions as presented before, but can also connect a simple attribute condition with the subsequent complex condition created with the same query factory.

```
// match all books that have an author named "Manik" and their title contains
// the word "Infinispan" or their description contains the word "clustering"
Query query = queryFactory.from(Book.class)
    .having("author.name").eq("Manik");
    .and(queryFactory.having("title").like("%Infinispan%")
        .or().having("description").like("%clustering%"))
    .toBuilder().build();
```

12.13. Projections

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 `Query.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.

TODO document what needs to be configured for an attribute to be available for projection.

```
// match all books that have the word "Infinispan" in their title or description
// and return only their title and publication year
Query query = queryFactory.from(Book.class)
    .select("title", "publicationYear")
    .having("title").like("%Infinispan%")
    .or().having("description").like("%Infinispan%"))
    .toBuilder().build();
```

12.14. Sorting

Ordering the results based on one or more attributes or attribute paths is done with the `QueryBuilder.orderBy()` method which accepts an attribute path and a sorting direction. If multiple sorting criteria are specified, then the order of invocation of `orderBy` method will dictate their precedence. But you have to think of the multiple sorting criteria as acting together on the tuple of specified attributes rather than in a sequence of individual sorting operations on each attribute.

TODO document what needs to be configured for an attribute to be available for sorting.

```
// match all books that have the word "Infinispan" in their title or description
// and return them sorted by the publication year and title
Query query = queryFactory.from(Book.class)
    .orderBy("publicationYear", SortOrder.DESC)
    .orderBy("title", SortOrder.ASC)
    .having("title").like("%Infinispan%")
    .or().having("description").like("%Infinispan%"))
    .toBuilder().build();
```

12.15. Pagination

You can limit the number of returned results by setting the *maxResults* property of *QueryBuilder*. This can be used in conjunction with setting the *startOffset* in order to achieve pagination of the result set.

```
// match all books that have the word "clustering" in their title
// sorted by publication year and title
// and return 3'rd page of 10 results
Query query = queryFactory.from(Book.class)
    .orderBy("publicationYear", SortOrder.DESC)
    .orderBy("title", SortOrder.ASC)
    .setStartOffset(20)
    .maxResults(10)
    .having("title").like("%clustering%")
    .toBuilder().build();
```



Even if the results being fetched are limited to *maxResults* you can still find the total number of matching results by calling *Query.getResultSize()*.

TODO Does pagination make sense if no stable sort criteria is defined? Luckily when running on Lucene and no sort criteria is specified we still have the order of relevance, but this has to be defined for other search engines.

12.16. 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. The supported aggregations are: avg, sum, count, max, min. The set of grouping fields is specified with the *groupBy(field)* method, which can be invoked multiple times. 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.

```
Query query = queryFactory.from(Book.class)
    .select(Expression.property("author"), Expression.count("title"))
    .having("title").like("%engine%")
    .toBuilder()
    .groupBy("author")
    .build();
```



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.

12.16.1. Aggregations

The following aggregation functions may be applied to a field: avg, sum, count, max, min

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

Table 6. Table sum return type

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

12.16.2. 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 may 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 may 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.

12.17. Using 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.

```
import org.infinispan.query.Search;
import org.infinispan.query.dsl.*;
[...]

QueryFactory queryFactory = Search.getQueryFactory(cache);
// Defining a query to search for various authors and publication years
Query query = queryFactory.from(Book.class)
    .select("title")
    .having("author").eq(Expression.param("authorName"))
    .and()
    .having("publicationYear").eq(Expression.param("publicationYear"))
    .toBuilder().build();

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

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

Alternatively, multiple parameters may be set at once by supplying a map of actual parameter values:

```
import java.util.Map;
import java.util.HashMap;

[...]

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.

12.18. 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).

12.18.1. 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* event.
- 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 the full power of the Query DSL except: grouping, aggregation, and sorting operations.

12.18.2. Running Continuous Queries

To create a continuous query you'll start by creating a Query object first. This is described in [the Query DSL section](#). Then you'll need to obtain the `ContinuousQuery` (`org.infinispan.query.api.continuous.ContinuousQuery`) object of your cache and register the query and a continuous query listener (`org.infinispan.query.api.continuous.ContinuousQueryListener`) with it. A `ContinuousQuery` object associated to a cache can be obtained by calling the static method `org.infinispan.client.hotrod.Search.getContinuousQuery(RemoteCache<K, V> cache)` if running in remote mode or `org.infinispan.query.Search.getContinuousQuery(Cache<K, V> cache)` when running in embedded mode. Once the listener has been created it may be registered by using the `addContinuousQueryListener` method of `ContinuousQuery`:

```
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.from(Person.class)
    .having("age").lt(21)
    .toBuilder().build();

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) {
        // just ignore it
    }

    @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*.

12.18.3. Removing Continuous Queries

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

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

12.18.4. Notes on performance of Continuous Queries

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.

12.19. More Query DSL samples

Probably the best way to explore using the Query DSL API is to have a look at our tests suite. [QueryDslConditionsTest](#) is a fine example.

Chapter 13. Infinispan as a storage for Lucene indexes

Infinispan includes a highly scalable distributed [Apache Lucene Directory](#) implementation.

This directory closely mimics the same semantics of the traditional filesystem and RAM-based directories, being able to work as a drop-in replacement for existing applications using Lucene and providing reliable index sharing and other features of Infinispan like node auto-discovery, automatic failover and rebalancing, optionally transactions, and can be backed by traditional storage solutions as filesystem, databases or cloud store engines.

The implementation extends Lucene's *org.apache.lucene.store.Directory* so it can be used to *store* the index in a cluster-wide shared memory, making it easy to distribute the index. Compared to rsync-based replication this solution is suited for use cases in which your application makes frequent changes to the index and you need them to be quickly distributed to all nodes. Consistency levels, synchronicity and guarantees, total elasticity and auto-discovery are all configurable; also changes applied to the index can optionally participate in a JTA transaction, optionally supporting XA transactions with recovery.

Two different *LockFactory* implementations are provided to guarantee only one *IndexWriter* at a time will make changes to the index, again implementing the same semantics as when opening an index on a local filesystem. As with other Lucene Directories, you can override the *LockFactory* if you prefer to use an alternative implementation.

13.1. Additional Links

Javadoc:

<http://docs.jboss.org/infinispan/9.0/apidocs/org/infinispan/lucene/impl/DirectoryLuceneV4.html>

Issue tracker: <https://jira.jboss.org/browse/ISPN/component/12312732> Source code: <https://github.com/infinispan/infinispan>

13.2. Lucene compatibility

Since Infinispan version 7 this Directory implementation is compatible exclusively with Apache Lucene versions 4.8.1, 4.9.0, 4.10.0, 4.10.1, 4.10.2: previous versions are compatible with a range of older Lucene versions, but backwards compatibility could no longer be maintained. If you need compatibility for an older version, either use an older version of Infinispan or you can get in touch with the developers if you are willing to help to create the backwards compatible versions.

13.3. How to use it

To create a Directory instance:

```
import org.apache.lucene.store.Directory;
import org.infinispan.lucene.directory.DirectoryBuilder;
import org.infinispan.Cache;

Cache cache = // create an Infinispan cache, configured as you like
Directory indexDir = DirectoryBuilder.newDirectoryInstance(cache, cache, cache,
indexName)

                                .create();
```

The *indexName* is a unique key to identify your index. It takes the same role as the path did on filesystem based indexes: you can create several different indexes giving them different names. When you use the same *indexName* in another instance connected to the same network (or instantiated on the same machine, useful for testing) they will join, form a cluster and share all content. Using a different *indexName* allows you to store different indexes in the same set of Caches.

The *cache* is passed three times in this example, as that is ok for a quick demo, but as the API suggests it's a good idea to tune each cache separately as they will be used in different ways. More details provided below.

New nodes can be added or removed dynamically, making the service administration very easy and also suited for cloud environments: it's simple to react to load spikes, as adding more memory and CPU power to the search system is done by just starting more nodes.

13.4. Limitations

As when using an *IndexWriter* on a filesystem based *Directory* , even on the clustered edition only one *IndexWriter* can be opened across the whole cluster.

As an example, [Hibernate Search](#) , which includes integration with this Lucene Directory since version 3.3, sends index change requests across a JMS queue, or a *JGroups* channel. Other valid approaches are to proxy the remote *IndexWriter* or just design your application in such a way that only one node attempts to write it.

Reading (searching) is of course possible in parallel, from any number of threads on each node; changes applied to the single *IndexWriter* are affecting results of all threads on all nodes in a very short time, or guaranteed to be visible after a commit when using transactions.

13.5. Configuration

Infinispan can be configured as LOCAL clustering mode, in which case it will disable clustering features and serve as a cache for the index, or any clustering mode. A transaction manager is not mandatory, but when enabled the changes to the index can participate in transactions.

Batching was required in previous versions, it's not strictly needed anymore.

As better explained in the javadocs of *org.infinispan.lucene.InfinispanDirectory* , it's possible for it to use more than a single cache, using specific configurations for different purposes. When using

readlocks, make sure to not enable transactions on this cache.

Any Infinispan configuration should work fine as long as caches are not configured to remove entries after thresholds.

13.6. Demo

There is a simple command-line demo of its capabilities distributed with Infinispan under `demos/lucene-directory`; make sure you grab the *"Binaries, server and demos"* package from [download page](#) , which contains all demos.

Start several instances, then try adding text in one instance and searching for it on the other. The configuration is not tuned at all, but should work out-of-the box without any changes. If your network interface has multicast enabled, it will cluster across the local network with other instances of the demo.

13.7. Maven dependencies

All you need is *org.infinispan:infinispan-lucene-directory* :

pom.xml

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-lucene-directory</artifactId>
  <version>${infinispan.version}</version>
</dependency>
```

13.8. Using a CacheLoader

Using a CacheLoader you can have the index content backed up to a permanent storage; you can use a shared store for all nodes or one per node, see [cache passivation](#) for more details.

When using a CacheLoader to store a Lucene index, to get best write performance you would need to configure the CacheLoader with *async=true* .

13.8.1. Storing the index in a database

It might be useful to store the Lucene index in a relational database; this would be very slow but Infinispan can act as a cache between the application and the JDBC interface, making this configuration useful in both clustered and non-clustered configurations. When storing indexes in a JDBC database, it's suggested to use the *JdbcStringBasedCacheStore* , which will need this attribute:

```
<property name="key2StringMapperClass" value=
  "org.infinispan.lucene.LuceneKey2StringMapper" />
```

13.8.2. Loading an existing Lucene Index

The *org.infinispan.lucene.cachestore.LuceneCacheLoader* is an Infinispan CacheLoader able to have Infinispan directly load data from an existing Lucene index into the grid. Currently this supports reading only.

Property	Description	Default
<i>location</i>	The path where the indexes are stored. Subdirectories (of first level only) should contain the indexes to be loaded, each directory matching the index name attribute of the <i>InfinispanDirectory</i> constructor.	none (mandatory)
<i>autoChunkSize</i>	A threshold in bytes: if any segment is larger than this, it will be transparently chunked in smaller cache entries up to this size.	32MB

It's worth noting that the IO operations are delegated to Lucene's standard *org.apache.lucene.store.FSDirectory* , which will select an optimal approach for the running platform.

Implementing write-through should not be hard: you're welcome to try implementing it.

13.9. Architectural limitations

This Directory implementation makes it possible to have almost real-time reads across multiple nodes. A fundamental limitation of the Lucene design is that only a single *IndexWriter* is allowed to make changes on the index: a pessimistic lock is acquired by the writer; this is generally ok as a single *IndexWriter instance* is very fast and accepts update requests from multiple threads. When sharing the Directory across Infinispan nodes the *IndexWriter* limitation is not lifted: since you can have only one instance, that reflects in your application as having to apply all changes on the same node. There are several strategies to write from multiple nodes on the same index:

Index write strategies

- One node writes, the other delegate to it sending messages
- Each node writes on turns
- Your application makes sure it will only ever apply index writes on one node

The *Infinispan Lucene Directory* protects its content by implementing a distributed locking strategy, though this is designed as a last line of defense and is not to be considered an efficient mechanism to coordinate multiple writes: if you don't apply one of the above suggestions and get high write contention from multiple nodes you will likely get timeout exception.

13.10. Suggestions for optimal performance

13.10.1. JGroups and networking stack

JGroups manages all network IO and as such it is a critical component to tune for your specific environment. Make sure to read the [JGroups reference documentation](#) , and play with the performance tests included in JGroups to make sure your network stack is setup appropriately. Don't forget to check also operating system level parameters, for example buffer sizes dedicated for networking. JGroups will log warning when it detects something wrong, but there is much more you can look into.

13.10.2. Using a CacheStore

Currently all CacheStore implementations provided by Infinispan have a significant slowdown; we hope to resolve that soon but for the time being if you need high performance on writes with the Lucene Directory the best option is to disable any CacheStore; the second best option is to configure the CacheStore as *async* . If you only need to load a Lucene index from read-only storage, see the above description for *org.infinispan.lucene.cachestore.LuceneCacheLoader* .

13.10.3. Apply standard Lucene tuning

All known options of Lucene apply to the Infinispan Lucene Directory as well; of course the effect might be less significant in some cases, but you should definitely read the [Apache Lucene documentation](#) .

13.10.4. Disable batching and transactions

Early versions required Infinispan to have batching or transactions enabled. This is no longer a requirement, and in fact disabling them should provide little improvement in performance.

13.10.5. Set the right chunk size

The chunk size is an optional parameter to be passed to the Directory builder. While it's optional, its default is suited only for testing and small demos, while setting a larger size can have a dramatic effect on performance especially when running on multiple nodes. To correctly set this variable you need to estimate what the expected size of your segments is; generally this is trivial by looking at the file size of the index segments generated by your application when it's using the standard FSDirectory. You then have to consider:

- The chunk size affects the size of internally created buffers, so you don't want an outrageously large array as you're going to waste precious JVM memory. Also consider that during index writing such arrays are frequently allocated.
- If a segment doesn't fit in the chunk size, it's going to be fragmented. When searching on a fragmented segment performance can't peak.

Using the *org.apache.lucene.index.IndexWriterConfig* you can tune your index writing to *approximately* keep your segment size to a reasonable level, from there then tune the chunksize, after having defined the chunksize you might want to revisit your network configuration settings.

13.10.6. Use dedicated Cache instances

When constructing the Directory instance you have the option to specify different caches. The *metadataCache* is going to be accessed frequently by all nodes and its content is very small, so it's best to use *REPL_SYNC* . The *chunksCache* contains the raw byte arrays of your index segments otherwise stored on filesystem, so - assuming your system is read-mostly - you might also want to use replication on this cache, but you have to consider if you have enough memory to store all the data replicated on all nodes; if not, you might be better off using *DIST_SYNC* , optionally enabling L1. The *distLocksCache* cache is similar to the *chunksCache* , just that it doesn't need a *CacheStore* even if you want to persist the index.

Chapter 14. CDI Support

Infinispan includes integration with [Contexts and Dependency Injection \(better known as CDI\)](#) via Infinispan's `infinispan-cdi` module. Configuration and injection of Infinispan's Cache interface is provided, and it is planned to bridge Cache listeners to the CDI event system as well. The module also provide partial support of the JCache (JSR-107) caching annotations - for further details see [Chapter 8](#) of the JCACHE specification.

14.1. Maven Dependencies

To include CDI support for Infinispan in your project:

pom.xml

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-cdi</artifactId>
  <version>${infinispan.version}</version>
</dependency>
```



Which version of Infinispan should I use?

We recommend using the latest final version of the `infinispan-cdi` module.

14.2. Embedded cache integration

14.2.1. Inject an embedded cache

By default you can inject the default Infinispan cache. Let's look at the following example:

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

public class GreetingService {
    @Inject
    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;
    }
}
```

If you want to use a specific cache rather than the default one, you just have to provide your own cache configuration and cache qualifier. For example, if you want to use a custom cache for the `GreetingService` you should write your own qualifier (such as `GreetingCache`) and define its configuration:

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

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

```
...
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("greeting-cache") // This is the cache name.
    @GreetingCache // This is the cache qualifier.
    @Produces
    public Configuration greetingCacheConfiguration() {
        return new ConfigurationBuilder()
            .eviction()
                .strategy(EvictionStrategy.LRU)
                .maxEntries(1000)
            .build();
    }

    // The same example without providing a custom configuration.
    // In this case the default cache configuration will be used.
    @ConfigureCache("greeting-cache")
    @GreetingCache
    @Produces
    public Configuration greetingCacheConfiguration;
}
```

To use this cache in the `GreetingService` add the `@GreetingCache` qualifier on your cache injection point. Simple!

14.2.2. Override the default embedded cache manager and configuration

You can override the default cache configuration used by the default embedded cache manager. For that, you just have to create one `Configuration` producer with the `@Default` qualifier as illustrated

in the following snippet:

```
public class Config {
    // By default CDI adds the @Default qualifier if no other qualifier is provided.
    @Produces
    public Configuration defaultEmbeddedCacheConfiguration() {
        return new ConfigurationBuilder()
            .eviction()
            .strategy(EvictionStrategy.LRU)
            .maxEntries(100)
            .build();
    }
}
```

It's also possible to override the default embedded cache manager used. The new default cache manager produced must have the `@Default` qualifier and the scope `@ApplicationScoped`.

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

public class Config {
    @Produces
    @ApplicationScoped
    public EmbeddedCacheManager defaultEmbeddedCacheManager() {
        return new DefaultCacheManager(new ConfigurationBuilder()
            .eviction()
            .strategy(EvictionStrategy.LRU)
            .maxEntries(100)
            .build());
    }
}
```

14.2.3. Configure the transport for clustered use

To use Infinispan in a clustered mode you have to configure the transport with the `GlobalConfiguration`. To achieve that override the default cache manager as explained in the previous section. Look at the following snippet:

```

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

@Produces
@ApplicationScoped
public EmbeddedCacheManager defaultClusteredCacheManager() {
    return new DefaultCacheManager(
        new GlobalConfigurationBuilder().transport().defaultTransport().build(),
        new ConfigurationBuilder().eviction().maxEntries(7).build()
    );
}

```

14.3. Remote cache integration

14.3.1. Inject a remote cache

With the CDI integration it's also possible to use a remote cache. For example you can inject the default RemoteCache as illustrated in the following snippet:

```

public class GreetingService {
    @Inject
    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;
    }
}

```

If you want to use another cache, for example the greeting-cache, add the @Remote qualifier on the cache injection point which contains the cache name.

```

public class GreetingService {
    @Inject @Remote("greeting-cache")
    private RemoteCache<String, String> cache;

    ...
}

```

Adding the @Remote cache qualifier on each injection point might be error prone. That's why the remote cache integration provides another way to achieve the same goal. For that you have to create your own qualifier annotated with @Remote :

```

@Remote("greeting-cache")
@Qualifier
@Target({ElementType.FIELD, ElementType.PARAMETER, ElementType.METHOD})
@Retention(RetentionPolicy.RUNTIME)
@Documented
public @interface RemoteGreetingCache {
}

```

To use this cache in the GreetingService add the qualifier `@RemoteGreetingCache` qualifier on your cache injection.

14.3.2. Override the default remote cache manager

Like the embedded cache integration, the remote cache integration comes with a default remote cache manager producer. This default remote cache manager can be overridden as illustrated in the following snippet:

```

public class Config {
    @Produces
    @ApplicationScoped
    public RemoteCacheManager defaultRemoteCacheManager() {
        return new RemoteCacheManager(localhost, 1544);
    }
}

```

14.4. Use a custom remote/embedded cache manager for one or more cache

It's possible to use a custom cache manager for one or more cache. You just need to annotate the cache manager producer with the cache qualifiers. Look at the following example:

```

public class Config {
    @GreetingCache
    @Produces
    @ApplicationScoped
    public EmbeddedCacheManager specificEmbeddedCacheManager() {
        return new DefaultCacheManager(new ConfigurationBuilder()
            .expiration()
            .lifespan(60000L)
            .build());
    }

    @RemoteGreetingCache
    @Produces
    @ApplicationScoped
    public RemoteCacheManager specificRemoteCacheManager() {
        return new RemoteCacheManager("localhost", 1544);
    }
}

```

With the above code the `GreetingCache` or the `RemoteGreetingCache` will be associated with the produced cache manager.



Producer method scope

To work properly the producers must have the scope `@ApplicationScoped`. Otherwise each injection of cache will be associated to a new instance of cache manager.

14.5. Use JCache caching annotations



There is now a separate module for JSR 107 (JCACHE) integration, including API. See [this chapter](#) for details.

The `infinispan-cdi` module provides a partial support of JCache caching annotations. These annotations provide a simple way to handle common use cases. The following caching annotations are defined in this specification:

- `@CacheResult` caches the result of a method call
- `@CachePut` caches a method parameter
- `@CacheRemoveEntry` removes an entry from a cache
- `@CacheRemoveAll` removes all entries from a cache



Annotations target type

These annotations must only be used on methods.

To use these annotations the following interceptors must be declared in your application `beans.xml`

```

<beans xmlns="http://java.sun.com/xml/ns/javaee"
       xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
       xsi:schemaLocation="http://java.sun.com/xml/ns/javaee
http://java.sun.com/xml/ns/javaee/beans_1_0.xsd">
    <interceptors>
        <class>org.infinispan.jcache.annotation.InjectedExceptionHandler</class>
        <class>org.infinispan.jcache.annotation.InjectedExceptionHandler</class>
        <class>
org.infinispan.jcache.annotation.InjectedExceptionHandler</class>
        <class>
org.infinispan.jcache.annotation.InjectedExceptionHandler</class>
    </interceptors>
</beans>

```

The following snippet of code illustrates the use of `@CacheResult` annotation. As you can see it simplifies the caching of the `GreetingService#greet` method results.

```

import javax.cache.interceptor.CacheResult;

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

```

The first version of the `GreetingService` and the above version have exactly the same behavior. The only difference is the cache used. By default it's the fully qualified name of the annotated method with its parameter types (e.g. `org.infinispan.example.GreetingService.greet(java.lang.String)`).

Can I use a different cache?

To use another cache specify its name with the `cacheName` attribute of the cache annotation. For example:

```

@CacheResult(cacheName = "greeting-cache")

```

14.6. Use Cache events and CDI

It is possible to receive Cache and Cache Manager level events using CDI Events. You can achieve it using `@Observes` annotation as shown in the following snippet:


```
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) {
        ...
    }
}
```



Check [Listeners and Notifications section](#) for more information about event types.

Chapter 15. JCache (JSR-107) provider

Starting with version 7.0.0, Infinispan provides an implementation of JCache 1.0.0 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 Infinispan's implementation of the specification, and explains key aspects of the API.

15.1. Dependencies

In order to start using Infinispan JCache implementation, a single dependency needs to be added to the Maven pom.xml file:

pom.xml

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-jcache</artifactId>
  <version>...</version> <!-- i.e. 7.0.0.Final -->
  <scope>test</scope>
</dependency>
```

15.2. Create a local cache

Creating a local cache, using default configuration options as defined by the JCache API specification, is as simple as doing the following:

```
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>());
```



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));
```

15.3. Store and retrieve data

Even though JCache API does not extend neither `java.util.Map` nor `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.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)` which avoids returning the potentially expensive operation of returning the previous value.

15.4. 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	<code>java.util.concurrent.ConcurrentMap<K, V></code>	<code>javax.cache.Cache<K, V></code>
store and no return	N/A	<code>void put(K key)</code>

Operation	<code>java.util.concurrent.ConcurrentMap<K, V></code>	<code>javax.cache.Cache<K, V></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>
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<K, V></code>	<code>javax.cache.Cache<K, V></code>
calculate size of cache	<code>int size()</code>	N/A
return all keys in the cache	<code>Set<K> keySet()</code>	N/A
return all values in the cache	<code>Collection<V> values()</code>	N/A
return all entries in the cache	<code>Set<Map.Entry<K, V>> 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<Cache.Entry<K, V>> iterator()</code>

15.5. 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>
  <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 16. Management Tooling

Management of Infinispan instances is all about exposing as much relevant statistical information that allows administrators to get a view of the state of each Infinispan instance. Taking in account that a single installation could be made up of several tens or hundreds Infinispan instances, providing clear and concise information in an efficient manner is imperative. The following sections dive into the range of management tooling that Infinispan provides.

16.1. JMX

Over the years, [JMX](#) has become the de facto standard for management and administration of middleware and as a result, the Infinispan team has decided to standardize on this technology for the exposure of management and statistical information.

16.1.1. Understanding The Exposed MBeans

By connecting to the VM(s) where Infinispan is running with a standard JMX GUI such as [JConsole](#) or [VisualVM](#) you should find the following MBeans:

- For CacheManager level JMX statistics, without further configuration, you should see an MBean called `org.infinispan:type=CacheManager,name="DefaultCacheManager"` with [properties specified by the CacheManager MBean](#).
- Using the `cacheManagerName` attribute in `globalJmxStatistics` XML element, or using the corresponding `GlobalJmxStatisticsConfigurationBuilder.cacheManagerName(String cacheManagerName)` call, you can name the cache manager in such way that the name is used as part of the JMX object name. So, if the name had been "Hibernate2LC", the JMX name for the cache manager would have been: `org.infinispan:type=CacheManager,name="Hibernate2LC"`. This offers a nice and clean way to manage environments where multiple cache managers are deployed, which follows [JMX best practices](#).
- For Cache level JMX statistics, you should see several different MBeans depending on which configuration options have been enabled. For example, if you have configured a write behind cache store, you should see an MBean exposing properties belonging to the cache store component. All Cache level MBeans follow the same format though which is the following: `org.infinispan:type=Cache,name="{name-of-cache}({cache-mode})",manager="{name-of-cache-manager}",component={component-name}` where:
 - `{name-of-cache}` has been substituted by the actual cache name. If this cache represents the default cache, its name will be `___defaultCache`.
 - `{cache-mode}` has been substituted by the cache mode of the cache. The cache mode is represented by the lower case version of the possible enumeration values shown [here](#).
 - `{name-of-cache-manager}` has been substituted by the name of the cache manager to which this cache belongs. The name is derived from the `cacheManagerName` attribute value in `globalJmxStatistics` element.
 - `{component-name}` has been substituted by one of the JMX component names in the [JMX reference documentation](#).

For example, the cache store JMX component MBean for a default cache configured with synchronous distribution would have the following name: `org.infinispan:type=Cache,name="___defaultcache(dist_sync)",manager="DefaultCacheManager",component=CacheStore`

Please note that cache and cache manager names are quoted to protect against illegal characters being used in these user-defined names.

16.1.2. Enabling JMX Statistics

The MBeans mentioned in the previous section are always created and registered in the MBeanServer allowing you to manage your caches but some of their attributes do not expose meaningful values unless you take the extra step of enabling collection of statistics. Gathering and reporting statistics via JMX can be enabled at 2 different levels:

CacheManager level

The CacheManager is the entity that governs all the cache instances that have been created from it. Enabling CacheManager statistics collections differs depending on the configuration style:

- If configuring the CacheManager via XML, make sure you add the following XML under the `<cache-container />` element:

```
<cache-container statistics="true"/>
```

- If configuring the CacheManager programmatically, simply add the following code:

```
GlobalConfigurationBuilder globalConfigurationBuilder = ...
globalConfigurationBuilder.globalJmxStatistics().enable();
```

Cache level

At this level, you will receive management information generated by individual cache instances. Enabling Cache statistics collections differs depending on the configuration style:

- If configuring the Cache via XML, make sure you add the following XML under the one of the top level cache elements, such as `<local-cache />`:

```
<local-cache statistics="true"/>
```

- If configuring the Cache programmatically, simply add the following code:

```
ConfigurationBuilder configurationBuilder = ...
configurationBuilder.jmxStatistics().enable();
```

16.1.3. Multiple JMX Domains

There can be situations where several CacheManager instances are created in a single VM, or Cache names belonging to different CacheManagers under the same VM clash.

Using different JMX domains for multi cache manager environments should be last resort. Instead, it's possible to name a cache manager in such way that it can easily be identified and used by monitoring tools. For example:

- Via XML:

```
<cache-container statistics="true" name="Hibernate2LC"/>
```

- Programmatically:

```
GlobalConfigurationBuilder globalConfigurationBuilder = ...
globalConfigurationBuilder.globalJmxStatistics()
    .enable()
    .cacheManagerName("Hibernate2LC");
```

Using either of these options should result on the CacheManager MBean name being: `org.infinispan:type=CacheManager,name="Hibernate2LC"`

For the time being, you can still set your own jmxDomain if you need to and we also allow duplicate domains, or rather duplicate JMX names, but these should be limited to very special cases where different cache managers within the same JVM are named equally.

16.1.4. Registering MBeans In Non-Default MBean Servers

Let's discuss where Infinispan registers all these MBeans. By default, Infinispan registers them in the [standard JVM MBeanServer platform](#). However, users might want to register these MBeans in a different MBeanServer instance. For example, an application server might work with a different MBeanServer instance to the default platform one. In such cases, users should implement the [MBeanServerLookup interface](#) provided by Infinispan so that the [getMBeanServer\(\) method](#) returns the MBeanServer under which Infinispan should register the management MBeans. You can find an example in the default [PlatformMBeanServerLookup class](#) used by Infinispan. So, once you have your implementation ready, simply configure Infinispan with the fully qualified name of this class. For example:

- Via XML:

```
<cache-container statistics="true">
  <jmx mbean-server-lookup="com.acme.MyMBeanServerLookup" />
</cache-container>
```

- Programmatically:


```
GlobalConfigurationBuilder globalConfigurationBuilder = ...
globalConfigurationBuilder.globalJmxStatistics()
    .enable()
    .mBeanServerLookup(new com.acme.MyMBeanServerLookup());
```

16.1.5. MBeans added in Infinispan 5.0

There has been a couple of noticeable additions in Infinispan 5.0 in terms of exposed MBeans:

1. MBeans related to Infinispan servers are now available that for the moment focus on the transport layer. A new MBean named `org.infinispan:type=Server,name={Memcached|HotRod},component=Transport` offers information such as: host name, port, bytes read, byte written, number of worker threads, etc.
2. When global JMX statistics are enabled, the JGroups channel MBean is also registered automatically under the name `org.infinispan:type=channel,cluster={name-of-your-cluster}`, so you can get key information of the group communication transport layer that's used to cluster Infinispan instances. To find out more about the information provided, check the [JGroups JMX documentation](#).

16.2. Hawt.io

[Hawt.io](#), a slick, fast, HTML5-based open source management console, also has support for Infinispan. Refer to [Hawt.io's documentation](#) for information regarding this plugin.

16.3. Writing plugins for other management tools

Any management tool that supports JMX already has basic support for Infinispan. However, custom plugins could be written to adapt the JMX information for easier consumption.

Chapter 17. Custom Interceptors

It is possible to add custom interceptors to Infinispan, both declaratively and programmatically. 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. For a detailed list refer to [CommandInterceptor](#) API.

17.1. 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. All custom interceptors need to extend
    org.jboss.cache.interceptors.base.CommandInterceptor
  -->
  <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>
```

17.2. 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.

17.3. Custom interceptor design

When writing a custom interceptor, you need to abide by the following rules.

- Custom interceptors must extend [BaseCustomInterceptor](#)
- 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 18. Running on Cloud Services

In order to turn on Cloud support for Infinispan library mode, one needs to add a new dependency to the classpath:

Cloud support in library mode

```
<dependency>
  <groupId>org.infinispan</groupId>
  <artifactId>infinispan-cloud</artifactId>
  <version>${infinispan.version}</version>
</dependency>
```

The above dependency adds `infinispan-core` to the classpath as well as some default configurations.

18.1. Amazon Web Services

Infinispan can be used on the Amazon Web Service (AWS) platform and similar cloud based environment in several ways. As Infinispan uses JGroups as the underlying communication technology, the majority of the configuration work is done JGroups. The default auto discovery won't work on EC2 as multicast is not allowed, but JGroups provides several other discovery protocols so we only have to choose one.

18.1.1. TCPPing, GossipRouter, S3_PING

The TCPPing approach contains a static list of the IP address of each member of the cluster in the JGroups configuration file. While this works it doesn't really help when cluster nodes are dynamically added to the cluster.

Sample TCPPing configuration

```
<config>
  <TCP bind_port="7800" />
  <TCPPING timeout="3000"
    initial_hosts=
    "${jgroups.tcpping.initial_hosts:localhost[7800],localhost[7801]}"
    port_range="1"
    num_initial_members="3"/>
  ...
  ...
</config>
```

See <http://community.jboss.org/wiki/JGroupsTCPPING> for more information about TCPPing.

18.1.2. GossipRouter

Another approach is to have a central server (Gossip, which each node will be configured to contact. This central server will tell each node in the cluster about each other node.

The address (ip:port) that the Gossip router is listening on can be injected into the JGroups configuration used by Infinispan. To do this pass the gossip routers address as a system property to the JVM e.g. `-DGossipRouterAddress="10.10.2.4[12001]"` and reference this property in the JGroups configuration that Infinispan is using e.g.

Sample TCPGOSSIP configuration

```
<config>
  <TCP bind_port="7800" />
  <TCPGOSSIP timeout="3000" initial_hosts="${GossipRouterAddress}"
num_initial_members="3" />
  ...
  ...
</config>
```

More on Gossip Router @ <http://www.jboss.org/community/wiki/JGroupsGossipRouter>

18.1.3. S3_PING

Finally you can configure your JGroups instances to use a shared storage to exchange the details of the cluster nodes. S3_PING was added to JGroups in 2.6.12 and 2.8, and allows the Amazon S3 to be used as the shared storage. It is experimental at the moment but offers another method of clustering without a central server. Be sure that you have signed up for Amazon S3 as well as EC2 to use this method.

Sample S3PING configuration

```
<config>
  <TCP bind_port="7800" />
  <S3_PING
    secret_access_key="replace this with you secret access key"
    access_key="replace this with your access key"
    location="replace this with your S3 bucket location" />
</config>
```

18.1.4. JDBC_PING

A similar approach to S3_PING, but using a JDBC connection to a shared database. On EC2 that is quite easy using Amazon RDS. See the [JDBC_PING Wiki page](#) for details.

Chapter 19. Kubernetes and OpenShift

Since OpenShift uses Kubernetes underneath both of them can use the same discovery protocol - [Kube_PING](#). The configuration is very straightforward:

Sample KUBE_PING configuration

```
<config>
  <TCP bind_addr="${match-interface:eth.*}" />
  <kubernetes.KUBE_PING />
  ...
  ...
</config>
```

The most important thing is to bind JGroups to `eth0` interface, which is [used by Docker containers for network communication](#).

KUBE_PING protocol is configured by environmental variables (which should be available inside a container). The most important thing is to set `OPENSHIFT_KUBE_PING_NAMESPACE` to proper namespace. It might be either hardcoded or populated via [Kubernetes' Downward API](#).

Since KUBE_PING uses Kubernetes API for obtaining available Pods, OpenShift requires adding additional privileges. Assuming that `oc project -q` returns current namespace and `default` is the service account name, one needs to run:

Adding additional OpenShift privileges

```
oc policy add-role-to-user view system:serviceaccount:$(oc project -q):default -n $(oc project -q)
```

After performing all above steps, the clustering should be enabled and all Pods should automatically form a cluster within a single namespace.

Chapter 20. Command-Line Interface (CLI)

Infinispan offers a simple Command-Line Interface (CLI) with which it is possible to interact with the data within the caches and with most of the internal components (e.g. transactions, cross-site backups, rolling upgrades).

The CLI is built out of two elements: a server-side module and the client command tool. The server-side module (`infinispan-cli-server-$VERSION.jar`) provides the actual interpreter for the commands and needs to be included alongside your application. Infinispan Server includes CLI support out of the box.

Currently the server (and the client) use the JMX protocol to communicate, but in a future release we plan to support other communication protocols (in particular our own Hot Rod).

The CLI offers both an interactive and a batch mode. To invoke the client, just run the provided `bin/ispn-cli.[sh|bat]` script. The following is a list of command-line switches which affect how the CLI can be started:

```
-c, --connect=URL      connects to a running instance of Infinispan.
                        JMX over RMI
jmx://[username[:password]]@host:port[/container[/cache]]
                        JMX over JBoss remoting
remoting://[username[:password]]@host:port[/container[/cache]]
-f, --file=FILE        reads input from the specified file instead of using
                        interactive mode. If FILE is '-', then commands will be read
                        from stdin
-h, --help              shows this help page
-v, --version           shows version information
```

- JMX over RMI is the traditional way in which JMX clients connect to MBeanServers. Please refer to the [JDK Monitoring and Management](#) documentation for details on how to configure the process to be monitored
- JMX over JBoss Remoting is the protocol of choice when your Infinispan application is running within JBoss AS7 or EAP6.

The connection to the application can also be initiated from within the CLI using the connect command.

```
[disconnected//]> connect jmx://localhost:12000
[jmx://localhost:12000/MyCacheManager/>
```

The CLI prompt will show the active connection information, including the currently selected CacheManager. Initially no cache is selected so, before performing any cache operations, one must be selected. For this the `cache` command is used. The CLI supports tab-completion for all commands and options and for most parameters where it makes sense to do so. Therefore typing `cache` and pressing TAB will show a list of active caches:

```
[jmx://localhost:12000/MyCacheManager/> cache  
__defaultcache namedCache  
[jmx://localhost:12000/MyCacheManager/]> cache __defaultcache  
[jmx://localhost:12000/MyCacheManager/__defaultcache]>
```

Pressing TAB at an empty prompt will show the list of all available commands:

alias	cache	container	encoding	get	locate	remove
site	upgrade					
abort	clearcache	create	end	help	put	replace
start	version					
begin	commit	disconnect	evict	info	quit	rollback
stats						

The CLI is based on [Æsh](#) and therefore offers many keyboard shortcuts to navigate and search the history of commands, to manipulate the cursor at the prompt, including both Emacs and VI modes of operation.

20.1. Commands

20.1.1. abort

The *abort* command is used to abort a running batch initiated by the *start* command

```
[jmx://localhost:12000/MyCacheManager/namedCache]> start  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> abort  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
null
```

20.1.2. begin

The *begin* command starts a transaction. In order for this command to work, the cache(s) on which the subsequent operations are invoked must have transactions enabled.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> begin  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> put b b  
[jmx://localhost:12000/MyCacheManager/namedCache]> commit
```

20.1.3. cache

The *cache* command selects the cache to use as default for all subsequent operations. If it is invoked without parameters it shows the currently selected cache.


```
[jmx://localhost:12000/MyCacheManager/namedCache]> cache ___defaultcache  
[jmx://localhost:12000/MyCacheManager/___defaultcache]> cache  
___defaultcache  
[jmx://localhost:12000/MyCacheManager/___defaultcache]>
```

20.1.4. clearcache

The *clearcache* command clears a cache from all content.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> clearcache  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
null
```

20.1.5. commit

The *commit* command commits an ongoing transaction

```
[jmx://localhost:12000/MyCacheManager/namedCache]> begin  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> put b b  
[jmx://localhost:12000/MyCacheManager/namedCache]> commit
```

20.1.6. container

The *container* command selects the default container (cache manager). Invoked without parameters it lists all available containers

```
[jmx://localhost:12000/MyCacheManager/namedCache]> container  
MyCacheManager OtherCacheManager  
[jmx://localhost:12000/MyCacheManager/namedCache]> container OtherCacheManager  
[jmx://localhost:12000/OtherCacheManager/]>
```

20.1.7. create

The *create* command creates a new cache based on the configuration of an existing cache definition

```
[jmx://localhost:12000/MyCacheManager/namedCache]> create newCache like namedCache  
[jmx://localhost:12000/MyCacheManager/namedCache]> cache newCache  
[jmx://localhost:12000/MyCacheManager/newCache]>
```

20.1.8. deny

When authorization is enabled and the role mapper has been configured to be the `ClusterRoleMapper`, principal to role mappings are stored within the cluster registry (a replicated cache available to all nodes). The *deny* command can be used to deny roles previously assigned to a principal:

```
[remoting://localhost:9999]> deny supervisor to user1
```

20.1.9. disconnect

The *disconnect* command disconnects the currently active connection allowing the CLI to connect to another instance.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> disconnect  
[disconnected//]
```

20.1.10. encoding

The *encoding* command is used to set a default codec to use when reading/writing entries from/to a cache. When invoked without arguments it shows the currently selected codec. This command is useful since currently remote protocols such as HotRod and Memcached wrap keys and values in specialized structures.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> encoding  
none  
[jmx://localhost:12000/MyCacheManager/namedCache]> encoding --list  
memcached  
hotrod  
none  
rest  
[jmx://localhost:12000/MyCacheManager/namedCache]> encoding hotrod
```

20.1.11. end

The *end* command is used to successfully end a running batch initiated by the *start* command

```
[jmx://localhost:12000/MyCacheManager/namedCache]> start  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> end  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
a
```

20.1.12. **evict**

The *evict* command is used to evict from the cache the entry associated with a specific key.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> evict a
```

20.1.13. **get**

The *get* command is used to show the value associated to a specified key. For primitive types and Strings, the *get* command will simply print the default representation. For other objects, a JSON representation of the object will be printed.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
a
```

20.1.14. **grant**

When authorization is enabled and the role mapper has been configured to be the ClusterRoleMapper, principal to role mappings are stored within the cluster registry (a replicated cache available to all nodes). The *grant* command can be used to grant new roles to a principal:

```
[remoting://localhost:9999]> grant supervisor to user1
```

20.1.15. **info**

The *info* command is used to show the configuration of the currently selected cache or container.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> info
GlobalConfiguration{asyncListenerExecutor=ExecutorFactoryConfiguration{factory=org.infinispan.executors.DefaultExecutorFactory@98add58},
asyncTransportExecutor=ExecutorFactoryConfiguration{factory=org.infinispan.executors.DefaultExecutorFactory@7bc9c14c},
evictionScheduledExecutor=ScheduledExecutorFactoryConfiguration{factory=org.infinispan.executors.DefaultScheduledExecutorFactory@7ab1a411},
replicationQueueScheduledExecutor=ScheduledExecutorFactoryConfiguration{factory=org.infinispan.executors.DefaultScheduledExecutorFactory@248a9705},
globalJmxStatistics=GlobalJmxStatisticsConfiguration{allowDuplicateDomains=true, enabled=true, jmxDomain='jboss.infinispan',
mBeanServerLookup=org.jboss.as.clustering.infinispan.MBeanServerProvider@6c0dc01,
cacheManagerName='local', properties={}},
transport=TransportConfiguration{clusterName='ISPN', machineId='null', rackId='null', siteId='null', strictPeerToPeer=false, distributedSyncTimeout=240000, transport=null,
nodeName='null', properties={}},
serialization=SerializationConfiguration{advancedExternalizers={1100=org.infinispan.server.core.CacheValue$Externalizer@5fab91d,
1101=org.infinispan.server.memcached.MemcachedValue$Externalizer@720bffd,
1104=org.infinispan.server.hotrod.ServerAddress$Externalizer@771c7eb2},
marshaller=org.infinispan.marshall.VersionAwareMarshaller@6fc21535, version=52,
classResolver=org.jboss.marshalling.ModularClassResolver@2efe83e5},
shutdown=ShutdownConfiguration{hookBehavior=DONT_REGISTER}, modules={},
site=SiteConfiguration{localSite='null'}}
```

20.1.16. locate

The *locate* command shows the physical location of a specified entry in a distributed cluster.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> locate a
[host/node1,host/node2]
```

20.1.17. put

The *put* command inserts an entry in the cache. If the cache previously contained a mapping for the key, the old value is replaced by the specified value. The user can control the type of data that the CLI will use to store the key and value. See the [Data Types](#) section.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a
[jmx://localhost:12000/MyCacheManager/namedCache]> put b 100
[jmx://localhost:12000/MyCacheManager/namedCache]> put c 41391
[jmx://localhost:12000/MyCacheManager/namedCache]> put d true
[jmx://localhost:12000/MyCacheManager/namedCache]> put e { "package.MyClass": {"i": 5,
"x": null, "b": true } }
```

The *put* command can optionally specify a lifespan and a maximum idle time.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a expires 10s  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a expires 10m maxidle 1m
```

20.1.18. replace

The *replace* command replaces an existing entry in the cache. If an old value is specified, then the replacement happens only if the value in the cache coincides.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> replace a b  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
b  
[jmx://localhost:12000/MyCacheManager/namedCache]> replace a b c  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
c  
[jmx://localhost:12000/MyCacheManager/namedCache]> replace a b d  
[jmx://localhost:12000/MyCacheManager/namedCache]> get a  
c
```

20.1.19. roles

When authorization is enabled and the role mapper has been configured to be the ClusterRoleMapper, principal to role mappings are stored within the cluster registry (a replicated cache available to all nodes). The *roles* command can be used to list the roles associated to a specific user, or to all users if one is not given:

```
[remoting://localhost:9999]> roles user1  
[supervisor, reader]
```

20.1.20. rollback

The *rollback* command rolls back an ongoing transaction

```
[jmx://localhost:12000/MyCacheManager/namedCache]> begin  
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a  
[jmx://localhost:12000/MyCacheManager/namedCache]> put b b  
[jmx://localhost:12000/MyCacheManager/namedCache]> rollback
```

20.1.21. site

The *site* command performs operations related to the administration of cross-site replication. It can be used to obtain information related to the status of a site and to change the status (online/offline)

```
[jmx://localhost:12000/MyCacheManager/namedCache]> site --status NYC
online
[jmx://localhost:12000/MyCacheManager/namedCache]> site --offline NYC
ok
[jmx://localhost:12000/MyCacheManager/namedCache]> site --status NYC
offline
[jmx://localhost:12000/MyCacheManager/namedCache]> site --online NYC
```

20.1.22. start

The *start* command initiates a batch of operations.

```
[jmx://localhost:12000/MyCacheManager/namedCache]> start
[jmx://localhost:12000/MyCacheManager/namedCache]> put a a
[jmx://localhost:12000/MyCacheManager/namedCache]> put b b
[jmx://localhost:12000/MyCacheManager/namedCache]> end
```

20.1.23. stats

The *stats* command displays statistics about a cache

```
[jmx://localhost:12000/MyCacheManager/namedCache]> stats
Statistics: {
  averageWriteTime: 143
  evictions: 10
  misses: 5
  hitRatio: 1.0
  readWriteRatio: 10.0
  removeMisses: 0
  timeSinceReset: 2123
  statisticsEnabled: true
  stores: 100
  elapsedTime: 93
  averageReadTime: 14
  removeHits: 0
  numberOfEntries: 100
  hits: 1000
}
LockManager: {
  concurrencyLevel: 1000
  numberOfLocksAvailable: 0
  numberOfLocksHeld: 0
}
```

20.1.24. upgrade

The *upgrade* command performs operations used during the rolling upgrade procedure. For a detailed description of this procedure please see [Rolling Upgrades](#)

```
[jmx://localhost:12000/MyCacheManager/namedCache]> upgrade --synchronize=hotrod --all
[jmx://localhost:12000/MyCacheManager/namedCache]> upgrade --disconnectsource=hotrod
--all
```

20.1.25. version

The *version* command displays version information about both the CLI client and the server

```
[jmx://localhost:12000/MyCacheManager/namedCache]> version
Client Version 5.2.1.Final
Server Version 5.2.1.Final
```

20.2. Data Types

The CLI understands the following types:

- string strings can either be quoted between single (') or double (") quotes, or left unquoted. In this case it must not contain spaces, punctuation and cannot begin with a number e.g. 'a string', key001
- int an integer is identified by a sequence of decimal digits, e.g. 256
- long a long is identified by a sequence of decimal digits suffixed by 'l', e.g. 1000l
- double
 - a double precision number is identified by a floating point number(with optional exponent part) and an optional 'd' suffix, e.g. 3.14
- float
 - a single precision number is identified by a floating point number(with optional exponent part) and an 'f' suffix, e.g. 10.3f
- boolean a boolean is represented either by the keywords true and false
- UUID a UUID is represented by its canonical form XXXXXXXX-XXXX-XXXX-XXXX-XXXXXXXXXXXX
- JSON serialized Java classes can be represented using JSON notation, e.g. {"package.MyClass":{"i":5,"x":null,"b":true}}. Please note that the specified class must be available to the CacheManager's class loader.

20.3. Time Values

A time value is an integer number followed by time unit suffix: days (d), hours (h), minutes (m), seconds (s), milliseconds (ms).

Chapter 21. Server Modules

Infinispan offers two alternative access methods: embedded mode and client-server mode.

- In Embedded mode the Infinispan libraries co-exist with the user application in the same JVM as shown in the following diagram

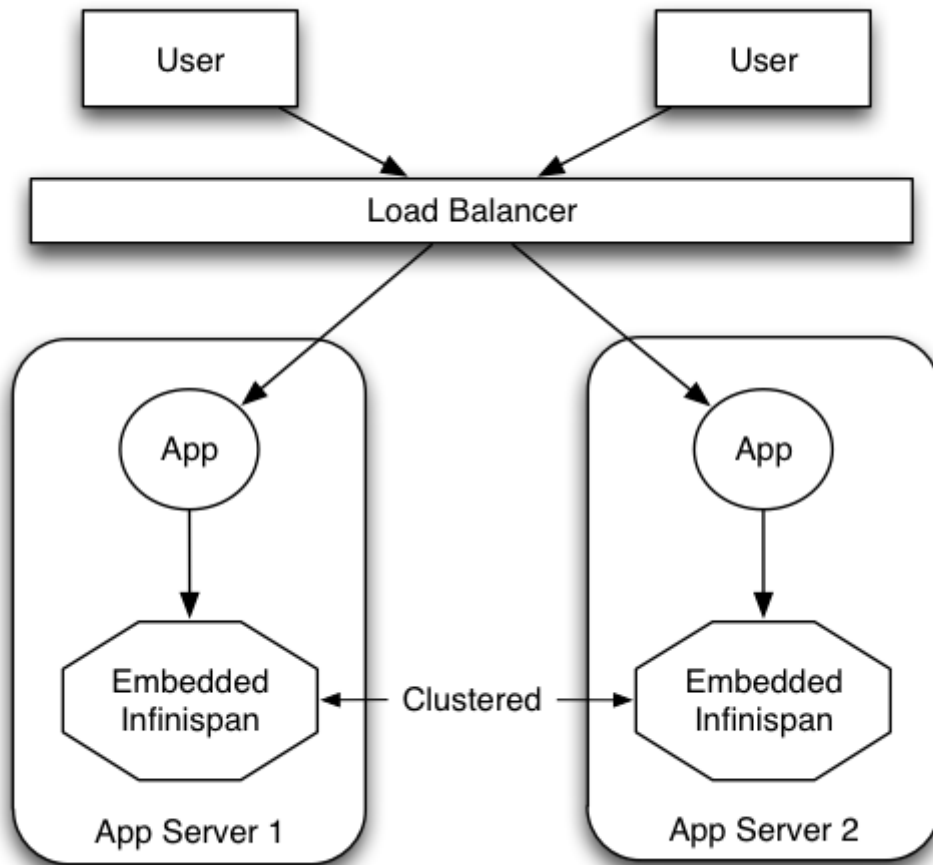


Figure 19. Peer-to-peer access

- Client-server mode is when applications access the data stored in a remote Infinispan server using some kind of network protocol

21.1. Why Client-Server?

There are situations when accessing Infinispan in a client-server mode might make more sense than embedding it within your application, for example, when trying to access Infinispan from a non-JVM environment. Since Infinispan is written in Java, if someone had a C++ application that wanted to access it, it couldn't just do it in a p2p way. On the other hand, client-server would be perfectly suited here assuming that a language neutral protocol was used and the corresponding client and server implementations were available.

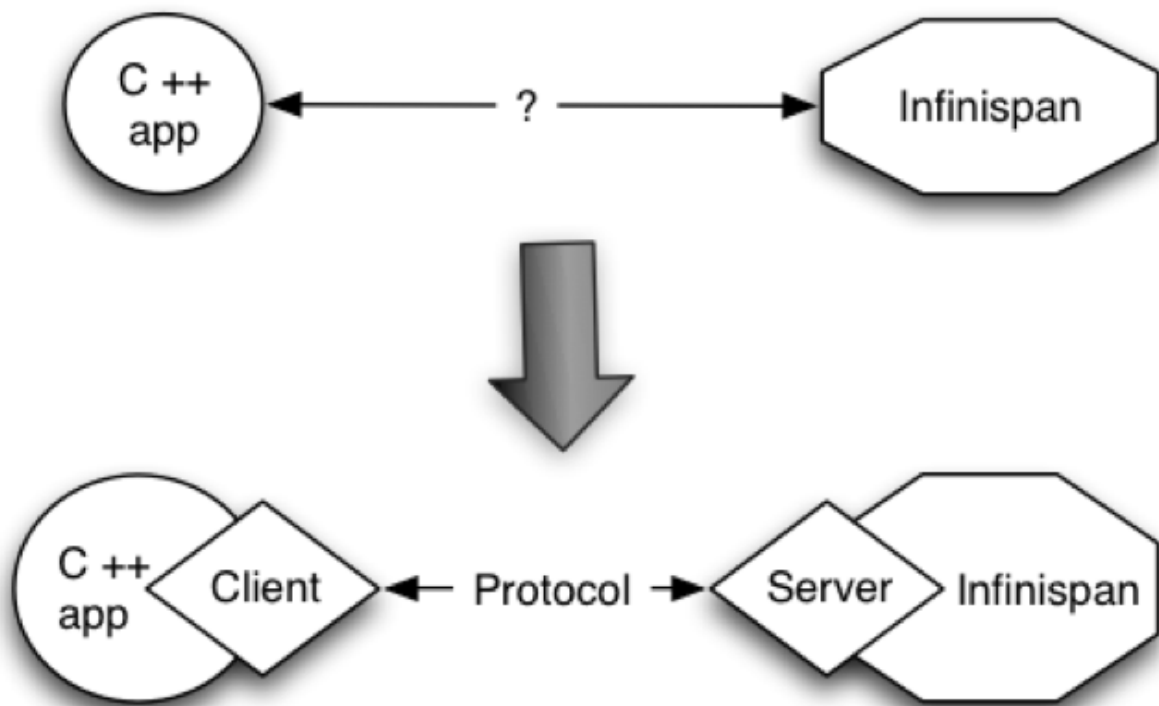


Figure 20. Non-JVM access

In other situations, Infinispan users want to have an elastic application tier where you start/stop business processing servers very regularly. Now, if users deployed Infinispan configured with distribution or state transfer, startup time could be greatly influenced by the shuffling around of data that happens in these situations. So in the following diagram, assuming Infinispan was deployed in p2p mode, the app in the second server could not access Infinispan until state transfer had completed.

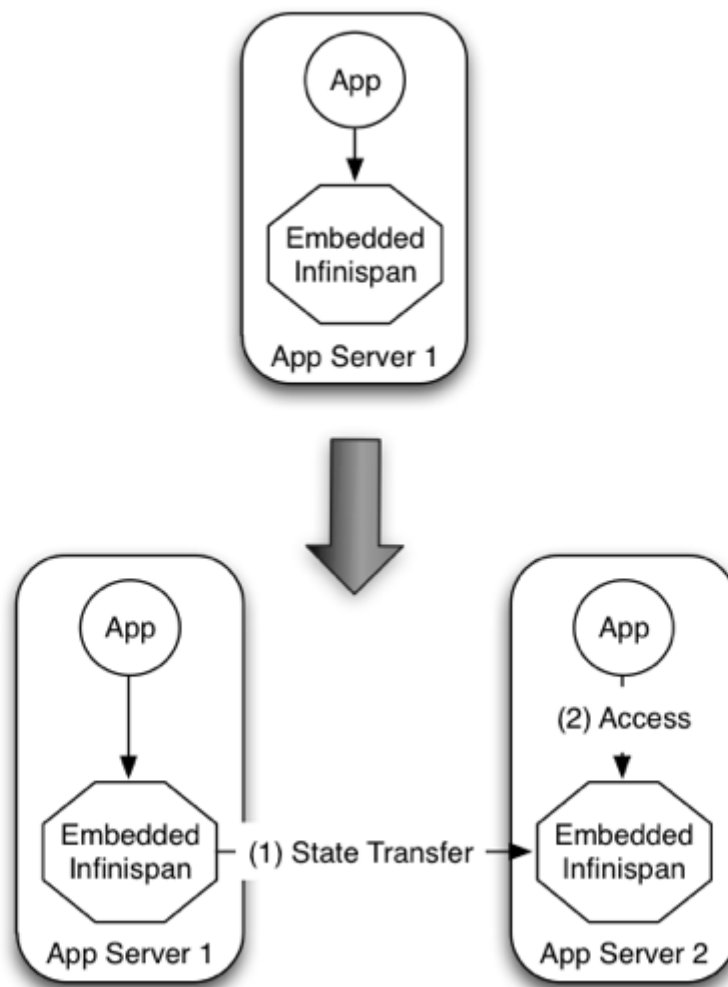


Figure 21. Elasticity issue with P2P

This effectively means that bringing up new application-tier servers is impacted by things like state transfer because applications cannot access Infinispan until these processes have finished and if the state being shifted around is large, this could take some time. This is undesirable in an elastic environment where you want quick application-tier server turnaround and predictable startup times. Problems like this can be solved by accessing Infinispan in a client-server mode because starting a new application-tier server is just a matter of starting a lightweight client that can connect to the backing data grid server. No need for rehashing or state transfer to occur and as a result server startup times can be more predictable which is very important for modern cloud-based deployments where elasticity in your application tier is important.

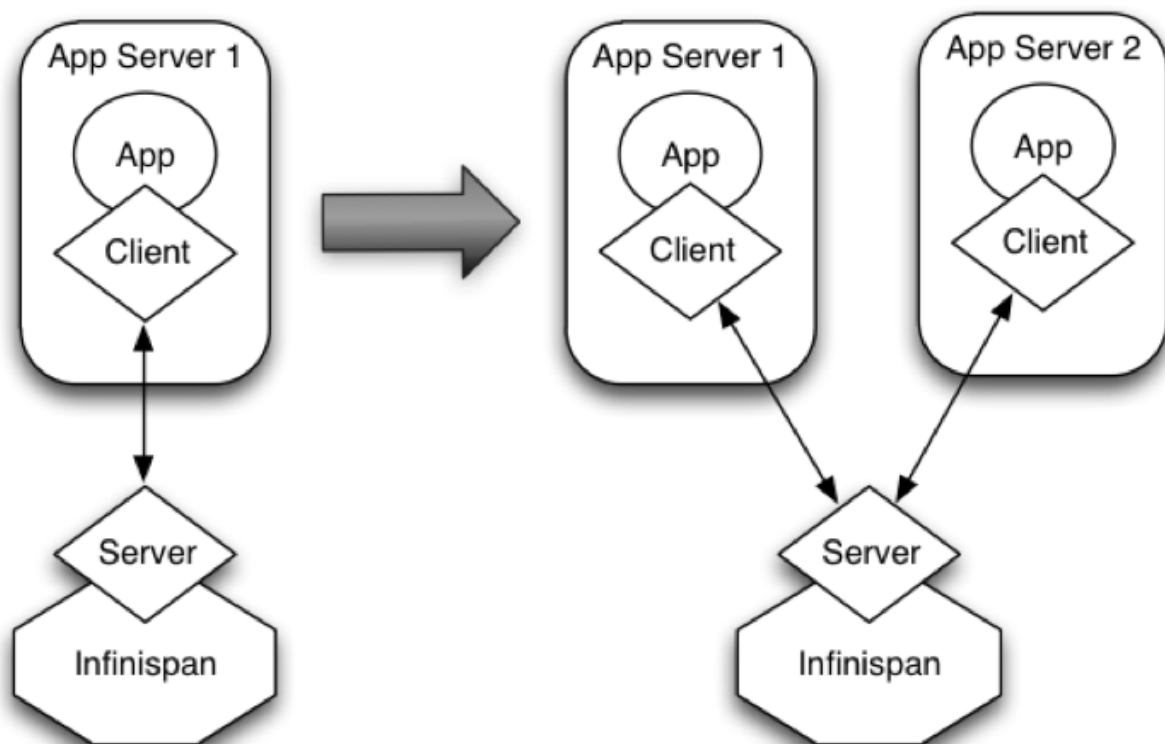


Figure 22. Achieving elasticity

Other times, it's common to find multiple applications needing access to data storage. In this cases, you could in theory deploy an Infinispan instance per each of those applications but this could be wasteful and difficult to maintain. Think about databases here, you don't deploy a database alongside each of your applications, do you? So, alternatively you could deploy Infinispan in client-server mode keeping a pool of Infinispan data grid nodes acting as a shared storage tier for your applications.

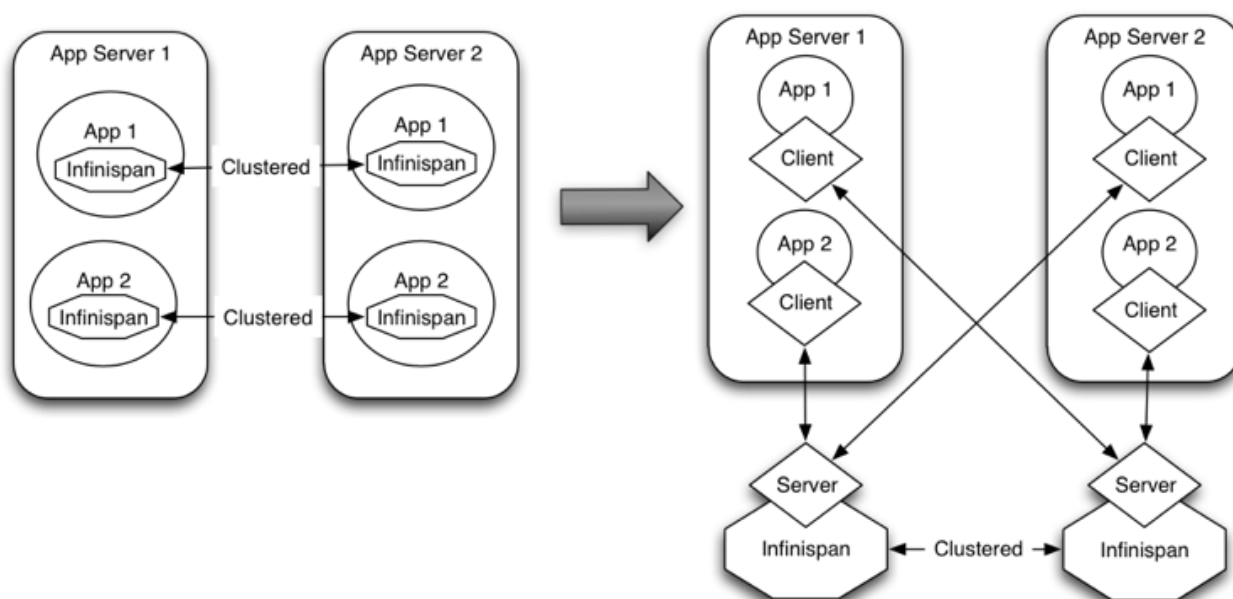


Figure 23. Shared data storage

Deploying Infinispan in this way also allows you to manage each tier independently, for example, you can upgrade your application or app server without bringing down your Infinispan data grid nodes.

21.2. Why use embedded mode?

Before talking about individual Infinispan server modules, it's worth mentioning that in spite of all the benefits, client-server Infinispan still has disadvantages over p2p. Firstly, p2p deployments are simpler than client-server ones because in p2p, all peers are equals to each other and hence this simplifies deployment. So, if this is the first time you're using Infinispan, p2p is likely to be easier for you to get going compared to client-server.

Client-server Infinispan requests are likely to take longer compared to p2p requests, due to the serialization and network cost in remote calls. So, this is an important factor to take in account when designing your application. For example, with replicated Infinispan caches, it might be more performant to have lightweight HTTP clients connecting to a server side application that accesses Infinispan in p2p mode, rather than having more heavyweight client side apps talking to Infinispan in client-server mode, particularly if data size handled is rather large. With distributed caches, the difference might not be so big because even in p2p deployments, you're not guaranteed to have all data available locally.

Environments where application tier elasticity is not so important, or where server side applications access state-transfer-disabled, replicated Infinispan cache instances are amongst scenarios where Infinispan p2p deployments can be more suited than client-server ones.

21.3. Server Modules

So, now that it's clear when it makes sense to deploy Infinispan in client-server mode, what are available solutions? All Infinispan server modules are based on the same pattern where the server backend creates an embedded Infinispan instance and if you start multiple backends, they can form a cluster and share/distribute state if configured to do so. The server types below primarily differ in the type of listener endpoint used to handle incoming connections.

Here's a brief summary of the available server endpoints.

- **Hot Rod Server Module** - This module is an implementation of the [Hot Rod binary protocol](#) backed by Infinispan which allows clients to do dynamic load balancing and failover and smart routing.
 - A [variety of clients](#) exist for this protocol.
 - If your clients are running Java, this should be your defacto server module choice because it allows for dynamic load balancing and failover. This means that Hot Rod clients can dynamically detect changes in the topology of Hot Rod servers as long as these are clustered, so when new nodes join or leave, clients update their Hot Rod server topology view. On top of that, when Hot Rod servers are configured with distribution, clients can detect where a particular key resides and so they can route requests smartly.
 - Load balancing and failover is dynamically provided by Hot Rod client implementations using information provided by the server.

- **REST Server Module** - The REST server, which is distributed as a WAR file, can be deployed in any servlet container to allow Infinispan to be accessed via a RESTful HTTP interface.
 - To connect to it, you can use any HTTP client out there and there're tons of different client implementations available out there for pretty much any language or system.
 - This module is particularly recommended for those environments where HTTP port is the only access method allowed between clients and servers.
 - Clients wanting to load balance or failover between different Infinispan REST servers can do so using any standard HTTP load balancer such as [mod_cluster](#) . It's worth noting though these load balancers maintain a static view of the servers in the backend and if a new one was to be added, it would require manual update of the load balancer.
- **Memcached Server Module** - This module is an implementation of the [Memcached text protocol](#) backed by Infinispan.
 - To connect to it, you can use any of the [existing Memcached clients](#) which are pretty diverse.
 - As opposed to Memcached servers, Infinispan based Memcached servers can actually be clustered and hence they can replicate or distribute data using consistent hash algorithms around the cluster. So, this module is particularly of interest to those users that want to provide failover capabilities to the data stored in Memcached servers.
 - In terms of load balancing and failover, there're a few clients that can load balance or failover given a static list of server addresses (perl's Cache::Memcached for example) but any server addition or removal would require manual intervention.
- **Websocket Server Module** - This module enables Infinispan to be accessed over a [Websocket](#) interface via a Javascript API.
 - This module is very specifically designed for Javascript clients and so that is the only client implementation available.
 - This module is particularly suited for developers wanting to enable access to Infinispan instances from their Javascript codebase.
 - Since websockets work on the same HTTP port, any HTTP load balancer would do to load balance and failover.
 - This module is **EXPERIMENTAL!** Beware!

21.4. Using Hot Rod Server

The Infinispan Server distribution contains a server module that implements Infinispan's custom binary protocol called Hot Rod. The protocol was designed to enable faster client/server interactions compared to other existing text based protocols and to allow clients to make more intelligent decisions with regards to load balancing, failover and even data location operations. Please refer to Infinispan Server's [documentation](#) for instructions on how to configure and run a HotRod server.

21.4.1. Hot Rod Protocol

The following articles provides detailed information about each version of the custom TCP client/server Hot Rod protocol.

- [Hot Rod Protocol 1.0](#)
- [Hot Rod Protocol 1.1](#)
- [Hot Rod Protocol 1.2](#)
- [Hot Rod Protocol 1.3](#)
- [Hot Rod Protocol 2.0](#)
- [Hot Rod Protocol 2.1](#)
- [Hot Rod Protocol 2.2](#)
- [Hot Rod Protocol 2.3](#)
- [Hot Rod Protocol 2.4](#)
- [Hot Rod Protocol 2.5](#)

Hot Rod Protocol 1.0



Infinispan versions

This version of the protocol is implemented since Infinispan 4.1.0.Final



All key and values are sent and stored as byte arrays. Hot Rod makes no assumptions about their types.

Some clarifications about the other types:

- vInt : Variable-length integers are defined defined as compressed, positive integers where the high-order bit of each byte indicates whether more bytes need to be read. The low-order seven bits are appended as increasingly more significant bits in the resulting integer value making it efficient to decode. Hence, values from zero to 127 are stored in a single byte, values from 128 to 16,383 are stored in two bytes, and so on:

Value	First byte	Second byte	Third byte
0	00000000		
1	00000001		
2	00000010		
...			
127	01111111		
128	10000000	00000001	
129	10000001	00000001	
130	10000010	00000001	
...			

Value	First byte	Second byte	Third byte
16,383	11111111	01111111	
16,384	10000000	10000000	00000001
16,385	10000001	10000000	00000001
...			

- signed vInt: The vInt above is also able to encode negative values, but will always use the maximum size (5 bytes) no matter how small the encoded value is. In order to have a small payload for negative values too, signed vInts uses ZigZag encoding on top of the vInt encoding. More details [here](#)
- vLong : Refers to unsigned variable length long values similar to vInt but applied to longer values. They're between 1 and 9 bytes long.
- String : Strings are always represented using UTF-8 encoding.

Request Header

The header for a request is composed of:

Table 7. Request header

Field Name	Size	Value
Magic	1 byte	0xA0 = request
Message ID	vLong	ID of the message that will be copied back in the response. This allows for hot rod clients to implement the protocol in an asynchronous way.
Version	1 byte	Infinispan hot rod server version. In this particular case, this is 10

Field Name	Size	Value
Opcode	1 byte	Request operation code: 0x01 = put (since 1.0) 0x03 = get (since 1.0) 0x05 = putIfAbsent (since 1.0) 0x07 = replace (since 1.0) 0x09 = replaceIfUnmodified (since 1.0) 0x0B = remove (since 1.0) 0x0D = removeIfUnmodified (since 1.0) 0x0F = containsKey (since 1.0) 0x11 = getWithVersion (since 1.0) 0x13 = clear (since 1.0) 0x15 = stats (since 1.0) 0x17 = ping (since 1.0) 0x19 = bulkGet (since 1.2) 0x1B = getWithMetadata (since 1.2) 0x1D = bulkGetKeys (since 1.2) 0x1F = query (since 1.3) 0x21 = authMechList (since 2.0) 0x23 = auth (since 2.0) 0x25 = addClientListener (since 2.0) 0x27 = removeClientListener (since 2.0) 0x29 = size (since 2.0) 0x2B = exec (since 2.1) 0x2D = putAll (since 2.1) 0x2F = getAll (since 2.1) 0x31 = iterationStart (since 2.3) 0x33 = iterationNext (since 2.3) 0x35 = iterationEnd (since 2.3)
Cache Name Length	vInt	Length of cache name. If the passed length is 0 (followed by no cache name), the operation will interact with the default cache.
Cache Name	string	Name of cache on which to operate. This name must match the name of predefined cache in the Infinispan configuration file.
Flags	vInt	A variable length number representing flags passed to the system. Each flags is represented by a bit. Note that since this field is sent as variable length, the most significant bit in a byte is used to determine whether more bytes need to be read, hence this bit does not represent any flag. Using this model allows for flags to be combined in a short space. Here are the current values for each flag: 0x0001 = force return previous value
Client Intelligence	1 byte	This byte hints the server on the client capabilities: 0x01 = basic client, interested in neither cluster nor hash information 0x02 = topology-aware client, interested in cluster information 0x03 = hash-distribution-aware client, that is interested in both cluster and hash information

Field Name	Size	Value
Topology Id	vInt	This field represents the last known view in the client. Basic clients will only send 0 in this field. When topology-aware or hash-distribution-aware clients will send 0 until they have received a reply from the server with the current view id. Afterwards, they should send that view id until they receive a new view id in a response.
Transaction Type	1 byte	This is a 1 byte field, containing one of the following well-known supported transaction types (For this version of the protocol, the only supported transaction type is 0): 0 = Non-transactional call, or client does not support transactions. The subsequent TX_ID field will be omitted. 1 = X/Open XA transaction ID (XID). This is a well-known, fixed-size format.
Transaction Id	byte array	The byte array uniquely identifying the transaction associated to this call. Its length is determined by the transaction type. If transaction type is 0, no transaction id will be present.

Response Header

The header for a response is composed of:

Table 8. Response header

Field Name	Size	Value
Magic	1 byte	0xA1 = response
Message ID	vLong	ID of the message, matching the request for which the response is sent.

Field Name	Size	Value
Opcode	1 byte	Response operation code: 0x02 = put (since 1.0) 0x04 = get (since 1.0) 0x06 = putIfAbsent (since 1.0) 0x08 = replace (since 1.0) 0x0A = replaceIfUnmodified (since 1.0) 0x0C = remove (since 1.0) 0x0E = removeIfUnmodified (since 1.0) 0x10 = containsKey (since 1.0) 0x12 = getWithVersion (since 1.0) 0x14 = clear (since 1.0) 0x16 = stats (since 1.0) 0x18 = ping (since 1.0) 0x1A = bulkGet (since 1.0) 0x1C = getWithMetadata (since 1.2) 0x1E = bulkGetKeys (since 1.2) 0x20 = query (since 1.3) 0x22 = authMechList (since 2.0) 0x24 = auth (since 2.0) 0x26 = addClientListener (since 2.0) 0x28 = removeClientListener (since 2.0) 0x2A = size (since 2.0) 0x2C = exec (since 2.1) 0x2E = putAll (since 2.1) 0x30 = getAll (since 2.1) 0x32 = iterationStart (since 2.3) 0x34 = iterationNext (since 2.3) 0x36 = iterationEnd (since 2.3) 0x50 = error (since 1.0)
Status	1 byte	Status of the response, possible values: 0x00 = No error 0x01 = Not put/removed/replaced 0x02 = Key does not exist 0x81 = Invalid magic or message id 0x82 = Unknown command 0x83 = Unknown version 0x84 = Request parsing error 0x85 = Server Error 0x86 = Command timed out
Topology Change Marker	string	This is a marker byte that indicates whether the response is prepended with topology change information. When no topology change follows, the content of this byte is 0. If a topology change follows, its contents are 1.



Exceptional error status responses, those that start with 0x8 ..., are followed by the length of the error message (as a vInt) and error message itself as String.

Topology Change Headers

The following section discusses how the response headers look for topology-aware or hash-distribution-aware clients when there's been a cluster or view formation change. Note that it's the server that makes the decision on whether it sends back the new topology based on the current topology id and the one the client sent. If they're different, it will send back the new topology.

Topology-Aware Client Topology Change Header

This is what topology-aware clients receive as response header when a topology change is sent back:

Field Name	Size	Value
Response header with topology change marker	variable	See previous section.
Topology Id	vInt	Topology ID
Num servers in topology	vInt	Number of Infinispan Hot Rod servers running within the cluster. This could be a subset of the entire cluster if only a fraction of those nodes are running Hot Rod servers.
m1: Host/IP length	vInt	Length of hostname or IP address of individual cluster member that Hot Rod client can use to access it. Using variable length here allows for covering for hostnames, IPv4 and IPv6 addresses.
m1: Host/IP address	string	String containing hostname or IP address of individual cluster member that Hot Rod client can use to access it.
m1: Port	2 bytes (Unsigned Short)	Port that Hot Rod clients can use to communicate with this cluster member.
m2: Host/IP length	vInt	
m2: Host/IP address	string	
m2: Port	2 bytes (Unsigned Short)	
...etc		

Distribution-Aware Client Topology Change Header

This is what hash-distribution-aware clients receive as response header when a topology change is sent back:

Field Name	Size	Value
Response header with topology change marker	variable	See previous section.

Field Name	Size	Value
Topology Id	vInt	Topology ID
Num Key Owners	2 bytes (Unsigned Short)	Globally configured number of copies for each Infinispan distributed key
Hash Function Version	1 byte	Hash function version, pointing to a specific hash function in use. See Hot Rod hash functions for details.
Hash space size	vInt	Modulus used by Infinispan for for all module arithmetic related to hash code generation. Clients will likely require this information in order to apply the correct hash calculation to the keys.
Num servers in topology	vInt	Number of Infinispan Hot Rod servers running within the cluster. This could be a subset of the entire cluster if only a fraction of those nodes are running Hot Rod servers.
m1: Host/IP length	vInt	Length of hostname or IP address of individual cluster member that Hot Rod client can use to access it. Using variable length here allows for covering for hostnames, IPv4 and IPv6 addresses.
m1: Host/IP address	string	String containing hostname or IP address of individual cluster member that Hot Rod client can use to access it.
m1: Port	2 bytes (Unsigned Short)	Port that Hot Rod clients can use to communicate with this cluster member.
m1: Hashcode	4 bytes	32 bit integer representing the hashcode of a cluster member that a Hot Rod client can use to identify in which cluster member a key is located having applied the CSA to it.
m2: Host/IP length	vInt	
m2: Host/IP address	string	
m2: Port	2 bytes (Unsigned Short)	
m2: Hashcode	4 bytes	
...etc		

It's important to note that since hash headers rely on the consistent hash algorithm used by the server and this is a factor of the cache interacted with, hash-distribution-aware headers can only be returned to operations that target a particular cache. Currently ping command does not target any cache (this is to change as per [ISPN-424](#)), hence calls to ping command with hash-topology-aware client settings will return a hash-distribution-aware header with "Num Key Owners", "Hash Function Version", "Hash space size" and each individual host's hash code all set to 0. This type of header will also be returned as response to operations with hash-topology-aware client settings that are targeting caches that are not configured with distribution.

Operations

Get (0x03)/Remove (0x0B)/ContainsKey (0x0F)/GetWithVersion (0x11)

Common request format:

Field Name	Size	Value
Header	variable	Request header
Key Length	vInt	Length of key. Note that the size of a vint can be up to 5 bytes which in theory can produce bigger numbers than Integer.MAX_VALUE. However, Java cannot create a single array that's bigger than Integer.MAX_VALUE, hence the protocol is limiting vint array lengths to Integer.MAX_VALUE.
Key	byte array	Byte array containing the key whose value is being requested.

Get response (0x04):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if key retrieved 0x02 = if key does not exist
Value Length	vInt	If success, length of value
Value	byte array	If success, the requested value

Remove response (0x0C):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if key removed 0x02 = if key does not exist
Previous value Length	vInt	If force return previous value flag was sent in the request and the key was removed, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.
Previous value	byte array	If force return previous value flag was sent in the request and the key was removed, previous value.

ContainsKey response (0x10):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if key exists 0x02 = if key does not exist

GetWithVersion response (0x12):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if key retrieved 0x02 = if key does not exist
Entry Version	8 bytes	Unique value of an existing entry's modification. The protocol does not mandate that entry_version values are sequential. They just need to be unique per update at the key level.
Value Length	vInt	If success, length of value
Value	byte array	If success, the requested value

BulkGet

Request (0x19):

Field Name	Size	Value
Header	variable	Request header
Entry count	vInt	Maximum number of Infinispan entries to be returned by the server (entry == key + associated value). Needed to support CacheLoader.load(int). If 0 then all entries are returned (needed for CacheLoader.loadAll()).

Response (0x20):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, data follows
More	1 byte	One byte representing whether more entries need to be read from the stream. So, when it's set to 1, it means that an entry follows, whereas when it's set to 0, it's the end of stream and no more entries are left to read. For more information on BulkGet look here
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
Value 1 Length	vInt	Length of value
Value 1	byte array	Retrieved value
More	1 byte	
Key 2 Length	vInt	
Key 2	byte array	

Field Name	Size	Value
Value 2 Length	vInt	
Value 2	byte array	
... etc		

Put (0x01)/PutIfAbsent (0x05)/Replace (0x07)

Common request format:

Field Name	Size	Value
Header	variable	Request header
Key Length	vInt	Length of key. Note that the size of a vint can be up to 5 bytes which in theory can produce bigger numbers than Integer.MAX_VALUE. However, Java cannot create a single array that's bigger than Integer.MAX_VALUE, hence the protocol is limiting vint array lengths to Integer.MAX_VALUE.
Key	byte array	Byte array containing the key whose value is being requested.
Lifespan	vInt	Number of seconds that a entry during which the entry is allowed to life. If number of seconds is bigger than 30 days, this number of seconds is treated as UNIX time and so, represents the number of seconds since 1/1/1970. If set to 0, lifespan is unlimited.
Max Idle	vInt	Number of seconds that a entry can be idle before it's evicted from the cache. If 0, no max idle time.
Value Length	vInt	Length of value
Value	byte-array	Value to be stored

Put response (0x02):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if stored
Previous value Length	vInt	If force return previous value flag was sent in the request and the key was put, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.
Previous value	byte array	If force return previous value flag was sent in the request and the key was put, previous value.

Replace response (0x08):

Field Name	Size	Value
Header	variable	Response header

Field Name	Size	Value
Response status	1 byte	0x00 = success, if stored 0x01 = if store did not happen because key does not exist
Previous value Length	vInt	If force return previous value flag was sent in the request, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.
Previous value	byte array	If force return previous value flag was sent in the request and the key was replaced, previous value.

PutIfAbsent response (0x06):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if stored 0x01 = if store did not happen because key was present
Previous value Length	vInt	If force return previous value flag was sent in the request, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.
Previous value	byte array	If force return previous value flag was sent in the request and the key was replaced, previous value.

ReplaceIfUnmodified

Request (0x09):

Field Name	Size	Value
Header	variable	Request header
Key Length	vInt	Length of key. Note that the size of a vint can be up to 5 bytes which in theory can produce bigger numbers than Integer.MAX_VALUE. However, Java cannot create a single array that's bigger than Integer.MAX_VALUE, hence the protocol is limiting vint array lengths to Integer.MAX_VALUE.
Key	byte array	Byte array containing the key whose value is being requested.
Lifespan	vInt	Number of seconds that a entry during which the entry is allowed to life. If number of seconds is bigger than 30 days, this number of seconds is treated as UNIX time and so, represents the number of seconds since 1/1/1970. If set to 0, lifespan is unlimited.
Max Idle	vInt	Number of seconds that a entry can be idle before it's evicted from the cache. If 0, no max idle time.
Entry Version	8 bytes	Use the value returned by GetWithVersion operation.
Value Length	vInt	Length of value

Field Name	Size	Value
Value	byte-array	Value to be stored

Response (0x0A):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if replaced 0x01 = if replace did not happen because key had been modified 0x02 = if not replaced because if key does not exist
Previous value Length	vInt	If force return previous value flag was sent in the request, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.
Previous value	byte array	If force return previous value flag was sent in the request and the key was replaced, previous value.

RemoveIfUnmodified

Request (0x0D):

Field Name	Size	Value
Header	variable	Request header
Key Length	vInt	Length of key. Note that the size of a vint can be up to 5 bytes which in theory can produce bigger numbers than Integer.MAX_VALUE. However, Java cannot create a single array that's bigger than Integer.MAX_VALUE, hence the protocol is limiting vint array lengths to Integer.MAX_VALUE.
Key	byte array	Byte array containing the key whose value is being requested.
Entry Version	8 bytes	Use the value returned by GetWithVersion operation.

Response (0x0E):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if removed 0x01 = if remove did not happen because key had been modified 0x02 = if not removed because key does not exist
Previous value Length	vInt	If force return previous value flag was sent in the request, the length of the previous value will be returned. If the key does not exist, value length would be 0. If no flag was sent, no value length would be present.

Field Name	Size	Value
Previous value	byte array	If force return previous value flag was sent in the request and the key was removed, previous value.

Clear

Request (0x13):

Field Name	Size	Value
Header	variable	Request header

Response (0x14):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if cleared

PutAll

Bulk operation to put all key value entries into the cache at the same time.

Request (0x2D):

Field Name	Size	Value
Header	variable	Request header
Lifespan	vInt	Number of seconds that provided entries are allowed to live. If number of seconds is bigger than 30 days, this number of seconds is treated as UNIX time and so, represents the number of seconds since 1/1/1970. If set to 0, lifespan is unlimited.
Max Idle	vInt	Number of seconds that each entry can be idle before it's evicted from the cache. If 0, no max idle time.
Entry count	vInt	How many entries are being inserted
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
Value 1 Length	vInt	Length of value
Value 1	byte array	Retrieved value
Key 2 Length	vInt	
Key 2	byte array	
Value 2 Length	vInt	
Value 2	byte array	

Field Name	Size	Value
... continues until entry count is reached		

Response (0x2E):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if all put

GetAll

Bulk operation to get all entries that map to a given set of keys.

Request (0x2F):

Field Name	Size	Value
Header	variable	Request header
Key count	vInt	How many keys to find entries for
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
Key 2 Length	vInt	
Key 2	byte array	
... continues until key count is reached		

Response (0x30):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	
Entry count	vInt	How many entries are being returned
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
Value 1 Length	vInt	Length of value
Value 1	byte array	Retrieved value
Key 2 Length	vInt	

Field Name	Size	Value
Key 2	byte array	
Value 2 Length	vInt	
Value 2	byte array	
... continues until entry count is reached		0x00 = success, if the get returned successfully

Stats

Returns a summary of all available statistics. For each statistic returned, a name and a value is returned both in String UTF-8 format. The supported stats are the following:

Name	Explanation
timeSinceStart	Number of seconds since Hot Rod started.
currentNumberOfEntries	Number of entries currently in the Hot Rod server.
totalNumberOfEntries	Number of entries stored in Hot Rod server.
stores	Number of put operations.
retrievals	Number of get operations.
hits	Number of get hits.
misses	Number of get misses.
removeHits	Number of removal hits.
removeMisses	Number of removal misses.

Request (0x15):

Field Name	Size	Value
Header	variable	Request header

Response (0x16):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if stats retrieved
Number of stats	vInt	Number of individual stats returned.
Name 1 length	vInt	Length of named statistic.
Name 1	string	String containing statistic name.
Value 1 length	vInt	Length of value field.

Field Name	Size	Value
Value 1	string	String containing statistic value.
Name 2 length	vInt	
Name 2	string	
Value 2 length	vInt	
Value 2	String	
...etc		

Ping

Application level request to see if the server is available.

Request (0x17):

Field Name	Size	Value
Header	variable	Request header

Response (0x18):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if no errors

Error Handling

Error response (0x50)

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x8x = error response code
Error Message Length	vInt	Length of error message
Error Message	string	Error message. In the case of 0x84 , this error field contains the latest version supported by the hot rod server. Length is defined by total body length.

Multi-Get Operations

A multi-get operation is a form of get operation that instead of requesting a single key, requests a set of keys. The Hot Rod protocol does not include such operation but remote Hot Rod clients could easily implement this type of operations by either parallelizing/pipelining individual get requests. Another possibility would be for remote clients to use async or non-blocking get requests. For example, if a client wants N keys, it could send N async get requests and then wait for all the replies. Finally, multi-get is not to be confused with bulk-get operations. In bulk-gets, either all or a

number of keys are retrieved, but the client does not know which keys to retrieve, whereas in multi-get, the client defines which keys to retrieve.

Example - Put request

- Coded request

Byte	0	1	2	3	4	5	6	7
8	0xA0	0x09	0x41	0x01	0x07	0x4D ('M')	0x79 ('y')	0x43 ('C')
16	0x61 ('a')	0x63 ('c')	0x68 ('h')	0x65 ('e')	0x00	0x03	0x00	0x00
24	0x00	0x05	0x48 ('H')	0x65 ('e')	0x6C ('l')	0x6C ('l')	0x6F ('o')	0x00
32	0x00	0x05	0x57 ('W')	0x6F ('o')	0x72 ('r')	0x6C ('l')	0x64 ('d')	

- Field explanation

Field Name	Value	Field Name	Value
Magic (0)	0xA0	Message Id (1)	0x09
Version (2)	0x41	Opcode (3)	0x01
Cache name length (4)	0x07	Cache name(5-11)	'MyCache'
Flag (12)	0x00	Client Intelligence (13)	0x03
Topology Id (14)	0x00	Transaction Type (15)	0x00
Transaction Id (16)	0x00	Key field length (17)	0x05
Key (18 - 22)	'Hello'	Lifespan (23)	0x00
Max idle (24)	0x00	Value field length (25)	0x05
Value (26-30)	'World'		

- Coded response

Byte	0	1	2	3	4	5	6	7
8	0xA1	0x09	0x01	0x00	0x00			

- Field Explanation

Field Name	Value	Field Name	Value
Magic (0)	0xA1	Message Id (1)	0x09
Opcode (2)	0x01	Status (3)	0x00
Topology change marker (4)	0x00		

Hot Rod Protocol 1.1



Infinispan versions

This version of the protocol is implemented since Infinispan 5.1.0.FINAL

Request Header

The `version` field in the header is updated to `11`.

Distribution-Aware Client Topology Change Header



Updated for 1.1

This section has been modified to be more efficient when talking to distributed caches with virtual nodes enabled.

This is what hash-distribution-aware clients receive as response header when a topology change is sent back:

Field Name	Size	Value
Response header with topology change marker	variable	See previous section.
Topology Id	vInt	Topology ID
Num Key Owners	2 bytes (Unsigned Short)	Globally configured number of copies for each Infinispan distributed key
Hash Function Version	1 byte	Hash function version, pointing to a specific hash function in use. See Hot Rod hash functions for details.
Hash space size	vInt	Modulus used by Infinispan for for all module arithmetic related to hash code generation. Clients will likely require this information in order to apply the correct hash calculation to the keys.
Num servers in topology	vInt	Number of Infinispan Hot Rod servers running within the cluster. This could be a subset of the entire cluster if only a fraction of those nodes are running Hot Rod servers.
Num Virtual Nodes Owners	vInt	Field added in version 1.1 of the protocol that represents the number of configured virtual nodes. If no virtual nodes are configured or the cache is not configured with distribution, this field will contain 0.
m1: Host/IP length	vInt	Length of hostname or IP address of individual cluster member that Hot Rod client can use to access it. Using variable length here allows for covering for hostnames, IPv4 and IPv6 addresses.
m1: Host/IP address	string	String containing hostname or IP address of individual cluster member that Hot Rod client can use to access it.

Field Name	Size	Value
m1: Port	2 bytes (Unsigned Short)	Port that Hot Rod clients can use to communicate with this cluster member.
m1: Hashcode	4 bytes	32 bit integer representing the hashcode of a cluster member that a Hot Rod client can use to identify in which cluster member a key is located having applied the CSA to it.
m2: Host/IP length	vInt	
m2: Host/IP address	string	
m2: Port	2 bytes (Unsigned Short)	
m2: Hashcode	4 bytes	
...etc		

Server node hash code calculation

Adding support for virtual nodes has made version 1.0 of the Hot Rod protocol impractical due to bandwidth it would have taken to return hash codes for all virtual nodes in the clusters (this number could easily be in the millions). So, as of version 1.1 of the Hot Rod protocol, clients are given the base hash id or hash code of each server, and then they have to calculate the real hash position of each server both with and without virtual nodes configured. Here are the rules clients should follow when trying to calculate a node's hash code:

1. With *virtual nodes disabled* : Once clients have received the base hash code of the server, they need to normalize it in order to find the exact position of the hash wheel. The process of normalization involves passing the base hash code to the hash function, and then do a small calculation to avoid negative values. The resulting number is the node's position in the hash wheel:

```
public static int getNormalizedHash(int nodeBaseHashCode, Hash hashFct) {
    return hashFct.hash(nodeBaseHashCode) & Integer.MAX_VALUE; // make sure no negative
    numbers are involved.
}
```

2. With *virtual nodes enabled* : In this case, each node represents N different virtual nodes, and to calculate each virtual node's hash code, we need to take the the range of numbers between 0 and N-1 and apply the following logic:

- For virtual node with 0 as id, use the technique used to retrieve a node's hash code, as shown in the previous section.
- For virtual nodes from 1 to N-1 ids, execute the following logic:

```
public static int virtualNodeHashCode(int nodeBaseHashCode, int id, Hash hashFct) {
    int virtualNodeBaseHashCode = id;
    virtualNodeBaseHashCode = 31 * virtualNodeBaseHashCode + nodeBaseHashCode;
    return getNormalizedHash(virtualNodeBaseHashCode, hashFct);
}
```

Hot Rod Protocol 1.2



Infinispan versions

This version of the protocol is implemented since Infinispan 5.2.0.Final. Since Infinispan 5.3.0, HotRod supports encryption via SSL. However, since this only affects the transport, the version number of the protocol has not been incremented.

Request Header

The **version** field in the header is updated to **12**.

Two new request operation codes have been added:

- 0x1B = getWithMetadata request
- 0x1D = bulkKeysGet request

Two new flags have been added too:

- 0x0002= use cache-level configured default lifespan
- 0x0004= use cache-level configured default max idle

Response Header

Two new response operation codes have been added:

- 0x1C = getWithMetadata response
- 0x1E = bulkKeysGet response

Operations

GetWithMetadata

Request (0x1B):

Field Name	Size	Value
Header	variable	Request header

Field Name	Size	Value
Key Length	vInt	Length of key. Note that the size of a vint can be up to 5 bytes which in theory can produce bigger numbers than Integer.MAX_VALUE. However, Java cannot create a single array that's bigger than Integer.MAX_VALUE, hence the protocol is limiting vint array lengths to Integer.MAX_VALUE.
Key	byte array	Byte array containing the key whose value is being requested.

Response (0x1C):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, if key retrieved 0x02 = if key does not exist
Flag	1 byte	A flag indicating whether the response contains expiration information. The value of the flag is obtained as a bitwise OR operation between INFINITE_LIFESPAN (0x01) and INFINITE_MAXIDLE (0x02).
Created	Long	(optional) a Long representing the timestamp when the entry was created on the server. This value is returned only if the flag's INFINITE_LIFESPAN bit is not set.
Lifespan	vInt	(optional) a vInt representing the lifespan of the entry in seconds. This value is returned only if the flag's INFINITE_LIFESPAN bit is not set.
LastUsed	Long	(optional) a Long representing the timestamp when the entry was last accessed on the server. This value is returned only if the flag's INFINITE_MAXIDLE bit is not set.
MaxIdle	vInt	(optional) a vInt representing the maxIdle of the entry in seconds. This value is returned only if the flag's INFINITE_MAXIDLE bit is not set.
Entry Version	8 bytes	Unique value of an existing entry's modification. The protocol does not mandate that entry_version values are sequential. They just need to be unique per update at the key level.
Value Length	vInt	If success, length of value
Value	byte array	If success, the requested value

BulkKeysGet

Request (0x1D):

Field Name	Size	Value
Header	variable	Request header

Field Name	Size	Value
Scope	vInt	<p>0 = Default Scope - This scope is used by RemoteCache.keySet() method. If the remote cache is a distributed cache, the server launch a stream operation to retrieve all keys from all of the nodes. (Remember, a topology-aware Hot Rod Client could be load balancing the request to any one node in the cluster). Otherwise, it'll get keys from the cache instance local to the server receiving the request (that is because the keys should be the same across all nodes in a replicated cache).</p> <p>1 = Global Scope - This scope behaves the same to Default Scope.</p> <p>2 = Local Scope - In case when remote cache is a distributed cache, the server will not launch a stream operation to retrieve keys from all nodes. Instead, it'll only get keys local from the cache instance local to the server receiving the request.</p>

Response (0x1E):

Field Name	Size	Value
Header	variable	Response header
Response status	1 byte	0x00 = success, data follows
More	1 byte	One byte representing whether more keys need to be read from the stream. So, when it's set to 1, it means that an entry follows, whereas when it's set to 0, it's the end of stream and no more entries are left to read. For more information on BulkGet look here
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
More	1 byte	
Key 2 Length	vInt	
Key 2	byte array	
... etc		

Hot Rod Protocol 1.3



Infinispan versions

This version of the protocol is implemented since Infinispan 6.0.0.Final.

Request Header

The **version** field in the header is updated to **13**.

A new request operation code has been added:

- 0x1F = query request

Response Header

A new response operation code has been added:

- 0x20 = query response

Operations

Query

Request (0x1F):

Field Name	Size	Value
Header	variable	Request header
Query Length	vInt	The length of the protobuf encoded query object
Query	byte array	Byte array containing the protobuf encoded query object, having a length specified by previous field.

Response (0x20):

Field Name	Size	Value
Header	variable	Response header
Response payload Length	vInt	The length of the protobuf encoded response object
Response payload	byte array	Byte array containing the protobuf encoded response object, having a length specified by previous field.

As of Infinispan 6.0, the query and response objects are specified by the protobuf message types 'org.infinispan.client.hotrod.impl.query.QueryRequest' and 'org.infinispan.client.hotrod.impl.query.QueryResponse' defined in [remote-query/remote-query-client/src/main/resources/org/infinispan/query/remote/client/query.proto](#). These definitions could change in future Infinispan versions, but as long as these evolutions will be kept backward compatible (according to the rules defined [here](#)) no new Hot Rod protocol version will be introduced to accommodate this.

Hot Rod Protocol 2.0



Infinispan versions

This version of the protocol is implemented since Infinispan 7.0.0.Final.

Request Header

The request header no longer contains **Transaction Type** and **Transaction ID** elements since they're not in use, and even if they were in use, there are several operations for which they would not make sense, such as **ping** or **stats** commands. Once transactions are implemented, the protocol version will be upped, with the necessary changes in the request header.

The **version** field in the header is updated to **20**.

Two new flags have been added:

- 0x0008 = operation skips loading from configured cache loader.
- 0x0010 = operation skips indexing. Only relevant when the query module is enabled for the cache

The following new request operation codes have been added:

- 0x21 = auth mech list request
- 0x23 = auth request
- 0x25 = add client remote event listener request
- 0x27 = remove client remote event listener request
- 0x29 = size request

Response Header

The following new response operation codes have been added:

- 0x22 = auth mech list response
- 0x24 = auth mech response
- 0x26 = add client remote event listener response
- 0x28 = remove client remote event listener response
- 0x2A = size response

Two new error codes have also been added to enable clients more intelligent decisions, particularly when it comes to fail-over logic:

- 0x87 = Node suspected. When a client receives this error as response, it means that the node that responded had an issue sending an operation to a third node, which was suspected. Generally, requests that return this error should be failed-over to other nodes.
- 0x88 = Illegal lifecycle state. When a client receives this error as response, it means that the server-side cache or cache manager are not available for requests because either stopped, they're stopping or similar situation. Generally, requests that return this error should be failed-over to other nodes.

Some adjustments have been made to the responses for the following commands in order to better handle response decoding without the need to keep track of the information sent. More precisely, the way previous values are parsed has changed so that the status of the command response provides clues on whether the previous value follows or not. More precisely:

- Put response returns **0x03** status code when put was successful and previous value follows.
- PutIfAbsent response returns **0x04** status code only when the putIfAbsent operation failed because the key was present and its value follows in the response. If the putIfAbsent worked, there would have not been a previous value, and hence it does not make sense returning

anything extra.

- Replace response returns **0x03** status code only when replace happened and the previous or replaced value follows in the response. If the replace did not happen, it means that the cache entry was not present, and hence there's no previous value that can be returned.
- ReplaceIfUnmodified returns **0x03** status code only when replace happened and the previous or replaced value follows in the response.
- ReplaceIfUnmodified returns **0x04** status code only when replace did not happen as a result of the key being modified, and the modified value follows in the response.
- Remove returns **0x03** status code when the remove happened and the previous or removed value follows in the response. If the remove did not occur as a result of the key not being present, it does not make sense sending any previous value information.
- RemoveIfUnmodified returns **0x03** status code only when remove happened and the previous or replaced value follows in the response.
- RemoveIfUnmodified returns **0x04** status code only when remove did not happen as a result of the key being modified, and the modified value follows in the response.

Distribution-Aware Client Topology Change Header

In Infinispan 5.2, virtual nodes based consistent hashing was abandoned and instead segment based consistent hash was implemented. In order to satisfy the ability for Hot Rod clients to find data as reliably as possible, Infinispan has been transforming the segment based consistent hash to fit Hot Rod 1.x protocol. Starting with version 2.0, a brand new distribution-aware topology change header has been implemented which supports segment based consistent hashing suitably and provides 100% data location guarantees.

Field Name	Size	Value
Response header with topology change marker	variable	
Topology Id	vInt	Topology ID
Num servers in topology	vInt	Number of Infinispan Hot Rod servers running within the cluster. This could be a subset of the entire cluster if only a fraction of those nodes are running Hot Rod servers.
m1: Host/IP length	vInt	Length of hostname or IP address of individual cluster member that Hot Rod client can use to access it. Using variable length here allows for covering for hostnames, IPv4 and IPv6 addresses.
m1: Host/IP address	string	String containing hostname or IP address of individual cluster member that Hot Rod client can use to access it.
m1: Port	2 bytes (Unsigned Short)	Port that Hot Rod clients can use to communicate with this cluster member.
m2: Host/IP length	vInt	

Field Name	Size	Value
m2: Host/IP address	string	
m2: Port	2 bytes (Unsigned Short)	
...	...	
Hash Function Version	1 byte	Hash function version, pointing to a specific hash function in use. See Hot Rod hash functions for details.
Num segments in topology	vInt	Total number of segments in the topology
Number of owners in segment	1 byte	This can be either 0, 1 or 2 owners.
First owner's index	vInt	Given the list of all nodes, the position of this owner in this list. This is only present if number of owners for this segment is 1 or 2.
Second owner's index	vInt	Given the list of all nodes, the position of this owner in this list. This is only present if number of owners for this segment is 2.

Given this information, Hot Rod clients should be able to recalculate all the hash segments and be able to find out which nodes are owners for each segment. Even though there could be more than 2 owners per segment, Hot Rod protocol limits the number of owners to send for efficiency reasons.

Operations

Auth Mech List

Request (0x21):

Field Name	Size	Value
Header	variable	Request header

Response (0x22):

Field Name	Size	Value
Header	variable	Response header
Mech count	vInt	The number of mechs
Mech 1	string	String containing the name of the SASL mech in its IANA-registered form (e.g. GSSAPI, CRAM-MD5, etc)
Mech 2	string	
...etc		

The purpose of this operation is to obtain the list of valid SASL authentication mechs supported by

the server. The client will then need to issue an Authenticate request with the preferred mech.

Authenticate

Request (0x23):

Field Name	Size	Value
Header	variable	Request header
Mech	string	String containing the name of the mech chosen by the client for authentication. Empty on the successive invocations
Response length	vInt	Length of the SASL client response
Response data	byte array	The SASL client response

Response (0x24):

Field Name	Size	Value
Header	variable	Response header
Completed	byte	0 if further processing is needed, 1 if authentication is complete
Challenge length	vInt	Length of the SASL server challenge
Challenge data	byte array	The SASL server challenge

The purpose of this operation is to authenticate a client against a server using SASL. The authentication process, depending on the chosen mech, might be a multi-step operation. Once complete the connection becomes authenticated

Add client listener for remote events

Request (0x25):

Field Name	Size	Value
Header	variable	Request header
Listener ID	byte array	Listener identifier
Include state	byte	When this byte is set to 1 , cached state is sent back to remote clients when either adding a cache listener for the first time, or when the node where a remote listener is registered changes in a clustered environment. When enabled, state is sent back as cache entry created events to the clients. If set to 0 , no state is sent back to the client when adding a listener, nor it gets state when the node where the listener is registered changes.
Key/value filter factory name	string	Optional name of the key/value filter factory to be used with this listener. The factory is used to create key/value filter instances which allow events to be filtered directly in the Hot Rod server, avoiding sending events that the client is not interested in. If no factory is to be used, the length of the string is 0 .

Field Name	Size	Value
Key/value filter factory parameter count	byte	The key/value filter factory, when creating a filter instance, can take an arbitrary number of parameters, enabling the factory to be used to create different filter instances dynamically. This count field indicates how many parameters will be passed to the factory. If no factory name was provided, this field is not present in the request.
Key/value filter factory parameter 1	byte array	First key/value filter factory parameter
Key/value filter factory parameter 2	byte array	Second key/value filter factory parameter
...		
Converter factory name	string	Optional name of the converter factory to be used with this listener. The factory is used to transform the contents of the events sent to clients. By default, when no converter is in use, events are well defined, according to the type of event generated. However, there might be situations where users want to add extra information to the event, or they want to reduce the size of the events. In these cases, a converter can be used to transform the event contents. The given converter factory name produces converter instances to do this job. If no factory is to be used, the length of the string is 0.
Converter factory parameter count	byte	The converter factory, when creating a converter instance, can take an arbitrary number of parameters, enabling the factory to be used to create different converter instances dynamically. This count field indicates how many parameters will be passed to the factory. If no factory name was provided, this field is not present in the request.
Converter factory parameter 1	byte array	First converter factory parameter
Converter factory parameter 2	byte array	Second converter factory parameter
...		

Response (0x26):

Field Name	Size	Value
Header	variable	Response header

Remove client listener for remote events

Request (0x27):

Field Name	Size	Value
Header	variable	Request header
Listener ID	byte array	Listener identifier

Response (0x28):

Field Name	Size	Value
Header	variable	Response header

Size

Request (0x29):

Field Name	Size	Value
Header	variable	Request header

Response (0x2A):

Field Name	Size	Value
Header	variable	Response header
Size	vInt	Size of the remote cache, which is calculated globally in the clustered set ups, and if present, takes cache store contents into account as well.

Exec

Request (0x2B):

Field Name	Size	Value
Header	variable	Request header
Script	string	Name of the script to execute
Parameter Count	vInt	The number of parameters
Parameter 1 Name	string	The name of the first parameter
Parameter 1 Length	vInt	The length of the first parameter
Parameter 1 Value	byte array	The value of the first parameter

Response (0x2C):

Field Name	Size	Value
Header	variable	Response header

Field Name	Size	Value
Response status	1 byte	0x00 = success, if execution completed successfully 0x85 = server error
Value Length	vInt	If success, length of return value
Value	byte array	If success, the result of the execution

Remote Events

Starting with Hot Rod 2.0, clients can register listeners for remote events happening in the server. Sending these events commences the moment a client adds a client listener for remote events.

Event Header:

Field Name	Size	Value
Magic	1 byte	0xA1 = response
Message ID	vLong	ID of event
Opcode	1 byte	Event type: 0x60 = cache entry created event 0x61 = cache entry modified event 0x62 = cache entry removed event 0x50 = error
Status	1 byte	Status of the response, possible values: 0x00 = No error
Topology Change Marker	1 byte	Since events are not associated with a particular incoming topology ID to be able to decide whether a new topology is required to be sent or not, new topologies will never be sent with events. Hence, this marker will always have 0 value for events.

Table 9. Cache entry created event

Field Name	Size	Value
Header	variable	Event header with 0x60 operation code
Listener ID	byte array	Listener for which this event is directed
Custom marker	byte	Custom event marker. For created events, this is 0.
Command retried	byte	Marker for events that are result of retried commands. If command is retried, it returns 1, otherwise 0.
Key	byte array	Created key
Version	long	Version of the created entry. This version information can be used to make conditional operations on this cache entry.

Table 10. Cache entry modified event

Field Name	Size	Value
Header	variable	Event header with 0x61 operation code
Listener ID	byte array	Listener for which this event is directed
Custom marker	byte	Custom event marker. For created events, this is 0.
Command retried	byte	Marker for events that are result of retried commands. If command is retried, it returns 1, otherwise 0.
Key	byte array	Modified key
Version	long	Version of the modified entry. This version information can be used to make conditional operations on this cache entry.

Table 11. Cache entry removed event

Field Name	Size	Value
Header	variable	Event header with 0x62 operation code
Listener ID	byte array	Listener for which this event is directed
Custom marker	byte	Custom event marker. For created events, this is 0.
Command retried	byte	Marker for events that are result of retried commands. If command is retried, it returns 1, otherwise 0.
Key	byte array	Removed key

Table 12. Custom event

Field Name	Size	Value
Header	variable	Event header with event specific operation code
Listener ID	byte array	Listener for which this event is directed
Custom marker	byte	Custom event marker. For custom events, this is 1.
Event data	byte array	Custom event data, formatted according to the converter implementation logic.

Hot Rod Protocol 2.1



Infinispan versions

This version of the protocol is implemented since Infinispan 7.1.0.Final.

Request Header

The **version** field in the header is updated to 21.

Operations

Add client listener for remote events

An extra byte parameter is added at the end which indicates whether the client prefers client

listener to work with raw binary data for filter/converter callbacks. If using raw data, its value is **1** otherwise **0**.

Request format:

Field Name	Size	Value
Header	variable	Request header
Listener ID	byte array	...
Include state	byte	...
Key/value filter factory parameter count	byte	...
...		
Converter factory name	string	...
Converter factory parameter count	byte	...
...		
Use raw data	byte	If filter/converter parameters should be raw binary, then 1 , otherwise 0 .

Custom event

Starting with Hot Rod 2.1, custom events can return raw data that the Hot Rod client should not try to unmarshall before passing it on to the user. The way this is transmitted to the Hot Rod client is by sending **2** as the custom event marker. So, the format of the custom event remains like this:

Field Name	Size	Value
Header	variable	Event header with event specific operation code
Listener ID	byte array	Listener for which this event is directed
Custom marker	byte	Custom event marker. For custom events whose event data needs to be unmarshalled before returning to user the value is 1 . For custom events that need to return the event data as-is to the user, the value is 2 .
Event data	byte array	Custom event data. If the custom marker is 1 , the bytes represent the marshalled version of the instance returned by the converter. If custom marker is 2 , it represents the byte array, as returned by the converter.

Hot Rod Protocol 2.2



Infinispan versions

This version of the protocol is implemented since Infinispan 8.0

Added support for different time units.

Operations

Put/PutAll/PutIfAbsent/Replace/ReplaceIfUnmodified

Common request format:

Field Name	Size	Value
TimeUnits	Byte	Time units of lifespan (first 4 bits) and maxIdle (last 4 bits). Special units DEFAULT and INFINITE can be used for default server expiration and no expiration respectively. Possible values: 0x00 = SECONDS 0x01 = MILLISECONDS 0x02 = NANOSECONDS 0x03 = MICROSECONDS 0x04 = MINUTES 0x05 = HOURS 0x06 = DAYS 0x07 = DEFAULT 0x08 = INFINITE
Lifespan	vLong	Duration which the entry is allowed to life. Only sent when time unit is not DEFAULT or INFINITE
Max Idle	vLong	Duration that each entry can be idle before it's evicted from the cache. Only sent when time unit is not DEFAULT or INFINITE

Hot Rod Protocol 2.3



Infinispan versions

This version of the protocol is implemented since Infinispan 8.0

Operations

Iteration Start

Request (0x31):

Field Name	Size	Value
Segments size	signed vInt	Size of the bitset encoding of the segments ids to iterate on. The size is the maximum segment id rounded to nearest multiple of 8. A value -1 indicates no segment filtering is to be done

Field Name	Size	Value
Segments	byte array	(Optional) Contains the segments ids bitset encoded, where each bit with value 1 represents a segment in the set. Byte order is little-endian. Example: segments [1,3,12,13] would result in the following encoding: 00001010 00110000 size: 16 bits first byte: represents segments from 0 to 7, from which 1 and 3 are set second byte: represents segments from 8 to 15, from which 12 and 13 are set More details in the java.util.BitSet implementation. Segments will be sent if the previous field is not negative
FilterConverter size	signed vInt	The size of the String representing a KeyValueFilterConverter factory name deployed on the server, or -1 if no filter will be used
FilterConverter	UTF-8 byte array	(Optional) KeyValueFilterConverter factory name deployed on the server. Present if previous field is not negative
BatchSize	vInt	number of entries to transfers from the server at one go

Response (0x32):

Field Name	Size	Value
IterationId	String	The unique id of the iteration

Iteration Next

Request (0x33):

Field Name	Size	Value
IterationId	String	The unique id of the iteration

Response (0x34):

Field Name	Size	Value
Finished segments size	vInt	size of the bitset representing segments that were finished iterating
Finished segments	byte array	bitset encoding of the segments that were finished iterating
Entry count	vInt	How many entries are being returned
Key 1 Length	vInt	Length of key
Key 1	byte array	Retrieved key
Value 1 Length	vInt	Length of value
Value 1	byte array	Retrieved value

Field Name	Size	Value
Key 2 Length	vInt	
Key 2	byte array	
Value 2 Length	vInt	
Value 2	byte array	
... continues until entry count is reached		

Iteration End

Request (0x35):

Field Name	Size	Value
IterationId	String	The unique id of the iteration

Response (0x36):

Header	variable	Response header
Response status	1 byte	0x00 = success, if execution completed successfully 0x05 = for non existent IterationId

Hot Rod Protocol 2.4



Infinispan versions

This version of the protocol is implemented since Infinispan 8.1

This Hot Rod protocol version adds three new status code that gives the client hints on whether the server has compatibility mode enabled or not:

- **0x06**: Success status and compatibility mode is enabled.
- **0x07**: Success status and return previous value, with compatibility mode is enabled.
- **0x08**: Not executed and return previous value, with compatibility mode is enabled.

The Iteration Start operation can optionally send parameters if a custom filter is provided and it's parametrised:

Operations

Iteration Start

Request (0x31):

Field Name	Size	Value
Segments size	signed vInt	same as protocol version 2.3.

Field Name	Size	Value
Segments	byte array	same as protocol version 2.3.
FilterConverter size	signed vInt	same as protocol version 2.3.
FilterConverter	UTF-8 byte array	same as protocol version 2.3.
Parameters size	byte	the number of params of the filter. Only present when FilterConverter is provided.
Parameters	byte[][]	an array of parameters, each parameter is a byte array. Only present if Parameters size is greater than 0.
BatchSize	vInt	same as protocol version 2.3.

The Iteration Next operation can optionally return projections in the value, meaning more than one value is contained in the same entry.

Iteration Next

Response (0x34):

Field Name	Size	Value
Finished segments size	vInt	same as protocol version 2.3.
Finished segments	byte array	same as protocol version 2.3.
Entry count	vInt	same as protocol version 2.3.
Number of value projections	vInt	Number of projections for the values. If 1, behaves like version protocol version 2.3.
Key1 Length	vInt	same as protocol version 2.3.
Key1	byte array	same as protocol version 2.3.
Value1 projection1 length	vInt	length of value1 first projection
Value1 projection1	byte array	retrieved value1 first projection
Value1 projection2 length	vInt	length of value2 second projection
Value1 projection2	byte array	retrieved value2 second projection
... continues until all projections for the value retrieved	Key2 Length	vInt
same as protocol version 2.3.	Key2	byte array

Field Name	Size	Value
same as protocol version 2.3.	Value2 projection1 length	vInt
length of value 2 first projection	Value2 projection1	byte array
retrieved value 2 first projection	Value2 projection2 length	vInt
length of value 2 second projection	Value2 projection2	byte array
retrieved value 2 second projection	... continues until entry count is reached	

1. Stats:

Statistics returned by previous Hot Rod protocol versions were local to the node where the Hot Rod operation had been called. Starting with 2.4, new statistics have been added which provide global counts for the statistics returned previously. If the Hot Rod is running in local mode, these statistics are not returned:

Name	Explanation
globalCurrentNumberOfEntries	Number of entries currently across the Hot Rod cluster.
globalStores	Total number of put operations across the Hot Rod cluster.
globalRetrievals	Total number of get operations across the Hot Rod cluster.
globalHits	Total number of get hits across the Hot Rod cluster.
globalMisses	Total number of get misses across the Hot Rod cluster.
globalRemoveHits	Total number of removal hits across the Hot Rod cluster.
globalRemoveMisses	Total number of removal misses across the Hot Rod cluster.

Hot Rod Protocol 2.5



Infinispan versions

This version of the protocol is implemented since Infinispan 8.2

This Hot Rod protocol version adds support for metadata retrieval along with entries in the iterator. It includes two changes:

- Iteration Start request includes an optional flag
- IterationNext operation may include metadata info for each entry if the flag above is set

Iteration Start

Request (0x31):

Field Name	Size	Value
Segments size	signed vInt	same as protocol version 2.4.
Segments	byte array	same as protocol version 2.4.
FilterConverter size	signed vInt	same as protocol version 2.4.
FilterConverter	UTF-8 byte array	same as protocol version 2.4.
Parameters size	byte	same as protocol version 2.4.
Parameters	byte[][]	same as protocol version 2.4.
BatchSize	vInt	same as protocol version 2.4.
Metadata	1 byte	1 if metadata is to be returned for each entry, 0 otherwise

Iteration Next

Response (0x34):

Field Name	Size	Value
Finished segments size	vInt	same as protocol version 2.4.
Finished segments	byte array	same as protocol version 2.4.
Entry count	vInt	same as protocol version 2.4.
Number of value projections	vInt	same as protocol version 2.4.
Metadata (entry 1)	1 byte	If set, entry has metadata associated
Expiration (entry 1)	1 byte	A flag indicating whether the response contains expiration information. The value of the flag is obtained as a bitwise OR operation between INFINITE_LIFESPAN (0x01) and INFINITE_MAXIDLE (0x02). Only present if the metadata flag above is set

Field Name	Size	Value
Created (entry 1)	Long	(optional) a Long representing the timestamp when the entry was created on the server. This value is returned only if the flag's INFINITE_LIFESPAN bit is not set.
Lifespan (entry 1)	vInt	(optional) a vInt representing the lifespan of the entry in seconds. This value is returned only if the flag's INFINITE_LIFESPAN bit is not set.
LastUsed (entry 1)	Long	(optional) a Long representing the timestamp when the entry was last accessed on the server. This value is returned only if the flag's INFINITE_MAXIDLE bit is not set.
MaxIdle (entry 1)	vInt	(optional) a vInt representing the maxIdle of the entry in seconds. This value is returned only if the flag's INFINITE_MAXIDLE bit is not set.
Entry Version (entry 1)	8 bytes	Unique value of an existing entry's modification. Only present if Metadata flag is set
Key 1 Length	vInt	same as protocol version 2.4.
Key 1	byte array	same as protocol version 2.4.
Value 1 Length	vInt	same as protocol version 2.4.
Value 1	byte array	same as protocol version 2.4.
Metadata (entry 2)	1 byte	Same as for entry 1
Expiration (entry 2)	1 byte	Same as for entry 1
Created (entry 2)	Long	Same as for entry 1
Lifespan (entry 2)	vInt	Same as for entry 1
LastUsed (entry 2)	Long	Same as for entry 1
MaxIdle (entry 2)	vInt	Same as for entry 1
Entry Version (entry 2)	8 bytes	Same as for entry 1
Key 2 Length	vInt	
Key 2	byte array	
Value 2 Length	vInt	
Value 2	byte array	
... continues until entry count is reached		

21.4.2. Hot Rod Hash Functions

Infinispan makes use of a consistent hash function to place nodes on a hash wheel, and to place keys of entries on the same wheel to determine where entries live.

In Infinispan 4.2 and earlier, the hash space was hardcoded to 10240, but since 5.0, the hash space is [Integer.MAX_INT](#) . Please note that since Hot Rod clients should not assume a particular hash space by default, every time a hash-topology change is detected, this value is sent back to the client via the Hot Rod protocol.

When interacting with Infinispan via the Hot Rod protocol, it is mandated that keys (and values) are byte arrays, to ensure platform neutral behavior. As such, smart-clients which are aware of hash distribution on the backend would need to be able to calculate the hash codes of such byte array keys, again in a platform-neutral manner. To this end, the hash functions used by Infinispan are versioned and documented, so that it can be re-implemented by non-Java clients if needed.

The version of the hash function in use is provided in the Hot Rod protocol, as the hash function version parameter.

1. Version 1 (single byte, 0x01) The initial version of the hash function in use is based on [Austin Appleby's MurmurHash 2.0 algorithm](#) , a fast, non-cryptographic hash that exhibits excellent distribution, collision resistance and avalanche behavior. The specific version of the algorithm used is the slightly slower, endian-neutral version that allows consistent behavior across both big- and little-endian CPU architectures. Infinispan's version also hard-codes the hash seed as -1. For details of the algorithm, please visit [Austin Appleby's MurmurHash 2.0 page](#). Other implementations are detailed on [Wikipedia](#) . This hash function was the default one used by the Hot Rod server until Infinispan 4.2.1. Since Infinispan 5.0, the server never uses hash version 1. Since Infinispan 9.0, the client ignores hash version 1.
2. Version 2 (single byte, 0x02) Since Infinispan 5.0, a new hash function is used by default which is based on [Austin Appleby's MurmurHash 3.0 algorithm](#). Detailed information about the hash function can be found in this [wiki](#). Compared to 2.0, it provides better performance and spread. Since Infinispan 7.0, the server only uses version 2 for HotRod 1.x clients.
3. Version 3 (single byte, 0x03) Since Infinispan 7.0, a new hash function is used by default. The function is still based on [wiki](#), but is also aware of the hash segments used in the server's [ConsistentHash](#).

21.4.3. Java Hot Rod client

Hot Rod is a binary, language neutral protocol. This article explains how a Java client can interact with a server via the Hot Rod protocol. A reference implementation of the protocol written in Java can be found in all Infinispan distributions, and this article focuses on the capabilities of this java client.



Looking for more clients? Visit [this website](#) for clients written in a variety of different languages.

Configuration

The Java Hot Rod client can be configured both programmatically and externally, through a configuration file.

The code snippet below illustrates the creation of a client instance using the available Java fluent API:

```
org.infinispan.client.hotrod.configuration.ConfigurationBuilder cb
    = new org.infinispan.client.hotrod.configuration.ConfigurationBuilder();
cb.tcpNoDelay(true)
  .connectionPool()
    .numTestsPerEvictionRun(3)
    .testOnBorrow(false)
    .testOnReturn(false)
    .testWhileIdle(true)
  .addServer()
    .host("localhost")
    .port(11222);
RemoteCacheManager rmc = new RemoteCacheManager(cb.build());
```

For a complete reference to the available configuration option please refer to the [ConfigurationBuilder](#)'s javadoc.

It is also possible to configure the Java Hot Rod client using an properties file, e.g.:

```

infinispan.client.hotrod.transport_factory =
org.infinispan.client.hotrod.impl.transport.tcp.TcpTransportFactory
infinispan.client.hotrod.server_list = 12{infinispanversion}.0.1:11222
infinispan.client.hotrod.marshaller =
org.infinispan.commons.marshall.jboss.GenericJBossMarshaller
infinispan.client.hotrod.async_executor_factory =
org.infinispan.client.hotrod.impl.async.DefaultAsyncExecutorFactory
infinispan.client.hotrod.default_executor_factory.pool_size = 1
infinispan.client.hotrod.default_executor_factory.queue_size = 10000
infinispan.client.hotrod.tcp_no_delay = true
infinispan.client.hotrod.request_balancing_strategy =
org.infinispan.client.hotrod.impl.transport.tcp.RoundRobinBalancingStrategy
infinispan.client.hotrod.key_size_estimate = 64
infinispan.client.hotrod.value_size_estimate = 512
infinispan.client.hotrod.force_return_values = false

## below is connection pooling config
maxActive=-1
maxTotal = -1
maxIdle = -1
whenExhaustedAction = 1
timeBetweenEvictionRunsMillis=120000
minEvictableIdleTimeMillis=300000
testWhileIdle = true
minIdle = 1

```

The properties file is then passed to one of constructors of [RemoteCacheManager](#). For a complete reference of the available configuration options for the properties file please refer to [RemoteCacheManager](#)'s javadoc.

Basic API

Below is a sample code snippet on how the client API can be used to store or retrieve information from a Hot Rod server using the Java Hot Rod client. It assumes that a Hot Rod server has been started bound to the default location (localhost:11222)


```
//API entry point, by default it connects to localhost:11222
CacheContainer cacheContainer = new RemoteCacheManager();

//obtain a handle to the remote default cache
Cache<String, String> cache = cacheContainer.getCache();

//now add something to the cache and make sure it is there
cache.put("car", "ferrari");
assert cache.get("car").equals("ferrari");

//remove the data
cache.remove("car");
assert !cache.containsKey("car") : "Value must have been removed!";
```

The client API maps the local API: [RemoteCacheManager](#) corresponds to [DefaultCacheManager](#) (both implement [CacheContainer](#)). This common API facilitates an easy migration from local calls to remote calls through Hot Rod: all one needs to do is switch between [DefaultCacheManager](#) and [RemoteCacheManager](#) - which is further simplified by the common [CacheContainer](#) interface that both inherit.

All keys can be retrieved from the remote cache (whether it's local, replicated, or distributed) by using `keySet()` method. If the remote cache is a distributed cache, the server will perform a distributed stream operation to retrieve all keys from clustered nodes, and return all keys to the client. Please use this method with care if there are large number of keys.

```
Set keys = remoteCache.keySet();
```

Alternatively, if memory is a concern, use the remote iterator api to retrieve entries from the server:

```

// Retrieve all entries in batches of 1000
int batchSize = 1000;
try (CloseableIterator<Entry<Object, Object>> iterator = remoteCache.retrieveEntries(
    null, batchSize)) {
    while(iterator.hasNext()) {
        // Do something
    }
}

// Filter by segment
Set<Integer> segments = ...
try (CloseableIterator<Entry<Object, Object>> iterator = remoteCache.retrieveEntries(
    null, segments, batchSize)) {
    while(iterator.hasNext()) {
        // Do something
    }
}

// Filter by custom filter
try (CloseableIterator<Entry<Object, Object>> iterator = remoteCache.retrieveEntries(
    "myFilterConverterFactory", segments, batchSize)) {
    while(iterator.hasNext()) {
        // Do something
    }
}

```

In order to use custom filters, it's necessary to deploy them first in the server. Follow the steps:

- Create a factory for the filter extending [KeyValueFilterConverterFactory](#), annotated with `@NamedFactory` containing the name of the factory, example:

```

import java.io.Serializable;

import org.infinispan.filter.AbstractKeyValueFilterConverter;
import org.infinispan.filter.KeyValueFilterConverter;
import org.infinispan.filter.KeyValueFilterConverterFactory;
import org.infinispan.filter.NamedFactory;
import org.infinispan.metadata.Metadata;

@NamedFactory(name = "myFilterConverterFactory")
public class MyKeyValueFilterConverterFactory implements
KeyValueFilterConverterFactory {

    @Override
    public KeyValueFilterConverter<String, SampleEntity1, SampleEntity2>
getFilterConverter() {
        return new MyKeyValueFilterConverter();
    }
    // Filter implementation. Should be serializable or externalizable for DIST caches
    static class MyKeyValueFilterConverter extends AbstractKeyValueFilterConverter
<String, SampleEntity1, SampleEntity2> implements Serializable {
        @Override
        public SampleEntity2 filterAndConvert(String key, SampleEntity1 entity, Metadata
metadata) {
            // returning null will case the entry to be filtered out
            // return SampleEntity2 will convert from the cache type SampleEntity1
        }
    }
}

```

- Create a jar with a `META-INF/services/org.infinispan.filter.KeyValueFilterConverterFactory` file and within it, write the fully qualified class name of the filter factory class implementation.
- Optional: If the filter uses custom key/value classes, these must be included in the JAR so that the filter can correctly unmarshall key and/or value instances.
- Deploy the JAR file in the Infinispan Server.

Versioned API

A `RemoteCacheManager` provides instances of `RemoteCache` interface that represents a handle to the named or default cache on the remote cluster. API wise, it extends the `Cache` interface to which it also adds some new methods, including the so called versioned API. Please find below some examples of this API [but to understand the motivation behind it, make sure you read this section](#).

The code snippet bellow depicts the usage of these versioned methods:

```
// To use the versioned API, remote classes are specifically needed
RemoteCacheManager remoteCacheManager = new RemoteCacheManager();
RemoteCache<String, String> cache = remoteCacheManager.getCache();

remoteCache.put("car", "ferrari");
RemoteCache.VersionedValue valueBinary = remoteCache.getVersioned("car");

// removal only takes place only if the version has not been changed
// in between. (a new version is associated with 'car' key on each change)
assert remoteCache.remove("car", valueBinary.getVersion());
assert !cache.containsKey("car");
```

In a similar way, for replace:

```
remoteCache.put("car", "ferrari");
RemoteCache.VersionedValue valueBinary = remoteCache.getVersioned("car");
assert remoteCache.replace("car", "lamborghini", valueBinary.getVersion());
```

For more details on versioned operations refer to [RemoteCache](#) 's javadoc.

Async API

This cool feature is "borrowed" from the Infinispan core and it is largely discussed [here](#)

Client Event Listener API

Starting with Infinispan 7.0, Java Hot Rod clients can register listeners to receive cache-entry level events. In 7.0, cache entry created, modified and removed events are supported.

Creating a Client Event Listener

Creating a client listener is very similar to embedded listeners, except that different annotations and event classes are used. Here's an example of a client listener that prints out each event received:

```

import org.infinispan.client.hotrod.annotation.*;
import org.infinispan.client.hotrod.event.*;

@ClientListener
public class EventPrintListener {

    @ClientCacheEntryCreated
    public void handleCreatedEvent(ClientCacheEntryCreatedEvent e) {
        System.out.println(e);
    }

    @ClientCacheEntryModified
    public void handleModifiedEvent(ClientCacheEntryModifiedEvent e) {
        System.out.println(e);
    }

    @ClientCacheEntryRemoved
    public void handleRemovedEvent(ClientCacheEntryRemovedEvent e) {
        System.out.println(e);
    }
}

```

`ClientCacheEntryCreatedEvent` and `ClientCacheEntryModifiedEvent` instances provide information on the affected key, and the version of the entry. This version can be used to invoke conditional operations on the server, such as `replaceWithVersion` or `removeWithVersion`.

`ClientCacheEntryRemovedEvent` events are only sent when the remove operation succeeds. In other words, if a remove operation is invoked but no entry is found or no entry should be removed, no event is generated. Users interested in removed events, even when no entry was removed, can develop event customization logic to generate such events. More information can be found in the [customizing client events section](#).

All `ClientCacheEntryCreatedEvent`, `ClientCacheEntryModifiedEvent` and `ClientCacheEntryRemovedEvent` event instances also provide a `boolean isCommandRetried()` method that will return true if the write command that caused this had to be retried again due to a topology change. This could be a sign that this event has been duplicated or another event was dropped and replaced (eg: `ClientCacheEntryModifiedEvent` replaced `ClientCacheEntryCreatedEvent`).

Once the client listener implementation has been created, it needs to be registered with the server. To do so, execute:

```

RemoteCache<?, ?> cache = ...
cache.addClientListener(new EventPrintListener());

```

Remove a Client Event Listener

When an client event listener is not needed any more, it can be removed:

```
EventPrintListener listener = ...
cache.removeClientListener(listener);
```

Filtering Client Events

In order to avoid inundating clients with events, users can provide filtering functionality to limit the number of events fired by the server for a particular client listener. To enable filtering, a cache event filter factory needs to be created that produces filter instances:

```
import org.infinispan.notifications.cachelistener.filter.CacheEventFilterFactory;
import org.infinispan.filter.NamedFactory;

@NamedFactory(name = "static-filter")
class StaticCacheEventFilterFactory implements CacheEventFilterFactory {
    @Override
    public CacheEventFilterFactory<Integer, String> getFilter(Object[] params) {
        return new StaticCacheEventFilter();
    }
}

// Serializable, Externalizable or marshallable with Infinispan Externalizers
// needed when running in a cluster
class StaticCacheEventFilter implements CacheEventFilter<Integer, String>,
Serializable {
    @Override
    public boolean accept(Integer key, String oldValue, Metadata oldMetadata,
        String newValue, Metadata newMetadata, EventType eventType) {
        if (key.equals(1)) // static key
            return true;

        return false;
    }
}
```

The cache event filter factory instance defined above creates filter instances which statically filter out all entries except the one whose key is **1**.

To be able to register a listener with this cache event filter factory, the factory has to be given a unique name, and the Hot Rod server needs to be plugged with the name and the cache event filter factory instance. Plugging the Infinispan Server with a custom filter involves the following steps:

1. Create a JAR file with the filter implementation within it.
2. Optional: If the cache uses custom key/value classes, these must be included in the JAR so that the callbacks can be executed with the correctly unmarshalled key and/or value instances. If the client listener has `useRawData` enabled, this is not necessary since the callback key/value instances will be provided in binary format.
3. Create a **META-**

`INF/services/org.infinispan.notifications.cachelistener.filter.CacheEventFilterFactory` file within the JAR file and within it, write the fully qualified class name of the filter class implementation.

4. Deploy the JAR file in the Infinispan Server.

On top of that, the client listener needs to be linked with this cache event filter factory by adding the factory's name to the `@ClientListener` annotation:

```
@ClientListener(filterFactoryName = "static-filter")
public class EventPrintListener { ... }
```

And, register the listener with the server:

```
RemoteCache<?, ?> cache = ...
cache.addClientListener(new EventPrintListener());
```

Dynamic filter instances that filter based on parameters provided when the listener is registered are also possible. Filters use the parameters received by the filter factories to enable this option. For example:

```

import org.infinispan.notifications.cachelistener.filter.CacheEventFilterFactory;
import org.infinispan.notifications.cachelistener.filter.CacheEventFilter;

class DynamicCacheEventFilterFactory implements CacheEventFilterFactory {
    @Override
    public CacheEventFilter<Integer, String> getFilter(Object[] params) {
        return new DynamicCacheEventFilter(params);
    }
}

// Serializable, Externalizable or marshallable with Infinispan Externalizers
// needed when running in a cluster
class DynamicCacheEventFilter implements CacheEventFilter<Integer, String>,
Serializable {
    final Object[] params;

    DynamicCacheEventFilter(Object[] params) {
        this.params = params;
    }

    @Override
    public boolean accept(Integer key, String oldValue, Metadata oldMetadata,
        String newValue, Metadata newMetadata, EventType eventType) {
        if (key.equals(params[0])) // dynamic key
            return true;

        return false;
    }
}

```

The dynamic parameters required to do the filtering are provided when the listener is registered:

```

RemoteCache<?, ?> cache = ...
cache.addClientListener(new EventPrintListener(), new Object[]{1}, null);

```



Filter instances have to be marshallable when they are deployed in a cluster so that the filtering can happen right where the event is generated, even if the event is generated in a different node to where the listener is registered. To make them marshallable, either make them extend `Serializable`, `Externalizable`, or provide a custom `Externalizer` for them.

Customizing Client Events contents

The events generated by default contain just enough information to make the event relevant but they avoid cramming too much information in order to reduce the cost of sending them. Optionally, the information shipped in the events can be customised in order to contain more information, such as values, or to contain even less information. This customization is done with `CacheEventConverter` instances generated by a `CacheEventConverterFactory`:


```

import org.infinispan.notifications.cachelistener.filter.CacheEventConverterFactory;
import org.infinispan.notifications.cachelistener.filter.CacheEventConverter;
import org.infinispan.filter.NamedFactory;

@NamedFactory(name = "static-converter")
class StaticConverterFactory implements CacheEventConverterFactory {
    final CacheEventConverter<Integer, String, CustomEvent> staticConverter = new
StaticCacheEventConverter();
    public CacheEventConverter<Integer, String, CustomEvent> getConverter(final
Object[] params) {
        return staticConverter;
    }
}

// Serializable, Externalizable or marshallable with Infinispan Externalizers
// needed when running in a cluster
class StaticCacheEventConverter implements CacheEventConverter<Integer, String,
CustomEvent>, Serializable {
    public CustomEvent convert(Integer key, String oldValue, Metadata oldMetadata,
String newValue, Metadata newMetadata, EventType eventType) {
        return new CustomEvent(key, newValue);
    }
}

// Needs to be Serializable, Externalizable or marshallable with Infinispan
Externalizers
// regardless of cluster or local caches
static class CustomEvent implements Serializable {
    final Integer key;
    final String value;
    CustomEvent(Integer key, String value) {
        this.key = key;
        this.value = value;
    }
}
}

```

In the example above, the converter generates a new custom event which includes the value as well as the key in the event. This will result in bigger event payloads compared with default events, but if combined with filtering, it can reduce its network bandwidth cost.



The target type of the converter must be either `Serializable` or `Externalizable`. In this particular case of converters, providing an Externalizer will not work by default since the default Hot Rod client marshaller does not support them.

Handling custom events requires a slightly different client listener implementation to the one demonstrated previously. To be more precise, it needs to handle `ClientCacheEntryCustomEvent` instances:

```
import org.infinispan.client.hotrod.annotation.*;
import org.infinispan.client.hotrod.event.*;

@ClientListener
public class CustomEventPrintListener {

    @ClientCacheEntryCreated
    @ClientCacheEntryModified
    @ClientCacheEntryRemoved
    public void handleCustomEvent(ClientCacheEntryCustomEvent<CustomEvent> e) {
        System.out.println(e);
    }
}
```

The `ClientCacheEntryCustomEvent` received in the callback exposes the custom event via `getEventData` method, and the `getType` method provides information on whether the event generated was as a result of cache entry creation, modification or removal.

Similar to filtering, to be able to register a listener with this converter factory, the factory has to be given a unique name, and the Hot Rod server needs to be plugged with the name and the cache event converter factory instance. Plugging the Infinispan Server with an event converter involves the following steps:

1. Create a JAR file with the converter implementation within it.
2. Optional: If the cache uses custom key/value classes, these must be included in the JAR so that the callbacks can be executed with the correctly unmarshalled key and/or value instances. If the client listener has `useRawData` enabled, this is not necessary since the callback key/value instances will be provided in binary format.
3. Create a `META-INF/services/org.infinispan.notifications.cachelistener.filter.CacheEventConverterFactory` file within the JAR file and within it, write the fully qualified class name of the converter class implementation.
4. Deploy the JAR file in the Infinispan Server.

On top of that, the client listener needs to be linked with this converter factory by adding the factory's name to the `@ClientListener` annotation:

```
@ClientListener(converterFactoryName = "static-converter")
public class CustomEventPrintListener { ... }
```

And, register the listener with the server:

```
RemoteCache<?, ?> cache = ...
cache.addClientListener(new CustomEventPrintListener());
```

Dynamic converter instances that convert based on parameters provided when the listener is registered are also possible. Converters use the parameters received by the converter factories to enable this option. For example:

```
import org.infinispan.notifications.cachelistener.filter.CacheEventConverterFactory;
import org.infinispan.notifications.cachelistener.filter.CacheEventConverter;

@NamedFactory(name = "dynamic-converter")
class DynamicCacheEventConverterFactory implements CacheEventConverterFactory {
    public CacheEventConverter<Integer, String, CustomEvent> getConverter(final
Object[] params) {
        return new DynamicCacheEventConverter(params);
    }
}

// Serializable, Externalizable or marshallable with Infinispan Externalizers needed
when running in a cluster
class DynamicCacheEventConverter implements CacheEventConverter<Integer, String,
CustomEvent>, Serializable {
    final Object[] params;

    DynamicCacheEventConverter(Object[] params) {
        this.params = params;
    }

    public CustomEvent convert(Integer key, String oldValue, Metadata oldMetadata,
String newValue, Metadata newMetadata, EventType eventType) {
        // If the key matches a key given via parameter, only send the key information
        if (params[0].equals(key))
            return new CustomEvent(key, null);

        return new CustomEvent(key, newValue);
    }
}
```

The dynamic parameters required to do the conversion are provided when the listener is registered:

```
RemoteCache<?, ?> cache = ...
cache.addClientListener(new EventPrintListener(), null, new Object[]{1});
```



Converter instances have to be marshallable when they are deployed in a cluster, so that the conversion can happen right where the event is generated, even if the event is generated in a different node to where the listener is registered. To make them marshallable, either make them extend `Serializable`, `Externalizable`, or provide a custom `Externalizer` for them.

Filtering and Customizing Client Events

If you want to do both event filtering and customization, it's easier to implement `org.infinispan.notifications.cachelistener.filter.CacheEventFilterConverter` which allows both filter and customization to happen in a single step. For convenience, it's recommended to extend `org.infinispan.notifications.cachelistener.filter.AbstractCacheEventFilterConverter` instead of implementing `org.infinispan.notifications.cachelistener.filter.CacheEventFilterConverter` directly. For example:

```
import org.infinispan.notifications.cachelistener.filter.CacheEventConverterFactory;
import org.infinispan.notifications.cachelistener.filter.CacheEventConverter;

@NamedFactory(name = "dynamic-filter-converter")
class DynamicCacheEventFilterConverterFactory implements
CacheEventFilterConverterFactory {
    public CacheEventFilterConverter<Integer, String, CustomEvent> getFilterConverter
(final Object[] params) {
        return new DynamicCacheEventFilterConverter(params);
    }
}

// Serializable, Externalizable or marshallable with Infinispan Externalizers needed
// when running in a cluster
//
class DynamicCacheEventFilterConverter extends AbstractCacheEventFilterConverter
<Integer, String, CustomEvent>, Serializable {
    final Object[] params;

    DynamicCacheEventFilterConverter(Object[] params) {
        this.params = params;
    }

    public CustomEvent filterAndConvert(Integer key, String oldValue, Metadata
oldMetadata,
        String newValue, Metadata newMetadata, EventType eventType) {
        // If the key matches a key given via parameter, only send the key information
        if (params[0].equals(key))
            return new CustomEvent(key, null);

        return new CustomEvent(key, newValue);
    }
}
```

Similar to filters and converters, to be able to register a listener with this combined filter/converter factory, the factory has to be given a unique name via the `@NamedFactory` annotation, and the Hot Rod server needs to be plugged with the name and the cache event converter factory instance. Plugging the Infinispan Server with an event converter involves the following steps:

1. Create a JAR file with the converter implementation within it.

2. Optional: If the cache uses custom key/value classes, these must be included in the JAR so that the callbacks can be executed with the correctly unmarshalled key and/or value instances. If the client listener has `useRawData` enabled, this is not necessary since the callback key/value instances will be provided in binary format.
3. Create a `META-INF/services/org.infinispan.notifications.cachelistener.filter.CacheEventFilterConverterFactory` file within the JAR file and within it, write the fully qualified class name of the converter class implementation.
4. Deploy the JAR file in the Infinispan Server.

From a client perspective, to be able to use the combined filter and converter class, the client listener must define the same filter factory and converter factory names, e.g.:

```
@ClientListener(filterFactoryName = "dynamic-filter-converter", converterFactoryName =  
"dynamic-filter-converter")  
public class CustomEventPrintListener { ... }
```

The dynamic parameters required in the example above are provided when the listener is registered via either filter or converter parameters. If filter parameters are non-empty, those are used, otherwise, the converter parameters:

```
RemoteCache<?, ?> cache = ...  
cache.addClientListener(new CustomEventPrintListener(), new Object[]{1}, null);
```

Event Marshalling

Hot Rod servers store data as byte arrays, but in spite of that, Java Hot Rod client users can still develop `CacheEventConverter` or `CacheEventFilter` instances that worked on typed objects. The way this is done is by making the Hot Rod server use the same marshaller as the one used by the Java Hot Rod client. This is enabled by default.

However, users are free to plug a custom `org.infinispan.commons.marshall.Marshaller` implementation in order to marshall objects using alternative techniques to the one used by default by the Hot Rod Java client. For example, a user might want to marshall objects using Google Protocol Buffers.

As indicated in the [Marshalling data](#) section, Hot Rod Java clients can be configured to use a different `org.infinispan.commons.marshall.Marshaller` instance. If doing this and deploying `CacheEventConverter` or `CacheEventFilter` instances, the same marshaller instance needs to be deployed in the server so that callback parameters of `CacheEventConverter` or `CacheEventFilter` instances can be correctly unmarshalled.

To deploy a Marshaller instance server-side, follow a similar method to the one used to deploy `CacheEventConverter` or `CacheEventFilter` instances:

1. Create a JAR file with the converter implementation within it.
2. Create a `META-INF/services/org.infinispan.commons.marshall.Marshaller` file within the JAR file

and within it, write the fully qualified class name of the marshaller class implementation.

3. Deploy the JAR file in the Infinispan Server.

Note that the Marshaller could be deployed in either a separate jar, or in the same jar as the `CacheEventConverter` and/or `CacheEventFilter` instances. Also, currently deployment of a single `org.infinispan.commons.marshall.Marshaller` instance is supported. If multiple marshaller instances are deployed, warning messages will be displayed as reminder indicating which marshaller instance will be used.

Client Event Listener State Consumption

Client listener annotation has an optional `includeCurrentState` attribute that specifies whether state will be sent to the client when the listener is added or when there's a failover of the listener.

By default, `includeCurrentState` is false, but if set to true and a client listener is added in a cache already containing data, the server iterates over the cache contents and sends an event for each entry to the client as a `ClientCacheEntryCreated` (or custom event if configured). This allows clients to build some local data structures based on the existing content. Once the content has been iterated over, events are received as normal, as cache updates are received. If the cache is clustered, the entire cluster wide contents are iterated over.

`includeCurrentState` also controls whether state is received when the node where the client event listener is registered fails and it's moved to a different node. The next section discusses this topic in depth.

Client Event Listener Failure Handling

When a Hot Rod client registers a client listener, it does so in a single node in a cluster. If that node fails, the Java Hot Rod client detects that transparently and fails over all listeners registered in the node that failed to another node.

During this fail over the client might miss some events. To avoid missing these events, the client listener annotation contains an optional parameter called `includeCurrentState` which if set to true, when the failover happens, the cache contents can iterated over and `ClientCacheEntryCreated` events (or custom events if configured) are generated. By default, `includeCurrentState` is set to false.

Java Hot Rod clients can be made aware of such fail over event by adding a callback to handle it:

```
@ClientCacheFailover
public void handleFailover(ClientCacheFailoverEvent e) {
    ...
}
```

This is very useful in use cases where the client has cached some data, and as a result of the fail over, taking in account that some events could be missed, it could decide to clear any locally cached data when the fail over event is received, with the knowledge that after the fail over event, it will receive events for the contents of the entire cache.

Near Caching

The Java Hot Rod client can be optionally configured with a near cache, which means that the Hot Rod client can keep a local cache that stores recently used data. Enabling near caching can significantly improve the performance of read operations `get` and `getVersioned` since data can potentially be located locally within the Hot Rod client instead of having to go remote.

To enable near caching, the user must set the near cache mode to `INVALIDATED`. By doing that near cache is populated upon retrievals from the server via calls to `get` or `getVersioned` operations. When near cached entries are updated or removed server-side, the cached near cache entries are invalidated. If a key is requested after it's been invalidated, it'll have to be re-fetched from the server.

When near cache is enabled, its size must be configured by defining the maximum number of entries to keep in the near cache. When the maximum is reached, near cached entries are evicted using a least-recently-used (LRU) algorithm. If providing 0 or a negative value, it is assumed that the near cache is unbounded.



Users should be careful when configuring near cache to be unbounded since it shifts the responsibility to keep the near cache's size within the boundaries of the client JVM to the user.

The Hot Rod client's near cache mode is configured using the `NearCacheMode` enumeration and calling:

```
import org.infinispan.client.hotrod.configuration.ConfigurationBuilder;
import org.infinispan.client.hotrod.configuration.NearCacheMode;
...

// Unbounded invalidated near cache
ConfigurationBuilder unbounded = new ConfigurationBuilder();
unbounded.nearCache().mode(NearCacheMode.INVALIDATED).maxEntries(-1);

// Bounded invalidated near cache
ConfigurationBuilder bounded = new ConfigurationBuilder();
bounded.nearCache().mode(NearCacheMode.INVALIDATED).maxEntries(100);
```



Near caches work the same way for local caches as they do for clustered caches, but in a clustered cache scenario, if the server node sending the near cache notifications to the Hot Rod client goes down, the Hot Rod client transparently fails over to another node in the cluster, clearing the near cache along the way.

Unsupported methods

Some of the `Cache` methods are not being supported by the `RemoteCache`. Calling one of these methods results in an `UnsupportedOperationException` being thrown. Most of these methods do not make sense on the remote cache (e.g. listener management operations), or correspond to methods that are not supported by local cache as well (e.g. `containsValue`). Another set of unsupported

operations are some of the atomic operations inherited from [ConcurrentMap](#) :

```
boolean remove(Object key, Object value);
boolean replace(Object key, Object value);
boolean replace(Object key, Object oldValue, Object value);
```

[RemoteCache](#) offers alternative versioned methods for these atomic operations, that are also network friendly, by not sending the whole value object over the network, but a version identifier. See the section on versioned API.

Each one of these unsupported operation is documented in the [RemoteCache](#) javadoc.

21.4.4. Return values

There is a set of methods that alter a cached entry and return the previous existing value, e.g.:

```
V remove(Object key);
V put(K key, V value);
```

By default on RemoteCache, these operations return null even if such a previous value exists. This approach reduces the amount of data sent over the network. However, if these return values are needed they can be enforced on a per invocation basis using flags:

```
cache.put("aKey", "initialValue");
assert null == cache.put("aKey", "aValue");
assert "aValue".equals(cache.withFlags(Flag.FORCE_RETURN_VALUE).put("aKey",
    "newValue"));
```

This default behavior can be changed through `force-return-value=true` configuration parameter (see configuration section below).

21.4.5. Intelligence

HotRod defines three level of intelligence for the clients:

1. basic client, interested in neither cluster nor hash information
2. topology-aware client, interested in cluster information
3. hash-distribution-aware client, that is interested in both cluster and hash information

The java client supports all 3 levels of intelligence. It is transparently notified whenever a new server is added/removed from the HotRod cluster. At startup it only needs to know the address of one HotRod server (ip:host). On connection to the server the cluster topology is piggybacked to the client, and all further requests are being dispatched to all available servers. Any further topology change is also piggybacked.

Distribution-aware client

Another aspect of the 3rd level of intelligence is the fact that it is hash-distribution-aware. This means that, for each operation, the client chooses the most appropriate remote server to go to: the data owner. As an example, for a `put(k,v)` operation, the client calculates `k`'s hash value and knows exactly on which server the data resides on. Then it picks up a tcp connection to that particular server and dispatches the operation to it. This means less burden on the server side which would otherwise need to lookup the value based on the key's hash. It also results in a quicker response from the server, as an additional network roundtrip is skipped. This hash-distribution-aware aspect is only relevant to the distributed HotRod clusters and makes no difference for replicated server deployments.

21.4.6. Request Balancing

Request balancing is only relevant when the server side is configured with replicated infinispn cluster (on distributed clusters the hash-distribution-aware client logic is used, as discussed in the previous paragraph). Because the client is topology-aware, it knows the list of available servers at all the time. Request balancing has to do with how the client dispatches requests to the available servers.

The default strategy is round-robin: requests are being dispatched to all existing servers in a circular manner. E.g. given a cluster of servers `{s1, s2, s3}` here is how request will be dispatched:

```
CacheContainer cacheContainer = new RemoteCacheManager();
Cache<String, String> cache = cacheContainer.getCache();

cache.put("key1", "aValue"); //this goes to s1
cache.put("key2", "aValue"); //this goes to s2
String value = cache.get("key1"); //this goes to s3

cache.remove("key2"); //this is dispatched to s1 again, and so on...
```

Custom types of balancing policies can be defined by implementing the [FailoverRequestBalancingStrategy](#) and by specifying it through the `infinispn.client.hotrod.request-balancing-strategy` configuration property. Please refer to configuration section for more details on this.

WARNING: [FailoverRequestBalancingStrategy](#)

is a newly added interface in Infinispn 7.0. Previously, users had to provide implementations of [FailoverRequestBalancingStrategy](#), which it has been deprecated starting with Infinispn 7.0.

Persistent connections

In order to avoid creating a TCP connection on each request (which is a costly operation), the client keeps a pool of persistent connections to all the available servers and it reuses these connections whenever it is possible. The validity of the connections is checked using an async thread that iterates over the connections in the pool and sends a HotRod ping command to the server. By using this connection validation process the client is being proactive: there's a high chance for broken

connections to be found while being idle in the pool and no on actual request from the application.

The number of connections per server, total number of connections, how long should a connection be kept idle in the pool before being closed - all these (and more) can be configured. Please refer to the javadoc of [RemoteCacheManager](#) for a list of all possible configuration elements.

Marshalling data

The Hot Rod client allows one to plug in a custom marshaller for transforming user objects into byte arrays and the other way around. This transformation is needed because of Hot Rod's binary nature - it doesn't know about objects.

The marshaller can be plugged through the "marshaller" configuration element (see Configuration section): the value should be the fully qualified name of a class implementing the [Marshaller](#) interface. This is a optional parameter, if not specified it defaults to the [GenericJBossMarshaller](#) - a highly optimized implementation based on the [JBoss Marshalling](#) library.

Since version 6.0, there's a new marshaller available to Java Hot Rod clients based on Protostream which generates portable payloads. You can find more information about it [here](#)

Statistics

Various server usage statistics can be obtained through the [RemoteCache](#) .stats() method. This returns a [ServerStatistics](#) object - please refer to javadoc for details on the available statistics.

Configuration

All the configurations are passed to the RemoteCacheManager's constructor as key-value pairs, through an instance of [java.util.Properties](#) or reference to a .properties file. Please refer to the javadoc of RemoteCacheManager for a exhaustive list of the possible configuration elements.

Multi-Get Operations

The Java Hot Rod client does not provide multi-get functionality out of the box but clients can build it themselves with the given APIs.

More info

It is highly recommended to read the following Javadocs (this is pretty much all the public API of the client):

- [RemoteCacheManager](#)
- [RemoteCache](#)

21.4.7. Failover capabilities

Hot Rod clients' capabilities to keep up with topology changes helps with request balancing and more importantly, with the ability to failover operations if one or several of the servers fail.

Some of the conditional operations mentioned above, including [putIfAbsent](#), [replace](#) with and

without version, and conditional `remove` have strict method return guarantees, as well as those operations where returning the previous value is forced.

In spite of failures, these methods return values need to be guaranteed, and in order to do so, it's necessary that these methods are not applied partially in the cluster in the event of failure. For example, imagine a `replace()` operation called in a server for key=k1 with `Flag.FORCE_RETURN_VALUE`, whose current value is `A` and the replace wants to set it to `B`. If the replace fails, it could happen that some servers contain `B` and others contain `A`, and during the failover, the original `replace()` could end up returning `B`, if the replace failovers to a node where `B` is set, or could end up returning `A`.

To avoid this kind of situations, whenever Java Hot Rod client users want to use conditional operations, or operations whose previous value is required, it's important that the cache is configured to be transactional in order to avoid incorrect conditional operations or return values.

Site Cluster Failover

On top of the in-cluster failover, Hot Rod clients are also able to failover to different clusters, which could be represented as an independent site.



This feature was introduced in Infinispan 8.1.

The way site cluster failover works is that if all the main cluster nodes are not available, the client checks to see if any other clusters have been defined in which cases it tries to failover to the alternative cluster. If the failover succeeds, the client will remain connected to the alternative cluster until this becomes unavailable, in which case it'll try any other clusters defined, and ultimately, it'll try the original server settings.

To configure a cluster in the Hot Rod client, one host/port pair details must be provided for each of the clusters configured. For example:

```
org.infinispan.client.hotrod.configuration.ConfigurationBuilder cb
    = new org.infinispan.client.hotrod.configuration.ConfigurationBuilder();
cb.addCluster().addClusterNode("remote-cluster-host", 11222);
RemoteCacheManager rmc = new RemoteCacheManager(cb.build());
```



Remember that regardless of the cluster definitions, the initial server(s) configuration must be provided unless the initial servers can be resolved using the default server host and port details.

Manual Site Cluster Switch

As well as supporting automatic site cluster failover, Java Hot Rod clients can also switch between site clusters manually by calling `RemoteCacheManager`'s `switchToCluster(clusterName)` and `switchToDefaultCluster()`.

Using `switchToCluster(clusterName)`, users can force a client to switch to one of the clusters pre-defined in the Hot Rod client configuration. To switch to the initial servers defined in the client configuration, call `switchToDefaultCluster()`.

21.4.8. Consistent Concurrent Updates With Hot Rod Versioned Operations

Data structures, such as Infinispan [Cache](#), that are accessed and modified concurrently can suffer from data consistency issues unless there're mechanisms to guarantee data correctness. Infinispan Cache, since it implements [ConcurrentMap](#), provides operations such as [link:http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#replace\(K, V\)\[conditional replace\]](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#replace(K, V)[conditional replace]), [link:http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#putIfAbsent\(K, V\)\[putIfAbsent\]](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#putIfAbsent(K, V)[putIfAbsent]), and [link:http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#remove\(java.lang.Object, java.lang.Object\)\[conditional remove\]](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#remove(java.lang.Object, java.lang.Object)[conditional remove]) to its clients in order to guarantee data correctness. It even allows clients to operate against cache instances within JTA transactions, hence providing the necessary data consistency guarantees.

However, when it comes to [Hot Rod protocol](#) backed servers, clients do not yet have the ability to start remote transactions but they can call instead versioned operations to mimic the conditional methods provided by the embedded Infinispan cache instance API. Let's look at a real example to understand how it works.

Data Consistency Problem

Imagine you have two ATMs that connect using Hot Rod to a bank where an account's balance is stored. Two closely followed operations to retrieve the latest balance could return 500 CHF (swiss francs) as shown below:

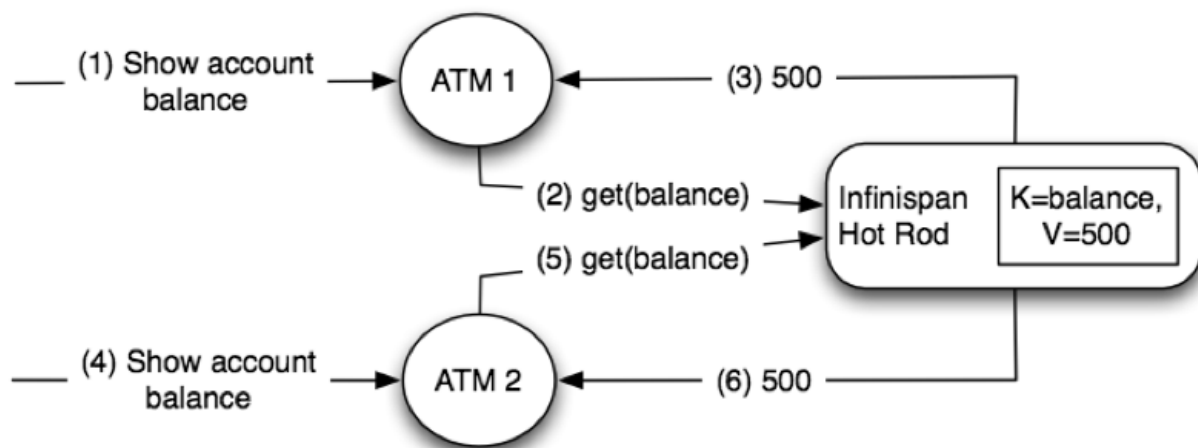
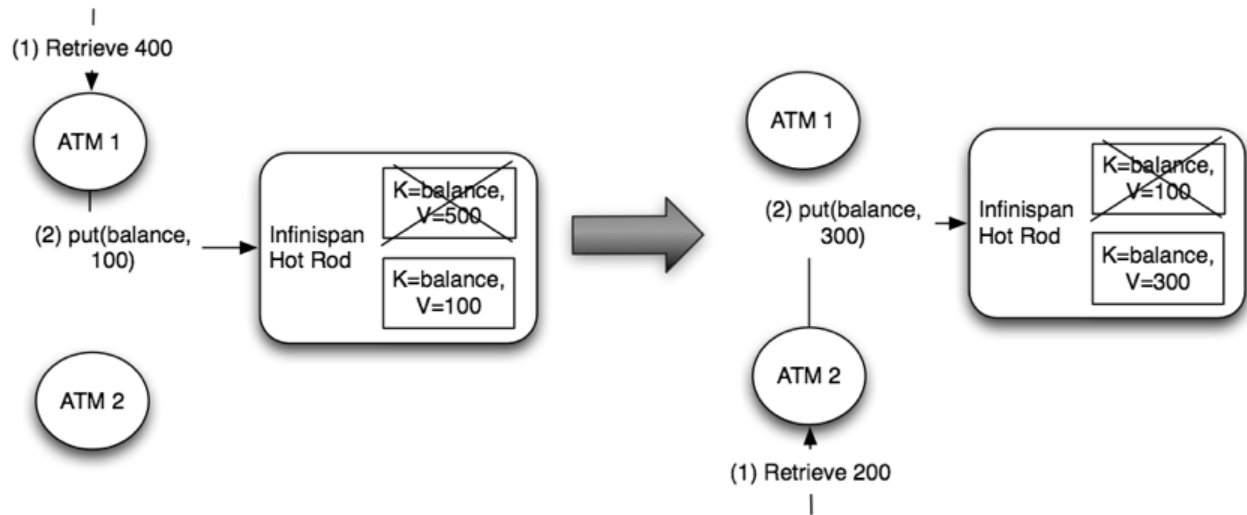


Figure 24. Concurrent readers

Next a customer connects to the first ATM and requests 400 CHF to be retrieved. Based on the last value read, the ATM could calculate what the new balance is, which is 100 CHF, and request a put with this new value. Let's imagine now that around the same time another customer connects to the ATM and requests 200 CHF to be retrieved. Let's assume that the ATM thinks it has the latest balance and based on its calculations it sets the new balance to 300 CHF:



Obviously, this would be wrong. Two concurrent updates have resulted in an incorrect account balance. The second update should not have been allowed since the balance the second ATM had was incorrect. Even if the ATM would have retrieved the balance before calculating the new balance, someone could have updated between the new balance being retrieved and the update. Before finding out how to solve this issue in a client-server scenario with Hot Rod, let's look at how this is solved when Infinispan clients run in peer-to-peer mode where clients and Infinispan live within the same JVM.

Embedded-mode Solution

If the ATM and the Infinispan instance storing the bank account lived in the same JVM, the ATM could use the [link: http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#replace\(K, V, V\)](http://docs.oracle.com/javase/6/docs/api/java/util/concurrent/ConcurrentMap.html#replace(K, V, V)) [conditional replace API] referred at the beginning of this article. So, it could send the previous known value to verify whether it has changed since it was last read. By doing so, the first operation could double check that the balance is still 500 CHF when it was to update to 100 CHF. Now, when the second operation comes, the current balance would not be 500 CHF any more and hence the conditional replace call would fail, hence avoiding data consistency issues:

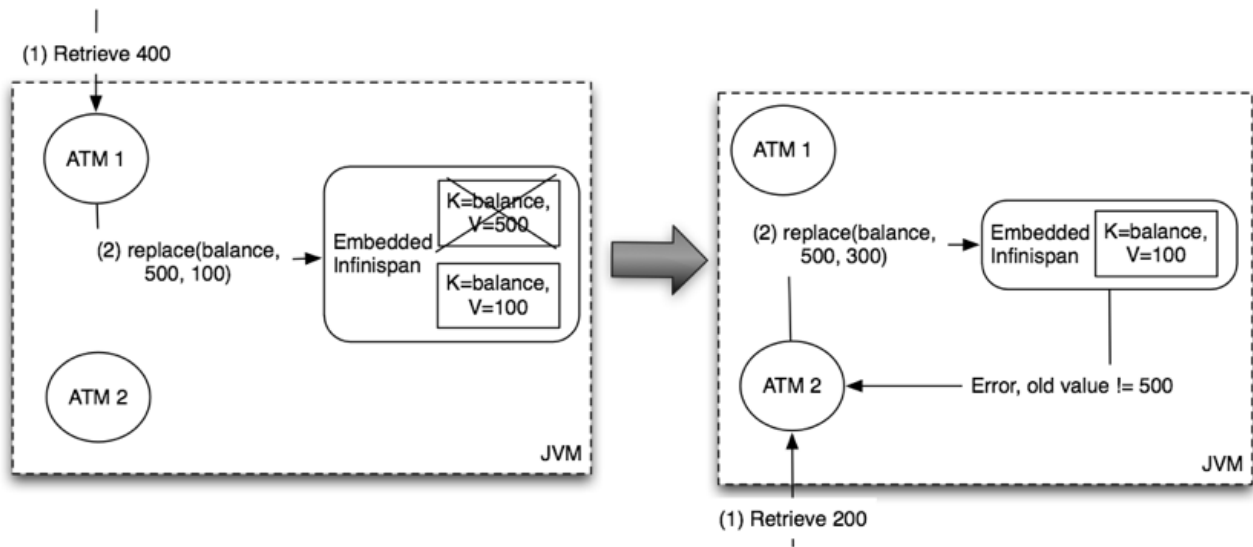


Figure 25. P2P solution

Client-Server Solution

In theory, Hot Rod could use the same p2p solution but sending the previous value would be not practical. In this example, the previous value is just an integer but the value could be a lot bigger and hence forcing clients to send it to the server would be rather wasteful. Instead, Hot Rod offers versioned operations to deal with this situation.

Basically, together with each key/value pair, Hot Rod stores a version number which uniquely identifies each modification. So, using an operation called [getVersioned](#) or [getWithVersion](#), clients can retrieve not only the value associated with a key, but also the current version. So, if we look at the previous example once again, the ATMs could call [getVersioned](#) and get the balance's version:

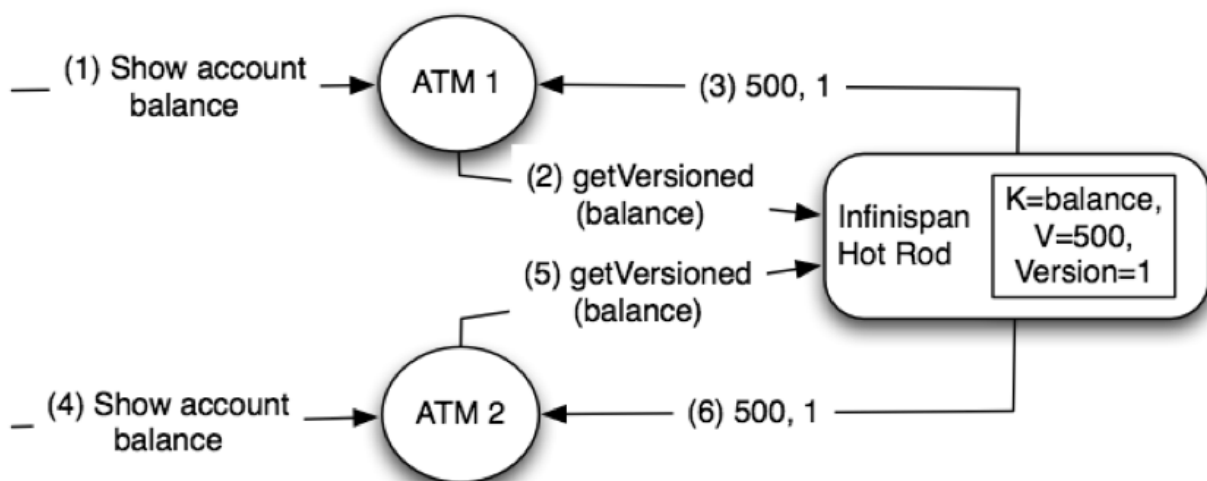


Figure 26. Get versioned

When the ATMs wanted to modify the balance, instead of just calling [put](#), they could call [replaceIfUnmodified](#) operation passing the latest version number of which the clients are aware of. The operation will only succeed if the version passed matches the version in the server. So, the first modification by the ATM would be allowed since the client passes 1 as version and the server side version for the balance is also 1. On the other hand, the second ATM would not be able to make the

modification because after the first ATMs modification the version would have been incremented to 2, and now the passed version (1) and the server side version (2) would not match:

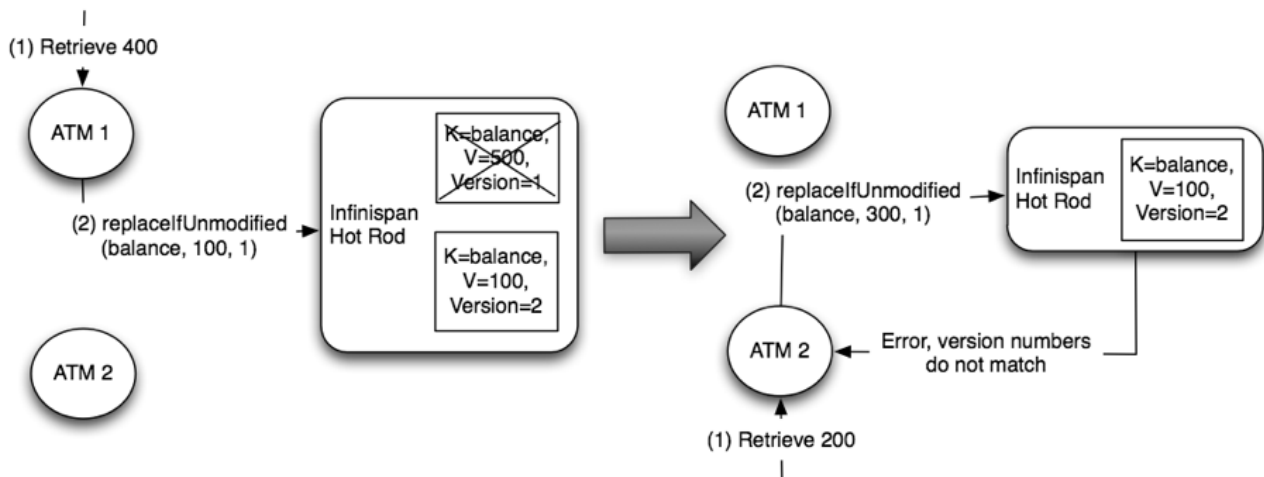


Figure 27. Replace if versions match

21.4.9. Interacting With Hot Rod Server From Within Same JVM

Normally, a Hot Rod server is accessed via a Hot Rod protocol client such as the Java Hot Rod client. However, there might be situations where not only do you want to access the Hot Rod server remotely, you might also want to access it locally from within the same JVM that the Hot Rod server is running. For example, you might have an Infinispan cache pushing changes [via the RemoteCacheStore to a Hot Rod server](#), and if the cache goes down, you might want to access the data directly from the Hot Rod server itself.

In this situations, we have to remember that the Hot Rod protocol specifies that keys and values are stored as byte arrays. This means that if the client code, using an existing Hot Rod client, stored Strings or Integers, or any other complex serializable or externalizable object, you won't be able to retrieve these objects straight from the cache that the Hot Rod server uses.

To actually get the fully constructed objects that you're after, you're gonna need to take the byte arrays stored within the Hot Rod server and unmarshall them into something that you can use. In the future, this is something that might be done for you, as suggested in [ISPN-706](#) (superseded by [ISPN-2281](#)), but for the time being, clients wanting to access Hot Rod server data will have to do it themselves.

Two different use cases need to be differentiated at this stage and to explain how to transform the Hot Rod server data into something usable, we'll assume that the clients are java clients:

Data Stored Directly Via A Hot Rod Client

The most common case is for a client to use a Hot Rod client library directly to store data in the Hot Rod server. In this case, assuming that the client used the existing Java Hot Rod client, the default marshaller used to marshall objects into byte arrays is the [GenericJBossMarshaller](#) . So, if a user wants to read data from the Hot Rod server directly, it would need to execute something along the lines of:

```

import org.infinispan.marshall.jboss.GenericJBossMarshaller;
import org.infinispan.util.ByteArrayKey;
import org.infinispan.server.core.CacheValue;
...

// Create a new instance of the marshaller:
GenericJBossMarshaller marshaller = new GenericJBossMarshaller();
Object key = ...

// Take the cache key and convert into a byte array,
// and wrap it with an instance of ByteArrayKey
ByteArrayKey bytesKey = new ByteArrayKey(marshaller.objectToByteBuffer(key));

// Internally, Hot Rod stores values wrapped in a CacheValue, so retrieve it
CacheValue cacheValue = (CacheValue) cache.get(bytesKey);

// Take the data part which is byte array and unmarshall it to retrieve the value
Object value = marshaller.objectFromByteBuffer(cacheValue.data());

```

If you want to store data directly in the HotRod server, you'd have to execute something like this:

```

import org.infinispan.marshall.jboss.GenericJBossMarshaller;
import org.infinispan.util.ByteArrayKey;
import org.infinispan.server.core.CacheValue;
...

// Create a new instance of the marshaller:
GenericJBossMarshaller marshaller = new GenericJBossMarshaller();
Object key = ...
Object value = ...

// Take the cache key and convert into a byte array,
// and wrap it with an instance of ByteArrayKey
ByteArrayKey bytesKey = new ByteArrayKey(marshaller.objectToByteBuffer(key));

// Internally, Hot Rod stores values wrapped in a CacheValue, so create instance
// Remember that you need to give it a version number, so either:
// 1. Increment previous value's version
// 2. Or generate a new version number that minimises potential clash
//    with a concurrent update to the same key in the cluster
CacheValue cacheValue = new CacheValue(marshaller.objectToByteBuffer(value), 1)

// Finally, store it in the cache
cache.put(bytesKey, cacheValue);

```

Data Stored Via Remote Cache Store

Other times, Hot Rod server might be storing data coming from a [RemoteCacheStore](#) , rather than

user code. In this case, there're a couple of differences to the code above. First of all, the marshaller is slightly different. Instead, the RemoteCacheStore uses the [VersionAwareMarshaller](#) which all it does is add Infinispan version information to the byte array generated. The second difference is that RemoteCacheStore stores internal cache entry classes, which apart from the value part, they contain other extra information. So, any code trying to read these directly from the Hot Rod server would need to take in account. For example, to read data from such Hot Rod server:

```
import org.infinispan.marshall.VersionAwareMarshaller;
import org.infinispan.util.ByteArrayKey;
import org.infinispan.server.core.CacheValue;
import org.infinispan.container.entries.CacheEntry;
...

// Create a new instance of the marshaller
VersionAwareMarshaller marshaller = new VersionAwareMarshaller();
Object key = ...

// Take the cache key and convert into a byte array,
// and wrap it with an instance of ByteArrayKey
ByteArrayKey bytesKey = new ByteArrayKey(marshaller.objectToByteBuffer(key));

// Internally, Hot Rod stores values wrapped in a CacheValue, so retrieve it
CacheValue cacheValue = (CacheValue) cache.get(bytesKey);

// However, in this case the data part of CacheValue does not contain directly
// the value. Instead, it contains an instance of CacheEntry, so we need to
// unmarshall that and then get the actual value
CacheEntry cacheEntry = (CacheEntry)
    marshaller.objectFromByteBuffer(cacheValue.data());
Object value = cacheEntry.getValue();
```

And to actually write data back into the Hot Rod server directly:

```

import org.infinispan.marshall.VersionAwareMarshaller;
import org.infinispan.util.ByteArrayKey;
import org.infinispan.server.core.CacheValue;
import org.infinispan.container.entries.CacheEntry;
import org.infinispan.container.entries.InternalEntryFactory;
...

// Create a new instance of the marshaller:
VersionAwareMarshaller marshaller = new VersionAwareMarshaller();
Object key = ...
Object value = ...

// Take the cache key and convert into a byte array
ByteArrayKey bytesKey = new ByteArrayKey(marshaller.objectToByteBuffer(key));

// With the value to store, a new CacheEntry instance needs to be created:
CacheEntry cacheEntry = InternalEntryFactory.create(bytesKey, value, ...)

// Internally, Hot Rod stores values wrapped in a CacheValue, so create instance
// Remember that you need to give it a version number, so either:
// 1. Increment previous value's version
// 2. Or generate a new version number that minimises potential clash
//    with a concurrent update to the same key in the cluster
CacheValue cacheValue = new CacheValue(
    marshaller.objectToByteBuffer(cacheEntry), 1)

// Finally, store it in the cache
cache.put(bytesKey, cacheValue);

```

Multiple Tiers of Caches

A combination of the Hot Rod protocol and [RemoteCacheLoader](#) opened the way for a set of new architectures in Infinispan, where layers of caches can exist and interact. This article takes a look at such a layered architecture.

Sample architecture/near caching

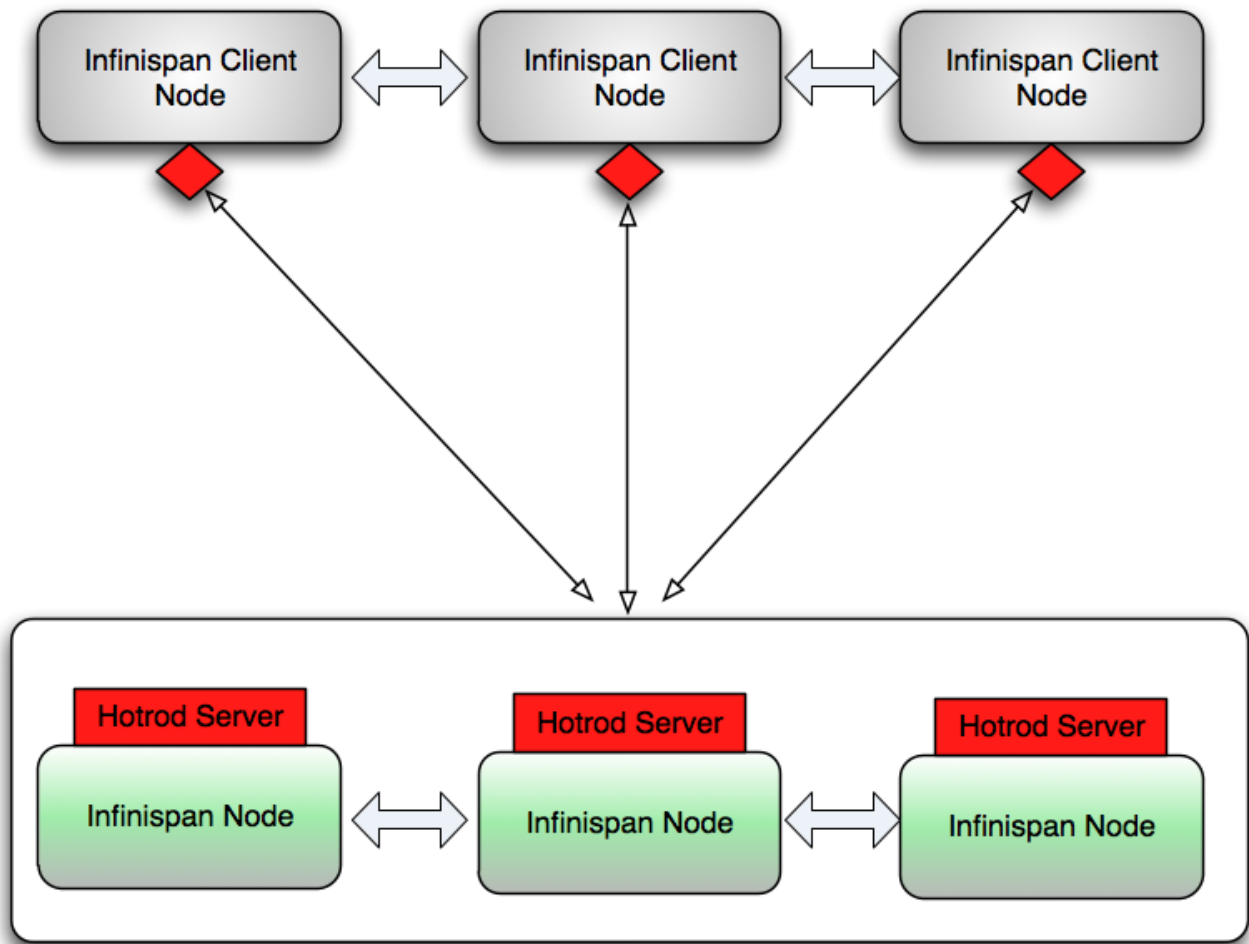


Figure 28. Multiple caching tiers

The diagram above shows an Infinispan server cluster running 3 hotrod servers. This cluster is accessed remotely, through HotRod, by another infinispan cluster: client cluster (upper part of the image). All the nodes in the server cluster are configured to run HotRod servers, so requests from remote loader are being balanced between them. The client cluster is configured with invalidation as cluster mode and a RemoteCacheLoader to access data stored in the server cluster. Application data is held on the server cluster which runs in DIST mode for scalability.

In this deployment the client code, running in same address space with the client cluster, holds all its data in the server cluster. Client cluster acts as an *near-cache* for frequently accessed entries.

21.4.10. Querying via the Java Hot Rod client

While previous Infinispan versions were already providing [indexing and searching](#) of Java entities to embedded clients, starting with Infinispan 6.0 and the introduction of the new [Hot Rod protocol version 1.3](#) we add support for remote, language neutral, querying.

This leap required two major changes:

- Since non-JVM clients cannot benefit from directly using [Apache Lucene's](#) Java API, Infinispan defines its own new [query language](#), based on an internal DSL that is easily implementable in all languages for which we currently have an implementation of the Hot Rod client.
- In order to enable indexing, the entities put in the cache by clients can no longer be opaque

binary blobs understood solely by the client. Their structure has to be known to both server and client, so a common way of encoding structured data had to be adopted. Furthermore, allowing multi-language clients to access the data requires a language and platform-neutral encoding. Google's [Protocol Buffers](#) was elected as an encoding format for both over-the-wire and storage due to its efficiency, robustness, good multi-language support and support for schema evolution.



As of 6.0, only the Java implementation of the Hot Rod client was upgraded to support querying. Clients for other languages will follow soon.

Storing Protobuf encoded entities

Remote clients that want to be able to index and query their stored entities must do so using the Protobuf encoding format. This is *key* for the search capability to work. But it's also possible to store Protobuf entities just for gaining the benefit of platform independence and not enable indexing if you do not need it.

Protobuf is all about structured data, so first thing you do to use it is define the structure of your data. This is accomplished by declaring protocol buffer message types in .proto files, like in the following example. Protobuf is a broad subject, we will not detail it here, so please consult the Protobuf [Developer Guide](#) for an in-depth explanation. It suffices to say for now that our example defines an entity (message type in protobuf speak) named *Book*, placed in a package named *book_sample*. Our entity declares several fields of primitive types and a repeatable field (an array basically) named *authors*. The *Author* message instances are embedded in the *Book* message instance.

library.proto

```
package book_sample;

message Book {
  required string title = 1;
  required string description = 2;
  required int32 publicationYear = 3; // no native Date type available in Protobuf

  repeated Author authors = 4;
}

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

There are a few important notes we need to make about Protobuf messages:

- nesting of messages is possible, but the resulting structure is strictly a tree, never a graph
- there is no concept of type inheritance
- collections are not supported but arrays can be easily emulated using repeated fields

Using Protobuf with the Java Hot Rod client is a two step process. First, the client must be configured to use a dedicated marshaller, *ProtoStreamMarshaller*. This marshaller uses the *ProtoStream* library to assist you in encoding your objects. The second step is instructing *ProtoStream* library on how to marshal your message types. The following example highlights this process.

```
import org.infinispan.client.hotrod.configuration.ConfigurationBuilder;
import org.infinispan.client.hotrod.marshall.ProtoStreamMarshaller;
import org.infinispan.protostream.SerializationContext;
...

ConfigurationBuilder clientBuilder = new ConfigurationBuilder();
clientBuilder.addServer()
    .host("127.0.0.1").port(11234)
    .marshaller(new ProtoStreamMarshaller());

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

SerializationContext srcCtx = ProtoStreamMarshaller.getSerializationContext
(remoteCacheManager);

srcCtx.registerProtofiles("/library.proto");
srcCtx.registerMarshaller(Book.class, new BookMarshaller());
srcCtx.registerMarshaller(Author.class, new AuthorMarshaller());

// Book and Author classes omitted for brevity
```

The interesting part in this sample is obtaining the *SerializationContext* associated to the *RemoteCacheManager* and then instructing *ProtoStream* about the protobuf types we want to marshal. The *SerializationContext* is provided by the library for this purpose. The *SerializationContext.registerProtoFiles* method receives the name of one or more classpath resources that is expected to be a protobuf definition containing our type declarations.



A *RemoteCacheManager* has no *SerializationContext* associated with it unless it was configured to use a *ProtoStreamMarshaller*.

The next relevant part is the registration of per entity marshallers for our domain model types. They must be provided by the user for each type or marshalling will fail. Writing marshallers is a simple process. The *BookMarshaller* example should get you started. The most important thing you need to consider is they need to be stateless and threadsafe as a single instance of them is being used.

```

import org.infinispan.protostream.MessageMarshaller;
...

public class BookMarshaller implements MessageMarshaller<Book> {

    @Override
    public String getTypeName() {
        return "book_sample.Book";
    }

    @Override
    public Class<? extends Book> getJavaClass() {
        return Book.class;
    }

    @Override
    public void writeTo(ProtoStreamWriter writer, Book book) throws IOException {
        writer.writeString("title", book.getTitle());
        writer.writeString("description", book.getDescription());
        writer.writeCollection("authors", book.getAuthors(), Author.class);
    }

    @Override
    public Book readFrom(ProtoStreamReader reader) throws IOException {
        String title = reader.readString("title");
        String description = reader.readString("description");
        int publicationYear = reader.readInt("publicationYear");
        Set<Author> authors = reader.readCollection("authors", new HashSet<Author>(),
Author.class);
        return new Book(title, description, publicationYear, authors);
    }
}

```

Once you've followed these steps to setup your client you can start reading and writing Java objects to the remote cache and the actual data stored in the cache will be protobuf encoded provided that marshallers were registered with the remote client for all involved types (*Book* and *Author* in our example). Keeping your objects stored in protobuf format has the benefit of being able to consume them with compatible clients written in different languages.

TODO Add reference to sample in C++ client user guide

Indexing of Protobuf encoded entries

After configuring the client as described in the previous section you can start configuring indexing for your caches on the server side. Activating indexing and the various indexing specific configurations is identical to embedded mode and is detailed in the [Querying Infinispan](#) chapter.

There is however an extra configuration step involved. While in embedded mode the indexing

metadata is obtained via Java reflection by analyzing the presence of various Hibernate Search annotations on the entry's class, this is obviously not possible if the entry is protobuf encoded. The server needs to extract the relevant metadata from the same descriptor (.proto file) as the client. The descriptors are stored in a dedicated cache on the server '`_protobuf_metadata`'. *Registering a new schema is therefore as simple as performing a put operation on that cache using the schema's name as a key and the schema itself as the value. Alternatively you can use the CLI (via the `cache-container=*:register-proto-schemas()` operation), the Console or the `ProtobufMetadataManager` MBean via JMX. Be aware that, when security is enabled, access to the schema cache via the remote protocols requires that the user belongs to the '`_schema_manager` role'* NOTE: Once indexing is enabled for a cache all fields of Protobuf encoded entries are going to be indexed. Future versions will allow you to select which fields to index (see [ISPN-3718](#)).

A remote query example

You've managed to configure both client and server to talk protobuf and you've enabled indexing. Let's put some data in the cache and try to search for it then!

```
import org.infinispan.client.hotrod.*;
import org.infinispan.query.dsl.*;
...

RemoteCacheManager remoteCacheManager = ...;
RemoteCache<Integer, Book> remoteCache = remoteCacheManager.getCache();

Book book1 = new Book();
book1.setTitle("Hibernate in Action");
remoteCache.put(1, book1);

Book book2 = new Book();
book2.setTile("Infinispan Data Grid Platform");
remoteCache.put(2, book2);

QueryFactory qf = Search.getQueryFactory(remoteCache);
Query query = qf.from(Book.class)
    .having("title").like("%Infinispan%").toBuilder()
    .build();

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

The key part of creating a query is obtaining the `QueryFactory` for the remote cache using the `org.infinispan.client.hotrod.Search.getQueryFactory()` method. Once you have this creating the query is similar to embedded mode which is covered in [this](#) section.

Running in Compatibility Mode

TODO

21.5. Scripting

Scripting is a feature of Infinispan Server which allows invoking server-side scripts from remote clients. Scripting leverages the JDK's `javax.script` `ScriptEngines`, therefore allowing the use of any JVM languages which offer one. By default, the JDK comes with Nashorn, a `ScriptEngine` capable of running JavaScript.

21.5.1. Installing scripts

Scripts are stored in a special script cache, named `'script_cache'`. *Adding a script is therefore as simple as putting it into the cache itself. If the name of the script contains a filename extension, e.g. `+myscript.js`, then that extension determines the engine that will be used to execute it. Alternatively the script engine can be selected using script metadata (see below). Be aware that, when security is enabled, access to the script cache via the remote protocols requires that the user belongs to the `'_script_manager'` role.*

21.5.2. Script metadata

Script metadata is additional information about the script that the user can provide to the server to affect how a script is executed. It is contained in a specially-formatted comment on the first lines of the script.

Properties are specified as `key=value` pairs, separated by commas. You can use several different comment styles: The `//`, `;;`, `#` depending on the scripting language you use. You can split metadata over multiple lines if necessary, and you can use single (`'`) or double (`"`) quotes to delimit your values.

The following are examples of valid metadata comments:

```
// name=test, language=javascript
// mode=local, parameters=[a,b,c]
```

Metadata properties

The following metadata property keys are available

- `mode`: defines the mode of execution of a script. Can be one of the following values:
 - `local`: the script will be executed only by the node handling the request. The script itself however can invoke clustered operations
 - `distributed`: runs the script using the Distributed Executor Service
- `language`: defines the script engine that will be used to execute the script, e.g. Javascript
- `extension`: an alternative method of specifying the script engine that will be used to execute the script, e.g. `js`
- `role`: a specific role which is required to execute the script
- `parameters`: an array of valid parameter names for this script. Invocations which specify

parameter names not included in this list will cause an exception.

- **datatype**: optional property providing information, in the form of Media Types (also known as MIME) about the type of the data stored in the caches, as well as parameter and return values. Currently it only accepts a single value which is `text/plain; charset=utf-8`, indicating that data is String UTF-8 format. This metadata parameter is designed for remote clients that only support a particular type of data, making it easy for them to retrieve, store and work with parameters.

Since the execution mode is a characteristic of the script, nothing special needs to be done on the client to invoke scripts in different modes.

21.5.3. Script bindings

The script engine within Infinispan exposes several internal objects as bindings in the scope of the script execution. These are:

- **cache**: the cache against which the script is being executed
- **marshaller**: the marshaller to use for marshalling/unmarshalling data to the cache
- **cacheManager**: the cacheManager for the cache
- **scriptingManager**: the instance of the script manager which is being used to run the script. This can be used to run other scripts from a script.

21.5.4. Script parameters

Aside from the standard bindings described above, when a script is executed it can be passed a set of named parameters which also appear as bindings. Parameters are passed as name,value pairs where name is a string and value can be any value that is understood by the marshaller in use.

The following is an example of a JavaScript script which takes two parameters, multiplicand and multiplier and multiplies them. Because the last operation is an expression evaluation, its result is returned to the invoker.

```
// mode=local,language=javascript
multiplicand * multiplier
```

To store the script in the script cache, use the following Hot Rod code:

```
RemoteCache<String, String> scriptCache = cacheManager.getCache("___script_cache");
scriptCache.put("multiplication.js",
    "// mode=local,language=javascript\n" +
    "multiplicand * multiplier\n");
```

21.5.5. Running Scripts using the Hot Rod Java client

The following example shows how to invoke the above script by passing two named parameters.

```
RemoteCache<String, Integer> cache = cacheManager.getCache();
// Create the parameters for script execution
Map<String, Object> params = new HashMap<>();
params.put("multiplicand", 10);
params.put("multiplier", 20);
// Run the script on the server, passing in the parameters
Object result = cache.execute("multiplication.js", params);
```

21.5.6. Distributed execution

The following is a script which runs within a Distributed Executor. Each node will return its address, and the results from all nodes will be collected in a List and returned to the client.

```
// mode:distributed,language=javascript
cacheManager.getAddress().toString();
```

21.6. Infinispan REST Server

The Infinispan Server distribution contains a server module that implements [RESTful](#) HTTP access to the Infinispan data grid, built on JAX_RS. Please refer to Infinispan Server's [documentation](#) for instructions on how to configure and run a REST server.

21.6.1. REST API

HTTP PUT and POST methods are used to place data in the cache, with URLs to address the cache name and key(s) - the data being the body of the request (the data can be anything you like). It is important that a Content-Type header is set. Other headers are used to control the cache settings and behaviour (detailed in that link).

Putting data in

PUT [/{cacheName}/{cacheKey}](#)

A PUT request of the above URL form will place the payload (body) in the given cache, with the given key (the named cache must exist on the server). For example <http://someserver/hr/payRoll/3> (in which case `hr` is the cache name, and `payRoll/3` is the key). Any existing data will be replaced, and Time-To-Live and Last-Modified values etc will be updated (if applicable).

POST [/{cacheName}/{cacheKey}](#)

Exactly the same as PUT, only if a value in a cache/key already exists, it will return a Http CONFLICT status (and the content will not be updated).

Headers

- Content-Type : MANDATORY (use [media/mime-types](#) for example: "application/json"). If you set the Content-Type to `application/x-java-serialized-object`, then it will be stored as a Java object

- `performAsync` : OPTIONAL true/false (if true, this will return immediately, and then replicate data to the cluster on its own. Can help with bulk data inserts/large clusters.)
- `timeToLiveSeconds` : OPTIONAL number (the number of seconds before this entry will automatically be deleted). If no parameter is sent, Infinispan assumes -1 as default value, which means that the entry will not expire. Passing any negative value will have the same effect.
- `maxIdleTimeSeconds` : OPTIONAL number (the number of seconds after last usage of this entry when it will automatically be deleted). If no parameter is sent, Infinispan assumes -1 as default value, which means that the entry will not expire as a result of idle time. Passing any negative value will have the same effect.

Passing 0 as parameter for `timeToLiveSeconds` and/or `maxIdleTimeSeconds`

- If both `timeToLiveSeconds` and `maxIdleTimeSeconds` are 0, the cache will use the default `lifespan` and `maxIdle` values configured in XML/programmatically
- If only `maxIdleTimeSeconds` is 0, it uses the `timeToLiveSeconds` value passed as parameter (or -1 if not present), and default `maxIdle` configured in XML/programmatically
- If only `timeToLiveSeconds` is 0, it uses default `lifespan` configured in XML/programmatically, and `maxIdle` is set to whatever came as parameter (or -1 if not present)

Getting data back out

HTTP GET and HEAD are used to retrieve data from entries.

`GET /{cacheName}/{cacheKey}`

This will return the data found in the given `cacheName`, under the given key - as the body of the response. A Content-Type header will be supplied which matches what the data was inserted as (other than if it is a Java object, see below). Browsers can use the cache directly of course (eg as a CDN). An `ETag` will be returned unique for each entry, as will the Last-Modified and Expires headers field indicating the state of the data at the given URL. ETags allow browsers (and other clients) to ask for data only in the case where it has changed (to save on bandwidth) - this is standard HTTP and is honoured by Infinispan.

Since Infinispan 5.3 it is possible to obtain additional information by appending the "extended" parameter on the query string, as follows:

```
GET /cacheName/cacheKey?extended
```

This will return the following custom headers:

- Cluster-Primary-Owner: the node name of the primary owner for this key
- Cluster-Node-Name: the JGroups node name of the server that has handled the request
- Cluster-Physical-Address: the physical JGroups address of the server that has handled the request.

HEAD /{cacheName}/{cacheKey}

The same as GET, only no content is returned (only the header fields). You will receive the same content that you stored. E.g., if you stored a String, this is what you get back. If you stored some XML or JSON, this is what you will receive. If you stored a binary (base 64 encoded) blob, perhaps a serialized Java object - you will need to; deserialize this yourself.

Similarly to the GET method, the HEAD method also supports returning extended information via headers. See above.

Listing keys

GET /{cacheName}

This will return a list of keys present in the given cacheName as the body of the response. The format of the response can be controlled via the Accept header as follows:

- application/xml - the list of keys will be returned in XML format.
- application/json - the list of keys will be return in JSON format.
- text/html - the list of keys will be returned in HTML format.
- text/plain - the list of keys will be returned in plain text format, one key per line

If the cache identified by cacheName is distributed, only the keys owned by the node handling the request will be returned. To return all keys, append the "global" parameter to the query, as follows:

```
GET /cacheName?global
```

Removing data

Data can be removed at the cache key/element level, or via a whole cache name using the HTTP delete method.

DELETE /{cacheName}/{cacheKey}

Removes the given key name from the cache.

DELETE /{cacheName}

Removes ALL the entries in the given cache name (i.e., everything from that path down). If the operation is successful, it returns 200 code.



Make it quicker!

Set the header performAsync to true to return immediately and let the removal happen in the background.

21.6.2. Client side code

Part of the point of a RESTful service is that you don't need to have tightly coupled client libraries/bindings. All you need is a HTTP client library. For Java, Apache HTTP Commons Client

works just fine (and is used in the integration tests), or you can use java.net API.

Ruby example

```
# Shows how to interact with Infinispan REST api from ruby.
# No special libraries, just standard net/http
#
# Author: Michael Neale
#
require 'net/http'

http = Net::HTTP.new('localhost', 8080)

#Create new entry
http.post('/infinispan/rest/MyData/MyKey', 'DATA HERE', {"Content-Type" => "text/plain"})

#get it back
puts http.get('/infinispan/rest/MyData/MyKey').body

#use PUT to overwrite
http.put('/infinispan/rest/MyData/MyKey', 'MORE DATA', {"Content-Type" => "text/plain"})

#and remove...
http.delete('/infinispan/rest/MyData/MyKey')

#Create binary data like this... just the same...
http.put('/infinispan/rest/MyImages/Image.png', File.read(
  '/Users/michaelneale/logo.png'), {"Content-Type" => "image/png"})

#and if you want to do json...
require 'rubygems'
require 'json'

#now for fun, lets do some JSON !
data = {:name => "michael", :age => 42 }
http.put('/infinispan/rest/Users/data/0', data.to_json, {"Content-Type" => "application/json"})
```

Python example

```
# Sample python code using the standard http lib only
#

import httplib

#putting data in
conn = httplib.HTTPConnection("localhost:8080")
data = "SOME DATA HERE \!" #could be string, or a file...
conn.request("POST", "/infinispan/rest/Bucket/0", data, {"Content-Type": "text/plain"
})
response = conn.getresponse()
print response.status

#getting data out
import httplib
conn = httplib.HTTPConnection("localhost:8080")
conn.request("GET", "/infinispan/rest/Bucket/0")
response = conn.getresponse()
print response.status
print response.read()
```

Java example

```
import java.io.BufferedReader;
import java.io.IOException;
import java.io.InputStreamReader;
import java.io.OutputStreamWriter;
import java.net.HttpURLConnection;
import java.net.URL;

/**
 * Rest example accessing Infinispan Cache.
 * @author Samuel Tauil (samuel@redhat.com)
 *
 */
public class RestExample {

    /**
     * Method that puts a String value in cache.
     * @param urlServerAddress
     * @param value
     * @throws IOException
     */
    public void putMethod(String urlServerAddress, String value) throws IOException {
        System.out.println("-----");
        System.out.println("Executing PUT");
        System.out.println("-----");
        URL address = new URL(urlServerAddress);
```

```

        System.out.println("executing request " + urlServerAddress);
        HttpURLConnection connection = (HttpURLConnection) address.openConnection();
        System.out.println("Executing put method of value: " + value);
        connection.setRequestMethod("PUT");
        connection.setRequestProperty("Content-Type", "text/plain");
        connection.setDoOutput(true);

        OutputStreamWriter outputStreamWriter = new OutputStreamWriter(connection
.getOutputStream());
        outputStreamWriter.write(value);

        connection.connect();
        outputStreamWriter.flush();

        System.out.println("-----");
        System.out.println(connection.getResponseCode() + " " + connection
.getResponseMessage());
        System.out.println("-----");

        connection.disconnect();
    }

    /**
     * Method that gets a value by a key in url as param value.
     * @param urlServerAddress
     * @return String value
     * @throws IOException
     */
    public String getMethod(String urlServerAddress) throws IOException {
        String line = new String();
        StringBuilder stringBuilder = new StringBuilder();

        System.out.println("-----");
        System.out.println("Executing GET");
        System.out.println("-----");

        URL address = new URL(urlServerAddress);
        System.out.println("executing request " + urlServerAddress);

        HttpURLConnection connection = (HttpURLConnection) address.openConnection();
        connection.setRequestMethod("GET");
        connection.setRequestProperty("Content-Type", "text/plain");
        connection.setDoOutput(true);

        BufferedReader&nbsp; bufferedReader = new BufferedReader(new InputStreamReader
(connection.getInputStream()));

        connection.connect();

        while ((line = bufferedReader.readLine()) != null) {
            stringBuilder.append(line + '\n');
        }
    }

```

```

    }

    System.out.println("Executing get method of value: " + stringBuilder.toString()
);

    System.out.println("-----");
    System.out.println(connection.getResponseCode() + " " + connection
.getResponseMessage());
    System.out.println("-----");

    connection.disconnect();

    return stringBuilder.toString();
}

/**
 * Main method example.
 * @param args
 * @throws IOException
 */
public static void main(String\[\] args) throws IOException {
    //Attention to the cache name "cacheX" it was configured in xml file with tag
    <*-cache name="cacheX">
    RestExample restExample = new RestExample();
    restExample.putMethod("http://localhost:8080/infinispan/rest/cacheX/1",
    "Infinispan REST Test");
    restExample.getMethod("http://localhost:8080/infinispan/rest/cacheX/1");

}
}

```

21.7. Using Infinispan Memcached Server

The Infinispan Server distribution contains a server module that implements the [Memcached text protocol](#). This allows Memcached clients to talk to one or several Infinispan backed Memcached servers. These servers could either be working standalone just like Memcached does where each server acts independently and does not communicate with the rest, or they could be clustered where servers replicate or distribute their contents to other Infinispan backed Memcached servers, thus providing clients with failover capabilities. Please refer to Infinispan Server's [documentation](#) for instructions on how to configure and run a Memcached server.

21.7.1. Command Clarifications

Flush All

Even in a clustered environment, `flush_all` command leads to the clearing of the Infinispan Memcached server where the call lands. There's no attempt to propagate this flush to other nodes in the cluster. This is done so that `flush_all` with delay use case can be reproduced with the Infinispan Memcached server. The aim of passing a delay to `flush_all` is so that different

Memcached servers in a full can be flushed at different times, and hence avoid overloading the database with requests as a result of all Memcached servers being empty. For more info, check the [Memcached text protocol section on flush_all](#) .

21.7.2. Unsupported Features

This section explains those parts of the memcached text protocol that for one reason or the other, are not currently supported by the Infinispan based memcached implementation.

Individual Stats

Due to difference in nature between the original memcached implementation which is C/C++ based and the Infinispan implementation which is Java based, there're some general purpose stats that are not supported. For these unsupported stats, Infinispan memcached server always returns 0.

Unsupported statistics

- pid
- pointer_size
- rusage_user
- rusage_system
- bytes
- curr_connections
- total_connections
- connection_structures
- auth_cmds
- auth_errors
- limit_maxbytes
- threads
- conn_yields
- reclaimed

Statistic Settings

The settings statistics section of the text protocol has not been implemented due to its volatility.

Settings with Arguments Parameter

Since the arguments that can be send to the Memcached server are not documented, Infinispan Memcached server does not support passing any arguments to stats command. If any parameters are passed, the Infinispan Memcached server will respond with a CLIENT_ERROR .

Delete Hold Time Parameter

Memcached does no longer honor the optional hold time parameter to delete command and so the

Infinispan based memcached server does not implement such feature either.

Verbosity Command

Verbosity command is not supported since Infinispan logging cannot be simplified to defining the logging level alone.

21.7.3. Talking To Infinispan Memcached Servers From Non-Java Clients

This section shows how to talk to Infinispan memcached server via non-java client, such as a python script.

Multi Clustered Server Tutorial

The example showcases the distribution capabilities of Infinispan memcached servers that are not available in the original memcached implementation.

- Start two clustered nodes: This configuration is the same one used for the GUI demo:

```
$ ./bin/standalone.sh -c clustered.xml -Djboss.node.name=nodeA
$ ./bin/standalone.sh -c clustered.xml -Djboss.node.name=nodeB
-Djboss.socket.binding.port-offset=100
```

Alternatively use

```
$ ./bin/domain.sh
```

Which automatically starts two nodes.

- Execute [test_memcached_write.py](#) script which basically executes several write operations against the Infinispan memcached server bound to port 11211. If the script is executed successfully, you should see an output similar to this:

```
Connecting to 127.0.0.1:11211
Testing set ['Simple_Key': Simple value] ... OK
Testing set ['Expiring_Key' : 999 : 3] ... OK
Testing increment 3 times ['Incr_Key' : starting at 1 ]
Initialise at 1 ... OK
Increment by one ... OK
Increment again ... OK
Increment yet again ... OK
Testing decrement 1 time ['Decr_Key' : starting at 4 ]
Initialise at 4 ... OK
Decrement by one ... OK
Testing decrement 2 times in one call ['Multi-Decr_Key' : 3 ]
Initialise at 3 ... OK
Decrement by 2 ... OK
```

- Execute [test_memcached_read.py](#) script which connects to server bound to 127.0.0.1:11311 and verifies that it can read the data that was written by the writer script to the first server. If the script is executed successfully, you should see an output similar to this:

```
Connecting to 127.0.0.1:11311
Testing get ['Simple_Key'] should return Simple value ... OK
Testing get ['Expiring_Key'] should return nothing... OK
Testing get ['Incr_Key'] should return 4 ... OK
Testing get ['Decr_Key'] should return 3 ... OK
Testing get ['Multi-Decr_Key'] should return 1 ... OK
```

21.8. Infinispan WebSocket Server

The Infinispan Server distribution contains a server module that implements the [WebSocket Interface](#) via a very simple Javascript "Cache" API. The WebSocket Interface was introduced as part of the HTML 5 specification. It defines a full-duplex communication channel to the browser, operating over a single socket (unlike Comet or Ajax) and is exposed to the browser via a Javascript interface. Please refer to Infinispan Server's [documentation](#) for instructions on how to configure and run a WebSocket server.



This is a highly experimental module.

21.8.1. Javascript API

Writing a web page that uses the Infinispan Cache API is trivial. The page simply needs to include a `<script />` declaration for the `infinispan-ws.js` Javascript source file. This script is served up by WebSocket Server.

So, for loading `infinispan-ws.js` from a WebSocket Server instance running on `www.acme.com:8181` (default port):

```
<script type="text/javascript" src="<a href="http://www.acme.com:61999/infinispan-
ws.js" target="_blank">http://www.acme.com:8181/infinispan-ws.js</a>" />
```

Creating a Client-Side Cache Object Instance

The client-side interface to a server-side Infinispan cache is the Cache Javascript object. It can be constructed as follows:

```
<script type="text/javascript">
  var cache = new Cache();

  // etc...
</script>
```

By default, the Cache instance will interface to the default Infinispan Cache associated with the WebSocket Server from which the `infinispan-ws.js` Javascript source file was loaded. So, in the above case, the Cache object instance will connect to the WebSocket Server running on `www.acme.com:8181` (i.e. `ws://www.acme.com:8181`).

The Infinispan Cache name and WebSocket Server address can be specified in the *Cache* object constructor as follows:

```
var cache = new Cache("omCache", "ws://ws.acmews.com:8181");
// etc...
```

Cache Operations

A number of cache operations can be performed via the Cache object instance such as *get* , *put* , *remove* , *notify* and *unnotify* .

The *get* and *notify* operations require a callback function to be registered with the Cache object instance. This callback function receives all add/update/remove notifications on any cache entries for which the *notify* function was invoked. It also asynchronously receives the result of a single invocation of the *get* function i.e. *get* can be thought of as "notify once, immediately".

The callback function is registered with the Cache object instance via the `registerCallback` function. The function should have 2 parameters - *key* and *value* , relating to the cache key and value.

```
var cache = new Cache();

// Ask to be notified about some cache entries...
cache.notify("orderStatus");
cache.notify("expectedDeliveryTime");

// Register the callback function for receiving notifications...
cache.registerCallback(cacheCallback);

// Cache callback function...
function cacheCallback(key, value) {
    // Handle notification...
}
```

Getting and updating data in the cache is done by simply calling the *get* , *put* and *remove* functions on the Cache object instance. These operations could be triggered by user interaction with a web form e.g.

```
<form onsubmit="return false;">

  <!-- Other form components... -->

  <!-- Buttons for making cache updates... -->
  <input type="button" value="Put"
    onclick="cache.put(this.form.key.value, this.form.val.value)" />
  <input type="button" value="Get"
    onclick="cache.get(this.form.key.value)" />
  <input type="button" value="Remove"
    onclick="cache.remove(this.form.key.value)" />
</form>
```

21.8.2. Sample code

Infinispan's source tree contains a sample HTML document that makes use of the WebSocket server. Browse through the source of this HTML document [here](#) .

21.8.3. Screencast

See the following [demo of the Infinispan WebSocket Server](#) in action.

21.8.4. Status

Prototype/Alpha.

21.8.5. Source

[Browse Infinispan's Git repository](#) .

Chapter 22. Embedded/Remote Compatibility

Infinispan offers the possibility to store and retrieve data in a [local embedded way](#), and also [remotely thanks to the multiple endpoints offered](#), but until now if you choose one way to access the data, you were stuck with it. For example, you could not store data using the embedded interface and retrieve it via REST.

Starting with Infinispan 5.3, it is now possible to configure Infinispan caches to work in a special, compatibility mode for those users interested in accessing Infinispan in multiple ways. Achieving such compatibility requires extra work from Infinispan in order to make sure that contents are converted back and forth between the different formats of each endpoint and this is the reason why compatibility mode is disabled by default.

22.1. Enable Compatibility Mode

For compatibility mode to work as expected, all endpoints need to be configured with the same cache manager, and need to talk to the same cache. If you're using the brand new [Infinispan Server distribution](#), this is all done for you. If you're in the mood to experiment with this in a standalone unit test, [this class](#) shows you how you can start multiple endpoints from a single class.

So, to get started using Infinispan's compatibility mode, it needs to be enabled, either via XML:

infinispan.xml

```
<local-cache>
  <compatibility/>
</local-cache>
```

Or programmatically:

```
ConfigurationBuilder builder = ...
builder.compatibility().enable();
```

The key thing to remember about Infinispan's compatibility mode is that where possible, it tries to store data unmarshalling or deserializing it. It does so because the most common use case is for it to store Java objects and having Java objects stored in deserialized form means that they're very easy to use from an embedded cache. With this in mind, it makes some assumptions. For example, if something is stored via Hot Rod, it's most likely coming from the reference Hot Rod client, which is written in Java, and which uses a marshaller that keeps binary payloads very compact. So, when the Hot Rod operation reaches the compatibility layer, it will try to unmarshall it, by default using the same default marshaller used by the Java Hot Rod client, hence providing good out-of-the-box support for the majority of cases.

22.1.1. Optional: Configuring Compatibility Marshaller

It could happen though the client might be using a Hot Rod client written for another language other than Java, say [Ruby](#) or [Python](#) . In this case, some kind of custom marshaller needs to be configured that either translates that serialized payload into a Java object to be stored in the cache, or keeps it in serialized form. Both options are valid, but of course it will have an impact on what kind of objects are retrieved from Infinispan if using the embedded cache. The marshaller is expected to implement [this interface](#) . Configuring the compatibility marshaller is optional and can be done via XML:

infinispan.xml

```
<local-cache>
  <compatibility marshaller="com.acme.CustomMarshaller"/>
</local-cache>
```

Or programmatically:

```
ConfigurationBuilder builder = ...
builder.compatibility().enable().marshaller(new com.acme.CustomMarshaller());
```

One concrete example of this marshaller logic can be found in the [SpyMemcachedCompatibleMarshaller](#) . [Spy Memcached](#) uses their own transcoders in order to marshall objects, so the compatibility marshaller created is in charge of marshalling/unmarshalling data stored via Spy Memcached client. If you want to retrieve data stored via Spy Memcached via say Hot Rod, you can [configure the Java Hot Rod client to use this same marshaller](#), and this is precisely what the test where the Spy Memcached marshaller is located is demonstrating.

22.2. Code examples

The best code examples available showing compatibility in action can be found in the [Infinispan Compatibility Mode testsuite](#), but more will be developed in the near future.

Chapter 23. Security

Security within Infinispan is implemented at several layers:

- within the core library, to provide coarse-grained access control to CacheManagers, Caches and data
- over remote protocols, to obtain credentials from remote clients and to secure the transport using encryption
- between nodes in a cluster, so that only authorized nodes can join and to secure the transport using encryption

In order to maximize compatibility and integration, Infinispan uses widespread security standards where possible and appropriate, such as X.509 certificates, SSL/TLS encryption and Kerberos/GSSAPI. Also, to avoid pulling in any external dependencies and to increase the ease of integration with third party libraries and containers, the implementation makes use of any facilities provided by the standard Java security libraries (JAAS, JSSE, JCA, JCE, SASL, etc). For this reason, the Infinispan core library only provides interfaces and a set of basic implementations.

23.1. Embedded Security

Applications interact with Infinispan using its API within the same JVM. The two main components which are exposed by the Infinispan API are CacheManagers and Caches. If an application wants to interact with a secured CacheManager and Cache, it should provide an identity which Infinispan's security layer will validate against a set of required roles and permissions. If the identity provided by the user application has sufficient permissions, then access will be granted, otherwise an exception indicating a security violation will be thrown. The identity is represented by the `javax.security.auth.Subject` class which is a wrapper around multiple Principals, e.g. a user and all the groups it belongs to. Since the Principal name is dependent on the owning system (e.g. a Distinguished Name in LDAP), Infinispan needs to be able to map Principal names to roles. Roles, in turn, represent one or more permissions. The following diagram shows the relationship between the various elements:

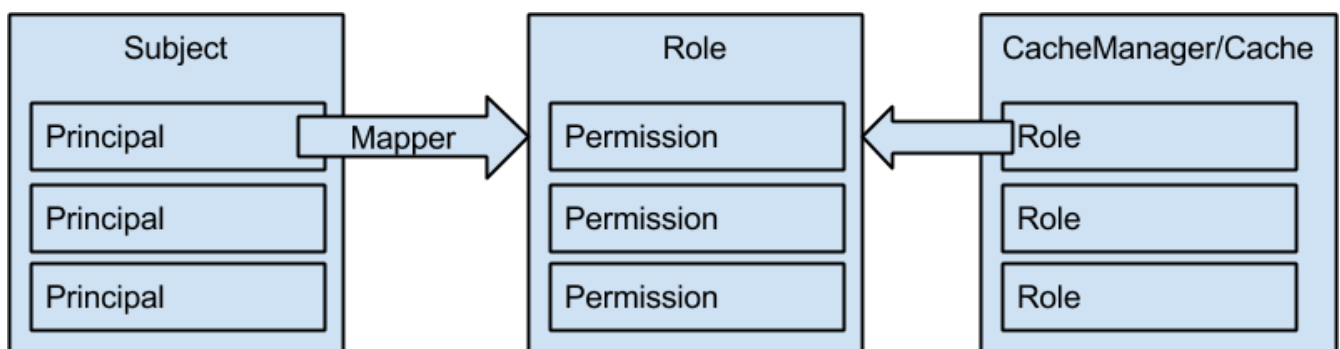


Figure 29. Roles/Permissions mapping

23.1.1. Embedded Permissions

Access to a cache manager or a cache is controlled by using a list of required permissions. Permissions are concerned with the type of action that is performed on one of the above entities

and not with the type of data being manipulated. Some of these permissions can be narrowed to specifically named entities, where applicable (e.g. a named cache). Depending on the type of entity, there are different types of permission available:

Cache Manager permissions

- CONFIGURATION (defineConfiguration): whether a new cache configuration can be defined
- LISTEN (addListener): whether listeners can be registered against a cache manager
- LIFECYCLE (stop): whether the cache manager can be stopped
- ALL: a convenience permission which includes all of the above

Cache permissions

- READ (get, contains): whether entries can be retrieved from the cache
- WRITE (put, putIfAbsent, replace, remove, evict): whether data can be written/replaced/removed/evicted from the cache
- EXEC (distexec, streams): whether code execution can be run against the cache
- LISTEN (addListener): whether listeners can be registered against a cache
- BULK_READ (keySet, values, entrySet, query): whether bulk retrieve operations can be executed
- BULK_WRITE (clear, putAll): whether bulk write operations can be executed
- LIFECYCLE (start, stop): whether a cache can be started / stopped
- ADMIN (getVersion, addInterceptor*, removeInterceptor, getInterceptorChain, getEvictionManager, getComponentRegistry, getDistributionManager, getAuthorizationManager, evict, getRpcManager, getCacheConfiguration, getCacheManager, getInvocationContextContainer, setAvailability, getDataContainer, getStats, getXAResource): whether access to the underlying components/internal structures is allowed
- ALL: a convenience permission which includes all of the above
- ALL_READ: combines READ and BULK_READ
- ALL_WRITE: combines WRITE and BULK_WRITE

Some permissions might need to be combined with others in order to be useful. For example, suppose you want to allow only "supervisors" to be able to run stream operations, while "standard" users can only perform puts and gets, you would define the following mappings:

```
<role name="standard" permission="READ WRITE" />
<role name="supervisors" permission="READ WRITE EXEC BULK"/>
```

23.1.2. Embedded API

When a DefaultCacheManager has been constructed with security enabled using either the programmatic or declarative configuration, it returns a SecureCache which will check the security context before invoking any operations on the underlying caches. A SecureCache also makes sure that applications cannot retrieve lower-level insecure objects (such as DataContainer). In Java,

executing code with a specific identity usually means wrapping the code to be executed within a `PrivilegedAction`:

```
import org.infinispan.security.Security;

Security.doAs(subject, new PrivilegedExceptionAction<Void>() {
    public Void run() throws Exception {
        cache.put("key", "value");
    }
});
```

If you are using Java 8, the above call can be simplified to:

```
Security.doAs(mySubject, PrivilegedAction<String>() -> cache.put("key", "value"));
```

Notice the use of `Security.doAs()` in place of the typical `Subject.doAs()`. While in Infinispan you can use either, unless you really need to modify the `AccessControlContext` for reasons specific to your application's security model, using `Security.doAs()` provides much better performance. If you need the current `Subject`, use the following:

```
Security.getSubject();
```

which will automatically retrieve the `Subject` either from the Infinispan's context or from the `AccessControlContext`.

Infinispan also fully supports running under a full-blown `SecurityManager`. The Infinispan distribution contains an example `security.policy` file which you should customize with the appropriate paths before supplying it to your JVM.

23.1.3. Embedded Configuration

There are two levels of configuration: global and per-cache. The global configuration defines the set of roles/permissions mappings while each cache can decide whether to enable authorization checks and the required roles.

Programmatic

```
GlobalConfigurationBuilder global = new GlobalConfigurationBuilder();
global
    .security()
        .authorization()
            .principalRoleMapper(new IdentityRoleMapper())
            .role("admin")
                .permission(CachePermission.ALL)
            .role("supervisor")
                .permission(CachePermission.EXEC)
                .permission(CachePermission.READ)
                .permission(CachePermission.WRITE)
            .role("reader")
                .permission(CachePermission.READ);
ConfigurationBuilder config = new ConfigurationBuilder();
config
    .security()
        .enable()
        .authorization()
            .role("admin")
            .role("supervisor")
            .role("reader");
```

Declarative

```
<infinispan>
  <cache-container default-cache="secured">
    <security>
      <authorization enabled="true">
        <identity-role-mapper />
        <role name="admin" permissions="ALL" />
        <role name="reader" permissions="READ" />
        <role name="writer" permissions="WRITE" />
        <role name="supervisor" permissions="READ WRITE EXEC BULK"/>
      </authorization>
    </security>
    <local-cache name="secured">
      <security>
        <authorization roles="admin reader writer supervisor" />
      </security>
    </local-cache>
  </cache-container>
</infinispan>
```

Role Mappers

In order to convert the Principals in a Subject into a set of roles to be used when authorizing, a

suitable `PrincipalRoleMapper` must be specified in the global configuration. Infinispan comes with 3 mappers and also allows you to provide a custom one:

- `IdentityRoleMapper` (Java: `org.infinispan.security.impl.IdentityRoleMapper`, XML: `<identity-role-mapper />`): this mapper just uses the Principal name as the role name
- `CommonNameRoleMapper` (Java: `org.infinispan.security.impl.CommonRoleMapper`, XML: `<common-name-role-mapper />`): if the Principal name is a Distinguished Name (DN), this mapper extracts the Common Name (CN) and uses it as a role name. For example the DN `cn=managers,ou=people,dc=example,dc=com` will be mapped to the role managers
- `ClusterRoleMapper` (Java: `org.infinispan.security.impl.ClusterRoleMapper` XML: `<cluster-role-mapper />`): a mapper which uses the `ClusterRegistry` to store principal to role mappings. This allows the use of the CLI's `GRANT` and `DENY` commands to add/remove roles to a principal.
- Custom role mappers (XML: `<custom-role-mapper class="a.b.c" />`): just supply the fully-qualified class name of an implementation of `org.infinispan.security.PrincipalRoleMapper`

23.2. Security Audit

Infinispan offers a pluggable audit logger which tracks whether a cache or a cache manager operation was allowed or denied. The audit logger is configured at the cache container authorization level:

Programmatic

```
GlobalConfigurationBuilder global = new GlobalConfigurationBuilder();
global
    .authorization()
    .auditLogger(new LoggingAuditLogger());
```

Declarative

```
<infinispan>
  <cache-container default-cache="secured">
    <security>
      <authorization audit-logger="org.infinispan.security.impl.LoggingAuditLogger"
">
        ...
      </authorization>
    </security>
    ...
  </cache-container>
</infinispan>
```

In embedded mode the default audit logger is `org.infinispan.security.impl.NullAuditLogger` which does nothing. Infinispan also comes with the `org.infinispan.security.impl.LoggingAuditLogger` which outputs audit logs through the available logging framework (e.g. Log4J) at level `TRACE` and category `AUDIT`. These logs look like:

```
[ALLOW|DENY] user READ cache[defaultCache]
```

Using an appropriate logging appender it is possible to send the AUDIT category either to a log file, a JMS queue, a database, etc. The user which is included in the log above is the name of the first non-java.security.acl.Group principal in the Subject.

23.3. Cluster security

JGroups can be configured so that nodes need to authenticate each other when joining / merging. The authentication uses SASL and is setup by adding the SASL protocol to your JGroups XML configuration above the GMS protocol, as follows:

```
<SASL mech="DIGEST-MD5"
  client_name="node_user"
  client_password="node_password"
  server_callback_handler_class=
"org.example.infinispan.security.JGroupsSaslServerCallbackHandler"
  client_callback_handler_class=
"org.example.infinispan.security.JGroupsSaslClientCallbackHandler"
  sasl_props="com.sun.security.sasl.digest.realm=test_realm" />
```

In the above example, the SASL mech will be DIGEST-MD5. Each node will need to declare the user and password it will use when joining the cluster. The behaviour of a node differs depending on whether it is the coordinator or any other node. The coordinator acts as the SASL server, whereas joining/merging nodes act as SASL clients. Therefore two different CallbackHandlers are required, the `server_callback_handler_class` will be used by the coordinator, and the `client_callback_handler_class` will be used by the other nodes. The SASL protocol in JGroups is only concerned with the authentication process. If you wish to implement node authorization, you can do so within the server callback handler, by throwing an Exception. The following example shows how this can be done:

```

public class AuthorizingServerCallbackHandler implements CallbackHandler {

    @Override
    public void handle(Callback[] callbacks) throws IOException,
        UnsupportedCallbackException {
        for (Callback callback : callbacks) {
            ...
            if (callback instanceof AuthorizeCallback) {
                AuthorizeCallback acb = (AuthorizeCallback) callback;
                UserProfile user = UserManager.loadUser(acb.getAuthenticationID());
                if (!user.hasRole("myclusterrole")) {
                    throw new SecurityException("Unauthorized node " +user);
                }
            }
            ...
        }
    }
}

```

Chapter 24. Integrations

Infinispan can be integrated with a number of other frameworks, as detailed below.

24.1. Using Infinispan as JPA-Hibernate Second Level Cache Provider

Following some of the principles set out by Brian Stansberry in [Using JBoss Cache 3 as a Hibernate 3.5 Second Level Cache](#) and taking in account improvements introduced by Infinispan, an Infinispan JPA/Hibernate second level cache provider has been developed. This wiki explains how to configure JPA/Hibernate to use the Infinispan and for those keen on lower level details, the key design decisions made and differences with previous JBoss Cache based cache providers.

If you're unfamiliar with JPA/Hibernate Second Level Caching, I'd suggest you to read Chapter 2.1 in [this guide](#) which explains the different types of data that can be cached.



On Caching

Query result caching, or entity caching, *may or may not improve* application performance. Be sure to benchmark your application with and without caching.

24.1.1. Configuration

1. First of all, to enable JPA/Hibernate second level cache with query result caching enabled, add either of the following:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.use_second_level_cache" value="true" />
<property name="hibernate.cache.use_query_cache" value="true" />
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.use_second_level_cache">true</property>
<property name="hibernate.cache.use_query_cache">true</property>
```

2. Now, configure the Infinispan cache region factory using one of the two options below:

- If the Infinispan CacheManager instance happens to be bound to JNDI select JndiInfinispanRegionFactory as the cacheregion factory and add the cache manager's JNDI name:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.region.factory_class" value=
"org.hibernate.cache.infinispan.JndiInfinispanRegionFactory" />
<property name="hibernate.cache.infinispan.cachemanager" value="java:CacheManager" />
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.region.factory_class"
>org.hibernate.cache.infinispan.JndiInfinispanRegionFactory</property>
<property name="hibernate.cache.infinispan.cachemanager">
java:CacheManager/entity</property>
```



JBoss Application Server

JBoss Application Server 6 and 7 deploy a shared Infinispan cache manager that can be used by all services, so when trying to configure applications with Infinispan second level cache, you should use the JNDI name for the cache manager responsible for the second level cache. By default, this is "java:CacheManager/entity". In any other application server, you can deploy your own cache manager and bind the CacheManager to JNDI, but in this cases it's generally preferred that the following method is used.

- If running JPA/Hibernate and Infinispan standalone or within third party Application Server, select the *InfinispanRegionFactory* as the cache region factory:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.region.factory_class" value=
"org.hibernate.cache.infinispan.InfinispanRegionFactory"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.region.factory_class"
>org.hibernate.cache.infinispan.InfinispanRegionFactory</property>
```

This is all the configuration you need to have JPA/Hibernate use Infinispan as cache provider with the default settings. You will still need to define which entities and queries need to be cached as defined in the Hibernate reference documentation, but that configuration aspect is not peculiar to Infinispan. This default configuration should suit the majority of use cases but sometimes, further configuration is required and to help with such situations, please check the following section where more advanced settings are discussed.

24.1.2. Default Configuration Explained

The aim of this section is to explain the default settings for each of the different global data type (entity, collection, query and timestamps) caches, why these were chosen and what are the available alternatives.

Defaults for Entity/Collection Caching

- For all entities and collections, whenever a new *entity or collection is read from database* and needs to be cached, *it's only cached locally* in order to reduce intra-cluster traffic. This option cannot be changed.
- All *entities and collections are configured to use a synchronous invalidation* as clustering mode.

This means that when an entity is updated, the updated cache will send a message to the other members of the cluster telling them that the entity has been modified. Upon receipt of this message, the other nodes will remove this data from their local cache, if it was stored there. This option can be changed to use replication by configuring entities or collections to use "replicated-entity" cache but it's generally not a recommended choice.

- *All entities and collections have initial state transfer disabled* since there's no need for it. It's not recommended that this is enabled.
- *entities and collections are configured to use READ_COMMITTED* as cache isolation level. It would only make sure to configure REPEATABLE_READ if the application evicts/clears entities from the Hibernate Session and then expects to repeatably re-read them in the same transaction. Otherwise, the Session's internal cache provides repeatable-read semantics. If you really need to use REPEATABLE_READ, you can simply configure entities or collections to use "entity-repeatable" cache.
- Entities and collections are configured with the following eviction settings. You can change these settings on a per entity or collection basis or per individual entity or collection type. More information in the "Advanced Configuration" section below.
 - Eviction wake up interval is 5 seconds.
 - Max number of entries are 10,000
 - Max idle time before expiration is 100 seconds
- *entites and collections are configured with lazy deserialization* which helps deserialization when entities or collections are stored in isolated deployments. If you're sure you'll never deploy your entities or collections in classloader isolated deployment archives, you can disable this setting.

Defaults for Query Caching

- The query cache is configured so that *queries are only cached locally* . Alternatively, you can configure query caching to use replication by selecting the "replicated-query" as query cache name. However, replication for query cache only makes sense if, and only if, all of this conditions are true:
 - Performing the query is quite expensive.
 - The same query is very likely to be repeatedly executed on different cluster nodes.
 - The query is unlikely to be invalidated out of the cache (Note: Hibernate must aggressively invalidate query results from the cache any time any instance of one of the entity types targeted by the query. All such query results are invalidated, even if the change made to the specific entity instance would not have affected the query result)
- *query cache uses the same cache isolation levels and eviction/expiration settings as for entities/collections* .
- *query cache has initial state transfer disabled* . It is not recommended that this is enabled.

Defaults for Timestamps Cache

- The *timestamps cache is configured with asynchronous replication* as clustering mode. Local or invalidated cluster modes are not allowed, since all cluster nodes must store all timestamps. As

a result, *no eviction/expiration is allowed for timestamp caches either* .

- The *timestamps cache is configured with a cluster cache loader (in Hibernate 3.6.0 or earlier it had state transfer enabled)* so that joining nodes can retrieve all timestamps. You shouldn't attempt to disable the cluster cache loader for the timestamps cache.

24.1.3. JTA Transactions Configuration

It is highly recommended that Hibernate is configured with JTA transactions so that both Hibernate and Infinispan cooperate within the same transaction and the interaction works as expected.

Otherwise, if Hibernate is configured for example with JDBC transactions, Hibernate will create a Transaction instance via `java.sql.Connection` and Infinispan will create a transaction via whatever `TransactionManager` returned by `hibernate.transaction.manager_lookup_class`. If `hibernate.transaction.manager_lookup_class` has not been populated, it will default on the dummy transaction manager. So, any work on the 2nd level cache will be done under a different transaction to the one used to commit the stuff to the database via Hibernate. In other words, your operations on the database and the 2LC are not treated as a single unit. Risks here include failures to update the 2LC leaving it with stale data while the database committed data correctly. It has also been observed that under some circumstances where JTA was not used, commit/rollbacks are not propagated to Infinispan.

To sum up, if you configure Hibernate with Infinispan, apply the following changes to your configuration file:

1. Unless your application uses JPA, you need to select the correct Hibernate transaction factory via the property *hibernate.transaction.factory_class* :

- If you're running within an application server, it's recommended that you use:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.transaction.factory_class" value=
"org.hibernate.transaction.CMTTransactionFactory"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.transaction.factory_class"
>org.hibernate.transaction.CMTTransactionFactory</property>
```

- If you're running in a standalone environment and you wanna enable JTA transaction factory, use:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.transaction.factory_class" value=
"org.hibernate.transaction.JTATransactionFactory"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.transaction.factory_class"
>org.hibernate.transaction.JTATransactionFactory</property>
```

The reason why JPA does not require a transaction factory class to be set up is because the entity manager already sets it to a variant of CMTTransactionFactory.

2. Select the correct Hibernate transaction manager lookup:

- If you're running within an application server, select the appropriate lookup class according to ["JTA Transaction Managers" table](#).

For example if you were running with the JBoss Application Server you would set:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.transaction.manager_lookup_class"
  value="org.hibernate.transaction.JBossTransactionManagerLookup"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.transaction.manager_lookup_class">
  org.hibernate.transaction.JBossTransactionManagerLookup
</property>
```

- If you are running standalone and you want to add a JTA transaction manager lookup, things get a bit more complicated. Due to a current limitation, Hibernate does not support injecting a JTA TransactionManager or JTA UserTransaction that are not bound to JNDI. In other words, if you want to use JTA, Hibernate expects your TransactionManager to be bound to JNDI and it also expects that UserTransaction instances are retrieved from JNDI. This means that in a standalone environment, you need to add some code that binds your TransactionManager and UserTransaction to JNDI. With this in mind and with the help of one of our community contributors, we've created an example that does just that: [JBoss Standalone JTA Example](#). Once you have the code in place, it's just a matter of selecting the correct Hibernate transaction manager lookup class, based on the JNDI names given. If you take *JBossStandaloneJtaExample* as an example, you simply have to add:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.transaction.manager_lookup_class"
  value="org.hibernate.transaction.JBossTransactionManagerLookup"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.transaction.manager_lookup_class">
  org.hibernate.transaction.JBossTransactionManagerLookup
</property>
```

As you probably have noted through this section, there wasn't a single mention of the need to configure [Infinispan's transaction manager lookup](#) and there's a good reason for that. Basically, the code within Infinispan cache provider takes the transaction manager that has been configured at the Hibernate level and uses that. Otherwise, if no Hibernate transaction manager lookup class has been defined, Infinispan uses a default dummy transaction manager.

Since Hibernate 4.0, the way Infinispan hooks into the transaction manager can be configured. By default, since 4.0, Infinispan interacts with the transaction manager as a JTA synchronization, resulting [in a faster interaction with the 2LC thanks to some key optimisations that the transaction manager can apply](#). However if desired, users can configure Infinispan to act as an XA resource (just like it did in 3.6 and earlier) by disabling the use of the synchronization. For example:

```
<!-- If using JPA, add to your persistence.xml: -->
<property name="hibernate.cache.infinispan.use_synchronization" value="false"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml: -->
<property name="hibernate.cache.infinispan.use_synchronization">
  false
</property>
```

24.1.4. Advanced Configuration

Infinispan has the capability of exposing statistics via JMX and since Hibernate 3.5.0.Beta4, you can enable such statistics from the Hibernate/JPA configuration file. By default, Infinispan statistics are turned off but when these are disabled via the following method, statistics for the Infinispan Cache Manager and all the managed caches (entity, collection, etc) are enabled:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.statistics" value="true"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml: -->
<property name="hibernate.cache.infinispan.statistics">true</property>
```

The Infinispan cache provider jar file contains an Infinispan configuration file, which is the one used by default when configuring the Infinispan standalone cache region factory. This file contains default cache configurations for all Hibernate data types that should suit the majority of use cases. However, if you want to use a different configuration file, you can configure it via the following property:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.cfg"
  value="/home/infinispan/cacheprovider-configs.xml"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml: -->
<property name="hibernate.cache.infinispan.cfg">
    /home/infinispan/cacheprovider-configs.xml
</property>
```

For each Hibernate cache data types, Infinispan cache region factory has defined a default cache name to look up in either the default, or the user defined, Infinispan cache configuration file. These default values can be found in the [Infinispan cache provider javadoc](#) . You can change these cache names using the following properties:

```
<!-- If using JPA, add to your persistence.xml: -->
<property name="hibernate.cache.infinispan.entity.cfg"
    value="custom-entity"/>
<property name="hibernate.cache.infinispan.collection.cfg"
    value="custom-collection"/>
<property name="hibernate.cache.infinispan.query.cfg"
    value="custom-collection"/>
<property name="hibernate.cache.infinispan.timestamp.cfg"
    value="custom-timestamp"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.infinispan.entity.cfg">
    custom-entity
</property>
<property name="hibernate.cache.infinispan.collection.cfg">
    custom-collection
</property>
<property name="hibernate.cache.infinispan.query.cfg">
    custom-collection
</property>
<property name="hibernate.cache.infinispan.timestamp.cfg">
    custom-timestamp
</property>
```

One of the key improvements brought in by Infinispan is the fact that cache instances are more lightweight than they used to be in JBoss Cache. This has enabled a radical change in the way entity/collection type cache management works. With the Infinispan cache provider, each entity/collection type gets each own cache instance, whereas in old JBoss Cache based cache providers, all entity/collection types would be sharing the same cache instance. As a result of this, locking issues related to updating different entity/collection types concurrently are avoided completely.

This also has an important bearing on the meaning of `hibernate.cache.infinispan.entity.cfg` and `hibernate.cache.infinispan.collection.cfg` properties. These properties define the template cache name that should be used for all entity/collection data types. So, with the above `hibernate.cache.infinispan.entity.cfg` configuration, when a region needs to be created for entity

com.acme.Person, the cache instance to be assigned to this entity will be based on a "custom-entity" named cache.

On top of that, this finer grained cache definition enables users to define cache settings on a per entity/collection basis. For example:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.com.acme.Person.cfg"
  value="person-entity"/>
<property name="hibernate.cache.infinispan.com.acme.Person.addresses.cfg"
  value="addresses-collection"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.infinispan.com.acme.Person.cfg">
  person-entity
</property>
<property name="hibernate.cache.infinispan.com.acme.Person.addresses.cfg">
  addresses-collection
</property>
```



For any entity or collection specific properties, if you are running within JBoss Application Server, JBoss EAP, or Wildfly, providing just the entity name is not enough. You need to add unit name and deployment name as well to each property in the following format:
`hibernate.cache.infinispan.<warname>.<unitname>.<FQN of entity>....`

Here, we're configuring the Infinispan cache provider so that for com.acme.Person entity type, the cache instance assigned will be based on a "person-entity" named cache, and for com.acme.Person.addresses collection type, the cache instance assigned will be based on a "addresses-collection" named cache. If either of these two named caches did not exist in the Infinispan cache configuration file, the cache provider would create a cache instance for com.acme.Person entity and com.acme.Person.addresses collection based on the default cache in the configuration file.

Furthermore, thanks to the excellent feedback from the Infinispan community and in particular, Brian Stansberry, we've decided to allow users to define the most commonly tweaked Infinispan cache parameters via hibernate.cfg.xml or persistence.xml, for example eviction/expiration settings. So, with the Infinispan cache provider, you can configure eviction/expiration this way:

```

<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.entity.eviction.strategy"
  value= "LRU"/>
<property name="hibernate.cache.infinispan.entity.eviction.wake_up_interval"
  value= "2000"/>
<property name="hibernate.cache.infinispan.entity.eviction.max_entries"
  value= "5000"/>
<property name="hibernate.cache.infinispan.entity.expiration.lifespan"
  value= "60000"/>
<property name="hibernate.cache.infinispan.entity.expiration.max_idle"
  value= "30000"/>

```

```

<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.infinispan.entity.eviction.strategy">
  LRU
</property>
<property name="hibernate.cache.infinispan.entity.eviction.wake_up_interval">
  2000
</property>
<property name="hibernate.cache.infinispan.entity.eviction.max_entries">
  5000
</property>
<property name="hibernate.cache.infinispan.entity.expiration.lifespan">
  60000
</property>
<property name="hibernate.cache.infinispan.entity.expiration.max_idle">
  30000
</property>

```

With the above configuration, you're overriding whatever eviction/expiration settings were defined for the default entity cache name in the Infinispan cache configuration used, regardless of whether it's the default one or user defined. More specifically, we're defining the following:

- All entities to use LRU eviction strategy
- The eviction thread to wake up every 2000 milliseconds
- The maximum number of entities for each entity type to be 5000 entries
- The lifespan of each entity instance to be 600000 milliseconds
- The maximum idle time for each entity instance to be 30000

You can also override eviction/expiration settings on a per entity/collection type basis in such way that the overridden settings only affect that particular entity (i.e. `com.acme.Person`) or collection type (i.e. `com.acme.Person.addresses`). For example:

```

<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.strategy"
  value= "FIFO"/>
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.wake_up_interval"
  value= "2500"/>
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.max_entries"
  value= "5500"/>
<property name="hibernate.cache.infinispan.com.acme.Person.expiration.lifespan"
  value= "65000"/>
<property name="hibernate.cache.infinispan.com.acme.Person.expiration.max_idle"
  value= "35000"/>

```

```

<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.strategy">
  FIFO
</property>
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.wake_up_interval">
  2500
</property>
<property name="hibernate.cache.infinispan.com.acme.Person.eviction.max_entries">
  5500
</property>
<property name="hibernate.cache.infinispan.com.acme.Person.expiration.lifespan">
  65000
</property>
<property name="hibernate.cache.infinispan.com.acme.Person.expiration.max_idle">
  35000
</property>

```

The aim of these configuration capabilities is to reduce the number of files needed to modify in order to define the most commonly tweaked parameters. So, by enabling eviction/expiration configuration on a per generic Hibernate data type or particular entity/collection type via `hibernate.cfg.xml` or `persistence.xml`, users don't have to touch to Infinispan's cache configuration file any more. We believe users will like this approach and so, if you there are any other Infinispan parameters that you often tweak and these cannot be configured via `hibernate.cfg.xml` or `persistence.xml`, please let the Infinispan team know by sending an email to infinispan-dev@lists.jboss.org.

Please note that query/timestamp caches work the same way they did with JBoss Cache based cache providers. In other words, there's a query cache instance and timestamp cache instance shared by all. It's worth noting that eviction/expiration settings are allowed for query cache but not for timestamp cache. So configuring an eviction strategy other than NONE for timestamp cache would result in a failure to start up.

Finally, from Hibernate 3.5.4 and 3.6 onwards, queries with specific cache region names are stored under matching cache instances. This means that you can now set query cache region specific settings. For example, assuming you had a query like this:


```
Query query = session.createQuery(
    "select account.branch from Account as account where account.holder = ?");
query.setCacheable(true);
query.setCacheRegion("AccountRegion");
```

The query would be stored under "AccountRegion" cache instance and users could control settings in similar fashion to what was done with entities and collections. So, for example, you could define specific eviction settings for this particular query region doing something like this:

```
<!-- If using JPA, add to your persistence.xml -->
<property name="hibernate.cache.infinispan.AccountRegion.eviction.strategy"
    value= "FIFO"/>
<property name="hibernate.cache.infinispan.AccountRegion.eviction.wake_up_interval"
    value= "10000"/>
```

```
<!-- If using Hibernate, add to your hibernate.cfg.xml -->
<property name="hibernate.cache.infinispan.AccountRegion.eviction.strategy">
    FIFO
</property>
<property name="hibernate.cache.infinispan.AccountRegion.eviction.wake_up_interval">
    10000
</property>
```

24.1.5. Handling custom identifiers types

When custom identifier types are used in Hibernate/JPA entities, specially in the case of composite identifiers, the resulting cache keys can end up holding references to `SessionFactory` instances. Serializing those properly in a clustered environment depends on being able to resolve the proper `SessionFactory` reference on deserialization, which can happen based on UUID (same JVM) or name (across JVMs).

When the resolution does not succeed, it's common to see errors similar to this:

```
java.io.InvalidObjectException: Could not find a SessionFactory [uuid=0d0cdf26-dfe6-
4285-9725-dfaa4821ecba,name=null]
    at org.hibernate.internal.SessionFactoryImpl.
locateSessionFactoryOnDeserialization(SessionFactoryImpl.java:1781)
    at org.hibernate.internal.SessionFactoryImpl.readResolve(SessionFactoryImpl.java
:1761)
```

The way to get around these error is by locking down the name of the `SessionFactory` across JVMs. This can be done by adding the following properties in the clustered application's configuration:

```
hibernate.session_factory_name = MySessionFactory
hibernate.session_factory_name_is_jndi = false
```



These properties are not necessary if deploying in JBoss Application Server, Wildfly or EAP containers, since the integration code already populates session factory name based on deployment unit information.

24.1.6. Integration with JBoss Application Server

In JBoss Application Server 7, Infinispan is the default second level cache provider and you can find details about its configuration [the AS7 JPA reference guide](#) .

Infinispan based Hibernate 2LC was developed as part of Hibernate 3.5 release and so it currently only works within AS 6 or higher. Hibernate 3.5 is not designed to work with AS/EAP 5.x or lower. To be able to run Infinispan based Hibernate 2LC in a lower AS version such as 5.1, the Infinispan 2LC module would require porting to Hibernate 3.3.



Looking to integrate Infinispan with Hibernate in JBoss AS/EAP 5.x? [Read this section!](#)

24.1.7. Using Infinispan as remote Second Level Cache?

Lately, several questions ([here](#) and [here](#)) have appeared in the Infinispan user forums asking whether it'd be possible to have an Infinispan second level cache that instead of living in the same JVM as the Hibernate code, it resides in a remote server, i.e. an Infinispan Hot Rod server. It's important to understand that trying to set up second level cache in this way is generally not a good idea for the following reasons:

- The purpose of a JPA/Hibernate second level cache is to store entities/collections recently retrieved from database or to maintain results of recent queries. So, part of the aim of the second level cache is to have data accessible locally rather than having to go to the database to retrieve it everytime this is needed. Hence, if you decide to set the second level cache to be remote as well, you're losing one of the key advantages of the second level cache: the fact that the cache is local to the code that requires it.
- Setting a remote second level cache can have a negative impact in the overall performance of your application because it means that cache misses require accessing a remote location to verify whether a particular entity/collection/query is cached. With a local second level cache however, these misses are resolved locally and so they are much faster to execute than with a remote second level cache.

There are however some edge cases where it might make sense to have a remote second level cache, for example:

- You are having memory issues in the JVM where JPA/Hibernate code and the second level cache is running. Off loading the second level cache to remote Hot Rod servers could be an interesting way to separate systems and allow you find the culprit of the memory issues more easily.

- Your application layer cannot be clustered but you still want to run multiple application layer nodes. In this case, you can't have multiple local second level cache instances running because they won't be able to invalidate each other for example when data in the second level cache is updated. In this case, having a remote second level cache could be a way out to make sure your second level cache is always in a consistent state, will all nodes in the application layer pointing to it.
- Rather than having the second level cache in a remote server, you want to simply keep the cache in a separate VM still within the same machine. In this case you would still have the additional overhead of talking across to another JVM, but it wouldn't have the latency of across a network. The benefit of doing this is that:
- Size the cache separate from the application, since the cache and the application server have very different memory profiles. One has lots of short lived objects, and the other could have lots of long lived objects.
- To pin the cache and the application server onto different CPU cores (using *numactl*), and even pin them to different physically memory based on the NUMA nodes.

24.2. Implementing standalone JPA JTA Hibernate application outside J2EE server using Infinispan 2nd level cache



From Hibernate 4.0.1 onwards, Infinispan now interacts as a synchronization rather than as an XA resource with the transaction manager when used as second-level cache, so there's no longer need to apply any of the changes suggested below!

Infinispans predecessor [JBoss Cache](#) requires integration with JTA when used as 2L-cache for a Hibernate application. At the moment of writing this article (Hibernate 3.5.0.Beta3) also Infinispan requires integration with JTA. Hibernate integrated with JTA is already largely used in EJB applications servers, but most users using Hibernate with Java SE outside any EJB container, still use the plain JDBC approach instead to use JTA.

According Hibernate documentation it should also possible to integrate JTA in a standalone application outside any EJB container, but I did hardly find any documentation how to do that in detail. (probably the reason is, that probably 95% of people is using hibernate within a EJB app. server or using SPRING). This article should give you some example how to realize a standalone Hibernate app. outside of a EJB container with JTA integration (and using Infinispan 2nd level cache).

As first thing you have to choose which implementation of TransactionManager to take. This article comes with examples for following OpenSource TransactionManagers:

1. JBoss
2. JOTM
3. Bitronix



Datasource/Transaction interaction

A very important aspect is not forgetting to couple the datasource with your transaction manager. In other words, the corresponding XAResource must be onto the transaction manager, otherwise only DML-statements but no commits/rollbacks are propagated to your database.

24.2.1. JBoss Transactions

The example with JBoss Transactions Transaction Manager was the most complex to implement, as JBoss's TransactionManager and UserTransaction objects are not declared serializable whilst its JNDI-server isn't able to bind non serializable objects out of the box. Special use of NonSerializableFactory is needed, requiring some additional custom code:

```
import hello.A; // a persistent class
import java.io.Serializable;
import java.sql.Connection;
import java.sql.SQLException;
import java.util.Properties;

import javax.naming.Context;
import javax.naming.InitialContext;
import javax.naming.Name;
import javax.naming.NameNotFoundException;
import javax.naming.Reference;
import javax.naming.StringRefAddr;
import javax.persistence.EntityManager;
import javax.persistence.Persistence;
import javax.transaction.TransactionManager;
import javax.transaction.UserTransaction;

import org.enhydra.jdbc.standard.StandardXADataSource;
import org.hibernate.Session;
import org.hibernate.SessionFactory;
import org.hibernate.ejb.HibernateEntityManagerFactory;
import org.hibernate.transaction.JBossTransactionManagerLookup;
import org.infinispan.transaction.lookup.JBossStandaloneJTAManagerLookup;
import org.jboss.util.naming.NonSerializableFactory;
import org.jnp.interfaces.NamingContext;
import org.jnp.server.Main;
import org.jnp.server.NamingServer;

public class JTAStandaloneExampleJBossTM {

    static JBossStandaloneJTAManagerLookup _ml = new JBossStandaloneJTAManagerLookup
();
```

```

public static void main(String[] args) {
    try {
        // Create an in-memory jndi
        NamingServer namingServer = new NamingServer();
        NamingContext.setLocal(namingServer);
        Main namingMain = new Main();
        namingMain.setInstallGlobalService(true);
        namingMain.setPort(-1);
        namingMain.start();

        Properties props = new Properties();
        props.put(Context.INITIAL_CONTEXT_FACTORY,
"org.jnp.interfaces.NamingContextFactory");
        props.put("java.naming.factory.url.pkgs",
"org.jboss.naming:org.jnp.interfaces");

        InitialContext ictx = new InitialContext( props );

        // as JBossTransactionManagerLookup extends JNDITransactionManagerLookup
        we must also register the TransactionManager
        bind("java:/TransactionManager", _ml.getTransactionManager(), _ml
.getTransactionManager().getClass(), ictx);

        // also the UserTransaction must be registered on jndi:
        org.hibernate.transaction.JTATransactionFactory#getUserTransaction() requires this
        bind(new JBossTransactionManagerLookup().getUserTransactionName(), _ml
.getUserTransaction(), _ml.getUserTransaction().getClass(), ictx);

        ExtendedXADatasource xads = new ExtendedXADatasource();
        xads.setDriverName("org.hsqldb.jdbcDriver");
        xads.setDriverName("com.p6spy.engine.spy.P6SpyDriver"); // comment this
        line if you don't want p6spy-logging
        xads.setUrl("jdbc:hsqldb:hsqldb://localhost");
        //xads.setTransactionManager(_ml.getTransactionManager()); useless here as
        this information is not serialized

        ictx.bind("java:/MyDatasource", xads);

        final HibernateEntityManagerFactory emf = (HibernateEntityManagerFactory)
Persistence.createEntityManagerFactory("helloworld");

        UserTransaction userTransaction = _ml.getUserTransaction();
        userTransaction.setTimeout(300000);
        //SessionFactory sf = (SessionFactory)
        ictx.lookup("java:/hibernate/MySessionFactory"); // if hibernate.session_factory_name
        set

        final SessionFactory sf = emf.getSessionFactory();

        userTransaction.begin();
        EntityManager em = emf.createEntityManager();
    }
}

```

```

        // do here your persistent work
        A a = new A();
        a.name= "firstvalue";
        em.persist(a);
        em.flush();    // do manually flush here as apparently
        FLUSH_BEFORE_COMPLETION seems not work, bug ?

        System.out.println("\nCreated and flushed instance a with id : " + a.oid +
        "  a.name set to:" + a.name);

        System.out.println("Calling userTransaction.commit() (Please check if the
        commit is effectively executed!)");
        userTransaction.commit();

        ictx.close();
        namingMain.stop();
        emf.close();

    } catch (Exception e) {
        e.printStackTrace();
    }
    System.exit(0);
}

public static class ExtendedXADataSource extends StandardXADataSource { // XAPool

    @Override
    public Connection getConnection() throws SQLException {

        if (getTransactionManager() == null) { // although already set before, it
        results null again after retrieving the datasource by jndi
            TransactionManager tm; // this is because the TransactionManager
        information is not serialized.
            try {
                tm = _ml.getTransactionManager();
            } catch (Exception e) {
                throw new SQLException(e);
            }
            setTransactionManager(tm); // resets the TransactionManager on the
        datasource retrieved by jndi,
                                     // this makes the datasource JTA-aware
        }

        // According to Enhydra documentation, here we must return the connection
        of our XAConnection
        // see http://cvs.forge.objectweb.org/cgi-
        bin/viewcvs.cgi/xapool/xapool/examples/xapooldatasource/DatabaseHelper.java?sortby=rev
        return super.getXAConnection().getConnection();
    }
}

```

```

}

/**
 * Helper method that binds the a non serializable object to the JNDI tree.
 *
 * @param jndiName Name under which the object must be bound
 * @param who Object to bind in JNDI
 * @param classType Class type under which should appear the bound object
 * @param ctx Naming context under which we bind the object
 * @throws Exception Thrown if a naming exception occurs during binding
 */
private static void bind(String jndiName, Object who, Class classType, Context
ctx) throws Exception {
    // Ah ! This service isn't serializable, so we use a helper class
    NonSerializableFactory.bind(jndiName, who);
    Name n = ctx.getNameParser("").parse(jndiName);
    while (n.size() > 1) {
        String ctxName = n.get(0);
        try {
            ctx = (Context) ctx.lookup(ctxName);
        } catch (NameNotFoundException e) {
            System.out.println("Creating subcontext:" + ctxName);
            ctx = ctx.createSubcontext(ctxName);
        }
        n = n.getSuffix(1);
    }

    // The helper class NonSerializableFactory uses address type nns, we go on to
    // use the helper class to bind the service object in JNDI
    StringRefAddr addr = new StringRefAddr("nns", jndiName);
    Reference ref = new Reference(classType.getName(), addr,
NonSerializableFactory.class.getName(), null);
    ctx.rebind(n.get(0), ref);
}

private static void unbind(String jndiName, Context ctx) throws Exception {
    NonSerializableFactory.unbind(jndiName);
    ctx.unbind(jndiName);
}
}

```

The content of the corresponding complete persistence.xml:

```

<persistence xmlns="http://java.sun.com/xml/ns/persistence" xmlns:xsi=
"http://www.w3.org/2001/XMLSchema-instance"   xsi:schemaLocation=
"http://java.sun.com/xml/ns/persistence
http://java.sun.com/xml/ns/persistence/persistence_1_0.xsd"   version="1.0">
  <persistence-unit name="helloworld" transaction-type="JTA">
    <jta-data-source>java:/MyDatasource</jta-data-source>
    <properties>
      <property name="hibernate.hbm2ddl.auto" value = "create"/>
      <property name="hibernate.archive.autodetection" value="class, hbm"/>
      <property name="hibernate.dialect" value="
org.hibernate.dialect.HSQLDialect"/>

      <property name="hibernate.jndi.class" value=
"org.jnp.interfaces.NamingContextFactory"/>
      <property name="hibernate.transaction.manager_lookup_class" value=
"org.hibernate.transaction.JBossTransactionManagerLookup"/>

      <property name="current_session_context_class" value="jta"/>
      <!-- <property name="hibernate.session_factory_name"
value="java:/hibernate/MySessionFactory"/> optional -->
      <property name="hibernate.transaction.factory_class" value=
"org.hibernate.transaction.JTATransactionFactory"/>
      <property name="hibernate.connection.release_mode" value="auto"/>
      <!-- setting above is important using XA-DataSource on SQLServer,
otherwise SQLServerException: The function START: has failed. No
transaction cookie was returned.-->

      <property name="hibernate.cache.use_second_level_cache" value="true"/>
      <property name="hibernate.cache.use_query_cache" value="true"/>

      <property name="hibernate.cache.region.factory_class"   value=
"org.hibernate.cache.infinispan.InfinispanRegionFactory"/>

    </properties>
  </persistence-unit>
</persistence>

```

24.2.2. JOTM

The example with JOTM is more simple, but apparently its JNDI implementation is not useable without wasting any rmi port. So it is not completely 'standalone' as the JNDI service is exposed outside your virtual machine.

```

import hello.A; // a persistent class

import java.sql.Connection;
import java.sql.SQLException;
import java.util.Properties;

```



```

import javax.naming.Context;
import javax.naming.InitialContext;
import javax.persistence.EntityManager;
import javax.persistence.EntityManagerFactory;
import javax.persistence.Persistence;
import javax.transaction.TransactionManager;
import javax.transaction.UserTransaction;

import org.enhydra.jdbc.standard.StandardXADataSource;
import org.hibernate.transaction.JOTMTransactionManagerLookup;
import org.objectweb.jotm.Jotm;
import org.objectweb.transaction.jta.TMService;

public class JTAExampleJOTM {

    static JOTMTransactionManagerLookup _ml = new JOTMTransactionManagerLookup();

    public static class ExtendedXADataSource extends StandardXADataSource { // XAPOOL
        @Override
        public Connection getConnection() throws SQLException {
            if (getTransactionManager() == null) { // although already set before, it
results null again after retrieving the datasource by jndi
                TransactionManager tm; // this is because the TransactionManager
information is not serialized.
                try {
                    tm = _ml.getTransactionManager(null);
                } catch (Exception e) {
                    throw new SQLException(e);
                }
                setTransactionManager(tm); // resets the TransactionManager on the
datasource retrieved by jndi,
// this makes the datasource JTA-aware
            }

            // According to Enhydra documantation, here we must return the connection
of our XAConnection
            // see http://cvs.forge.objectweb.org/cgi-
bin/viewcvs.cgi/xapool/xapool/examples/xapooldatasource/DatabaseHelper.java?sortby=rev
            return super.getXAConnection().getConnection();
        }
    }

    public static void main( String[] args )
    {
        try
        {
            java.rmi.registry.LocateRegistry.createRegistry(1099); // also possible to
lauch by command line rmiregistry
            System.out.println("RMI registry ready.");
        }
    }
}

```

```

        // following properties can be left out if specifying the values in a file
jndi.properties located into classpath
        Properties props = new Properties();
        props.put(Context.INITIAL_CONTEXT_FACTORY,
"org.ow2.carol.jndi.spi.MultiOrbInitialContextFactory");
        InitialContext jndiCtx = new InitialContext(props);

// XAPOOL
ExtendedXADataSource xads = new ExtendedXADataSource();
xads.setDriverName("org.hsqldb.jdbcDriver");
xads.setDriverName("com.p6spy.engine.spy.P6SpyDriver");
xads.setUrl("jdbc:hsqldb:hsqldb://localhost");

jndiCtx.bind("java:/MyDatasource", xads);

/* startup JOTM */
TMService jotm = new Jotm(true, false);
jotm.getUserTransaction().setTransactionTimeout(36000); // secs, important
JOTM default is only 60 secs !

/* and get a UserTransaction */
UserTransaction userTransaction = jotm.getUserTransaction();

jndiCtx.bind("java:comp/UserTransaction", jotm.getUserTransaction()); //
this is needed by hibernates JTATransactionFactory

/* get the Hibernate SessionFactory */
EntityManagerFactory emf = Persistence.createEntityManagerFactory(
"helloworld");
//SessionFactory sf = (SessionFactory)
jndiCtx.lookup("java:/hibernate/MySessionFactory");

// begin a new Transaction
userTransaction.begin();
EntityManager em = emf.createEntityManager();

A a = new A();
a.name= "firstvalue";
em.persist(a);
em.flush(); // do manually flush here as apparently
FLUSH_BEFORE_COMPLETION seems not work, bug ?

System.out.println("Calling userTransaction.commit() (Please check if the
commit is effectively executed!)");

```

```

        userTransaction.commit();

        // stop the transaction manager
        jotm.stop();
        jndiCtx.close();
        emf.close();

    }
    catch( Exception e )
    {
        e.printStackTrace();
    }
    System.exit(0);
}
}

```

Adjust following 2 properties in your persistence.xml:

persistence.xml

```

<property name="hibernate.jndi.class" value=
"org.ow2.carol.jndi.spi.MultiOrbInitialContextFactory"/>
<property name="hibernate.transaction.manager_lookup_class" value=
"org.hibernate.transaction.JOTMTransactionManagerLookup"/>

```

For using the JTA Hibernate application as servlet in tomcat please read <http://jotm.objectweb.org/current/jotm/doc/howto-tomcat-jotm.html> and also <https://forum.hibernate.org/viewtopic.php?f=1&t=1003866>

24.2.3. Bitronix

The Transaction Manager comes bundled with a fake in memory jndi-implementation which is ideal for standalone purpose. To integrate with Infinispan I did need a ad-hoc pre-alpha improvement (see attached [btm-ispn.jar](#) by courtesy of Mr. Ludovic Orban). Bitronix™ offers the so-called Last Resource Commit optimization (aka Last Resource Gambit or Last Agent optimization) and it allows a single non-XA database to participate in a XA transaction by cleverly ordering the resources. "Last Resource Commit" is not part of the XA spec as it doesn't cover the transaction-recovery aspect, so if your database does not support XA (or if you don't wish to have the Xa-driver performance overhead against the plain jdbc) then the "Last Resource Commit" feature should be ideal for the combination 1 single database plus infinispan.

```

import hello.A; // a persistent class

import java.util.Properties;

import javax.naming.Context;

```

```

import javax.naming.InitialContext;
import javax.persistence.EntityManager;
import javax.persistence.Persistence;
import javax.transaction.UserTransaction;

import org.hibernate.cache.infinispan.InfinispanRegionFactory;
import org.hibernate.ejb.HibernateEntityManagerFactory;
import org.hibernate.impl.SessionFactoryImpl;
import org.infinispan.manager.CacheManager;

import bitronix.tm.resource.ResourceRegistrar;
import bitronix.tm.resource.infinispan.InfinispanCacheManager;
import bitronix.tm.resource.jdbc.PoolingDataSource;

public class JTAExampleBTM {
    public static void main(String[] args) {
        try {
            Properties props = new Properties();
            props.put(Context.INITIAL_CONTEXT_FACTORY,
"bitronix.tm.jndi.BitronixInitialContextFactory");
            // Attention: BitronixInitialContextFactory isn't a real jndi
implementation: you can't do explicit bindings
            // It is ideal for hiberante standalone usage, as it automatically
'binds' the needed things: datasource + usertransaction

            System.out.println("create initial context");
            InitialContext ictx = new InitialContext(props);

            PoolingDataSource myDataSource = new PoolingDataSource();
            myDataSource.setClassName("bitronix.tm.resource.jdbc.lrc.LrcXADatasource
");

            myDataSource.setMaxPoolSize(5);
            myDataSource.setAllowLocalTransactions(true);

            myDataSource.getDriverProperties().setProperty("driverClassName",
"com.p6spy.engine.spy.P6SpyDriver");
            myDataSource.getDriverProperties().setProperty("url",
"jdbc:hsqldb:hsqldb://localhost");
            myDataSource.getDriverProperties().setProperty("user", "sa");
            myDataSource.getDriverProperties().setProperty("password", "");
            myDataSource.setUniqueName("java:/MyDatasource");
            myDataSource.setAutomaticEnlistingEnabled(true); // important to keep it
to true (default), otherwise commits/rollbacks are not propagated
            myDataSource.init(); // does also register the datasource on the Fake-
JNDI with Unique Name

            org.hibernate.transaction.BTMTransactionManagerLookup lokhiberante = new
org.hibernate.transaction.BTMTransactionManagerLookup();

```

```

        HibernateEntityManagerFactory emf = (HibernateEntityManagerFactory)
Persistence.createEntityManagerFactory("helloworld");
        SessionFactoryImpl sfi = (SessionFactoryImpl) emf.getSessionFactory();
        InfinispanRegionFactory infinispanregionfactory =
(InfinispanRegionFactory) sfi.getSettings().getRegionFactory();
        CacheManager manager = infinispanregionfactory.getCacheManager();

        // register Infinispan as a BTM resource
        InfinispanCacheManager icm = new InfinispanCacheManager();
        icm.setUniqueName("infinispan");
        ResourceRegistrar.register(icm);
        icm.setManager(manager);

        final UserTransaction userTransaction = (UserTransaction) ictx.lookup
(lokhiberante.getUserTransactionName());

        // begin a new Transaction
        userTransaction.begin();
        EntityManager em = emf.createEntityManager();

        A a = new A();
        a.name= "firstvalue";
        em.persist(a);
        em.flush();    // do manually flush here as apparently
FLUSH_BEFORE_COMPLETION seems not work, bug ?

        System.out.println("Calling userTransaction.commit() (Please check if the
commit is effectively executed!);
        userTransaction.commit();

        emf.close();

    } catch (Exception e) {
        e.printStackTrace();
        System.exit(1);
    }
    System.exit(0);
}
}

```

Adjust following 2 properties in your corresponding persistence.xml:

persistence.xml

```

<property name="hibernate.jndi.class" value=
"bitronix.tm.jndi.BitronixInitialContextFactory"/>
<property name="hibernate.transaction.manager_lookup_class" value=
"org.hibernate.transaction.BTMTransactionManagerLookup"/>

```

24.2.4. Atomikos

Last but not least, the Atomikos Transaction manager. It is currently the unique Transaction manager I've found with a online-documentation on [how to integrate with Hiberante without Spring, outside any J2EE container](#). . It seems to be the unique supporting XaDataSource together with Pooling, so it doesn't matter that It does not come with its own JNDI implementation (we will use the one of JBoss in following example).

```
import hello.A; // a persistent class

import java.io.Serializable;
import java.sql.Connection;
import java.sql.SQLException;
import java.util.Properties;

import javax.naming.Context;
import javax.naming.InitialContext;
import javax.naming.Name;
import javax.naming.NameNotFoundException;
import javax.naming.Reference;
import javax.naming.StringRefAddr;
import javax.persistence.EntityManager;
import javax.persistence.Persistence;
import javax.transaction.TransactionManager;
import javax.transaction.UserTransaction;

import org.hibernate.Session;
import org.hibernate.SessionFactory;
import org.hibernate.ejb.HibernateEntityManagerFactory;
import org.hibernate.impl.SessionFactoryImpl;

import org.jboss.util.naming.NonSerializableFactory;
import org.jnp.interfaces.NamingContext;
import org.jnp.server.Main;
import org.jnp.server.NamingServer;

import com.atomikos.icatch.jta.hibernate3.TransactionManagerLookup;
import com.atomikos.jdbc.AtomikosDataSourceBean;
import com.atomikos.jdbc.SimpleDataSourceBean;

public class JTASandaloneExampleAtomikos {

    public static void main(String[] args) {
        try {
            // Create an in-memory jndi
            NamingServer namingServer = new NamingServer();
            NamingContext.setLocal(namingServer);
            Main namingMain = new Main();
            namingMain.setInstallGlobalService(true);
            namingMain.setPort(-1);
```

```

        namingMain.start();

        Properties props = new Properties();
        props.put(Context.INITIAL_CONTEXT_FACTORY,
"org.jnp.interfaces.NamingContextFactory");
        props.put("java.naming.factory.url.pkgs",
"org.jboss.naming:org.jnp.interfaces");

        InitialContext ictx = new InitialContext( props );

        AtomikosDataSourceBean ds = new AtomikosDataSourceBean();
        ds.setUniqueResourceName("sqlserver_ds");
        ds.setXaDataSourceClassName(
"com.microsoft.sqlserver.jdbc.SQLServerXADataSource");
        Properties p = new Properties();
        p.setProperty ( "user" , "sa" );
        p.setProperty ( "password" , "" );
        p.setProperty ( "serverName" , "myserver" );
        ds.setXaProperties ( p );
        ds.setPoolSize(5);
        bind("java:/MyDatasource", ds, ds.getClass(), ictx);

        TransactionManagerLookup _ml = new TransactionManagerLookup();
        UserTransaction userTransaction = new com.atomikos.icatch.jta
.UserTransactionImp();

        bind("java:/TransactionManager", _ml.getTransactionManager(null), _ml
.getTransactionManager(null).getClass(), ictx);
        bind("java:comp/UserTransaction", userTransaction, userTransaction
.getClass(), ictx);

        HibernateEntityManagerFactory emf = (HibernateEntityManagerFactory)
Persistence.createEntityManagerFactory("helloworld");

        // begin a new Transaction
        userTransaction.begin();
        EntityManager em = emf.createEntityManager();

        A a = new A();
        a.name= "firstvalue";
        em.persist(a);
        em.flush();    // do manually flush here as apparently
FLUSH_BEFORE_COMPLETION seems not work, bug ?

        System.out.println("Calling userTransaction.commit() (Please check if the
commit is effectively executed!)");
        userTransaction.commit();

        emf.close();

    } catch (Exception e) {

```

```

        e.printStackTrace();
        System.exit(1);
    }
    System.exit(0);
}

/**
 * Helper method that binds the a non serializable object to the JNDI tree.
 *
 * @param jndiName Name under which the object must be bound
 * @param who Object to bind in JNDI
 * @param classType Class type under which should appear the bound object
 * @param ctx Naming context under which we bind the object
 * @throws Exception Thrown if a naming exception occurs during binding
 */
private static void bind(String jndiName, Object who, Class<?> classType, Context
ctx) throws Exception {
    // Ah ! This service isn't serializable, so we use a helper class
    NonSerializableFactory.bind(jndiName, who);
    Name n = ctx.getNameParser("").parse(jndiName);
    while (n.size() > 1) {
        String ctxName = n.get(0);
        try {
            ctx = (Context) ctx.lookup(ctxName);
        } catch (NameNotFoundException e) {
            System.out.println("Creating subcontext:" + ctxName);
            ctx = ctx.createSubcontext(ctxName);
        }
        n = n.getSuffix(1);
    }

    // The helper class NonSerializableFactory uses address type nns, we go on to
    // use the helper class to bind the service object in JNDI
    StringRefAddr addr = new StringRefAddr("nns", jndiName);
    Reference ref = new Reference(classType.getName(), addr,
NonSerializableFactory.class.getName(), null);
    ctx.rebind(n.get(0), ref);
}

private static void unbind(String jndiName, Context ctx) throws Exception {
    NonSerializableFactory.unbind(jndiName);
    ctx.unbind(jndiName);
}
}

```

Adjust following 2 properties in your corresponding persistence.xml:

persistence.xml

```
<property name="hibernate.jndi.class" value="org.jnp.interfaces.NamingContextFactory" />
<property name="hibernate.transaction.manager_lookup_class" value="com.atomikos.icatch.jta.hibernate3.TransactionManagerLookup"/>
```

And create a file named *jta.properties* in your classpath with following content:

jta.properties

```
com.atomikos.icatch.service=com.atomikos.icatch.standalone.UserTransactionServiceFactory
com.atomikos.icatch.automatic_resource_registration=false
com.atomikos.icatch.console_log_level=WARN
com.atomikos.icatch.force_shutdown_on_vm_exit=true
com.atomikos.icatch.enable_logging=false
```

24.3. Infinispan as Hibernate 2nd-Level Cache in JBoss AS 5.x

A JBoss AS 5.x application can be configured to use Infinispan 4.x as the Hibernate 2nd-level cache, replacing JBoss Cache.

1. Add the attached jar files to the ear lib directory. These include the core 4.1.0.GA Infinispan jar (infinispan-core.jar), the Hibernate/Infinispan integration jar back-ported from Hibernate 3.5 (hibernate-infinispan-3.3.2.GA_CP03.jar), the JGroups jar required by Infinispan 4.1.0 (jgroups-2.10.0.GA.jar), and other required 3rd party jars (river-1.2.3.GA.jar, marshalling-api-1.2.3.GA.jar)
2. Isolate the classloading to be ear-scoped by adding `META-INF/jboss-classloading.xml`

META-INF/jboss-classloading.xml

```
<classloading xmlns="urn:jboss:classloading:1.0" domain="simple-scoped" parent-first="false" />
```

3. Configure *persistence.xml* to use Infinispan instead of JBoss Cache:

```

<?xml version="1.0" encoding="UTF-8"?>
<persistence xmlns="http://java.sun.com/xml/ns/persistence"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://java.sun.com/xml/ns/persistence
http://java.sun.com/xml/ns/persistence/persistence_1_0.xsd"
  version="1.0">
<persistence-unit name="jpa-test">
  <jta-data-source>java:/PostgresDS</jta-data-source>
  <properties>
    <property name="hibernate.dialect" value=
"org.hibernate.dialect.HSQLDialect" />

    <property name="hibernate.session_factory_name" value=
"SessionFactory/infinispan" />

    <property name="hibernate.cache.use_query_cache" value="true" />
    <property name="hibernate.cache.use_second_level_cache" value="true" />
    <property name="hibernate.generate_statistics" value="true" />
    <property name="hibernate.cache.use_structured_entries" value="true" />

    <property name="hibernate.cache.region_prefix" value="infinispan" />

    <property name="hibernate.show_sql" value="true" />

    <property name="hibernate.hbm2ddl.auto" value="validate" />

    <!-- Infinispan second level cache configuration -->
    <property name="hibernate.cache.region.factory_class" value=
"org.hibernate.cache.infinispan.InfinispanRegionFactory" />
  </properties>
</persistence-unit>
</persistence>

```

24.4. Using Infinispan as a Spring Cache provider

Starting with version 3.1, the [Spring Framework](#) offers a [cache abstraction](#), enabling users to declaratively add caching support to applications via two simple annotations, [@Cacheable](#) and [@CacheEvict](#). While out of the box Spring's caching support is backed by [EHCACHE](#) it has been designed to easily support different cache providers. To that end Spring defines a simple and straightforward SPI other caching solutions may implement. Infinispan's very own spring modules do - amongst other things - exactly this and therefore users invested in Spring's programming model may easily have all their caching needs fulfilled through Infinispan.

Here's how.

24.4.1. Activating Spring Cache support

You activate Spring's cache support using xml:

```
<beans xmlns="http://www.springframework.org/schema/beans"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:cache="http://www.springframework.org/schema/cache"
  xmlns:p="http://www.springframework.org/schema/p"
  xsi:schemaLocation="
    http://www.springframework.org/schema/beans
    http://www.springframework.org/schema/beans/spring-beans.xsd
    http://www.springframework.org/schema/cache
    http://www.springframework.org/schema/cache/spring-cache.xsd">

    <cache:annotation-driven />

</beans>
```

somewhere in your application context. This enable the cache annotations in Spring. Alternatively, it can be done programmatically:

```
@EnableCaching @Configuration
public class Config {
}
```

Now, you will need to add Infinispan and Spring integration module to your classpath. For Maven users this might be achieved by adding these dependencies:

pom.xml for Spring 4 (embedded mode)

```
<dependencies>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-embedded</artifactId>
  </dependency>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-spring4-embedded</artifactId>
  </dependency>
</dependencies>
```

24.4.2. Telling Spring to use Infinispan as its caching provider

Spring cache provider SPI comprises two interfaces, `org.springframework.cache.CacheManager` and `org.springframework.cache.Cache` where a `CacheManager` serves as a factory for named `Cache` instances. By default Spring will look at runtime for a `CacheManager` implementation having the bean name "cacheManager" in an application's application context. So by putting

```
<!-- Infinispan cache manager -->
<bean id="cacheManager"
      class="org.infinispan.spring.provider.SpringEmbeddedCacheManagerFactoryBean"
      p:configurationFileLocation=
"classpath:/org/infinispan/spring/provider/sample/books-infinispan-config.xml" />
```

or using java config:

```
@EnableCaching
@Configuration
public class Config {

    @Bean
    public CacheManager cacheManager() {
        return new SpringEmbeddedCacheManager(infinispanCacheManager());
    }

    private EmbeddedCacheManager infinispanCacheManager() {
        return new DefaultCacheManager();
    }

}
```

somewhere in your application context you tell Spring to henceforth use Infinispan as its caching provider.

24.4.3. Adding caching to your application code

As outlined above enabling caching in your application code is as simple as adding `@Cacheable` and `@CacheEvict` to select methods. Suppose you've got a DAO for, say, books and you want book instances to be cached once they've been loaded from the underlying database using `BookDao#findBook(Integer bookId)`. To that end you annotate `findBook(Integer bookId)` with `@Cacheable`, as in

```
@Transactional
@Cacheable(value = "books", key = "#bookId")
Book findBook(Integer bookId) {...}
```

This will tell Spring to cache Book instances returned from calls to `findBook(Integer bookId)` in a named cache "books", using the parameter's "bookId" value as a cache key. Here, "#bookId" is an expression in the [Spring Expression Language](#) that evaluates to the `bookId` argument. If you don't specify the `key` attribute Spring will generate a hash from the supplied method arguments - in this case only `bookId` - and use that as a cache key. Essentially, you relinquish control over what cache key to use to Spring. Which may or may not be fine depending on your application's needs. Though the notion of actually deleting a book will undoubtedly seem alien and outright abhorrent to any sane reader there might come the time when your application needs to do just that. For whatever

reason. In this case you will want for such a book to be removed not only from the underlying database but from the cache, too. So you annotate `deleteBook(Integer bookId)` with `@CacheEvict` as in

```
@Transactional
@CacheEvict(value = "books", key = "#bookId")
void deleteBook(Integer bookId) {...}
```

and you may rest assured that no stray books be left in your application once you decide to remove them.

24.4.4. Conclusion

Hopefully you enjoyed our quick tour of Infinispan's support for Spring's cache abstraction and saw how easy it is for all your caching woes to be taken care of by Infinispan. More information may be found in Spring's [reference documentation](#). Also see [this link](#) - a very nice posting on the official Spring blog for a somewhat more comprehensive introduction to Spring's cache abstraction.

24.5. Infinispan modules for WildFly

The distribution includes a set of modules for WildFly. By installing these modules, it is possible to deploy user applications without packaging the Infinispan JARs within the deployments (WARs, EARs, etc), thus minimizing their size. In order not to conflict with the Infinispan modules which are already present within an WildFly installation, the modules provided by the Infinispan distribution are located within their own slot identified by the *major.minor* versions (e.g. slot="9.0").

In order to tell the WildFly deployer that we want to use the Infinispan APIs within our application, we need to add explicit dependencies to the deployment's MANIFEST:

MANIFEST.MF

```
Manifest-Version: 1.0
Dependencies: org.infinispan:{infinispanversion} services
```

If you are using Maven to generate your artifacts, mark the Infinispan dependencies as *provided* and configure your artifact archiver to generate the appropriate MANIFEST.MF file:

```
<dependencies>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-core</artifactId>
    <version>5.2.0.Final</version>
    <scope>provided</scope>
  </dependency>
  <dependency>
    <groupId>org.infinispan</groupId>
    <artifactId>infinispan-cache-store-jdbc</artifactId>
    <version>5.2.0.Final</version>
    <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:5.2 services,
org.infinispan.cache-store-jdbc:5.2 services</Dependencies>
          </manifestEntries>
        </archive>
      </configuration>
    </plugin>
  </plugins>
</build>
```

Chapter 25. Grid File System

Infinispan's `GridFileSystem` is a new, experimental API that exposes an Infinispan-backed data grid as a file system.



This is an *experimental* API. Use at your own risk.

Specifically, the API works as an extension to the JDK's `File`, `InputStream` and `OutputStream` classes: specifically, `GridFile`, `GridInputStream` and `GridOutputStream`. A helper class, `GridFilesystem`, is also included.

Essentially, the `GridFilesystem` is backed by 2 Infinispan caches - one for metadata (typically replicated) and one for the actual data (typically distributed). The former is replicated so that each node has metadata information locally and would not need to make RPC calls to list files, etc. The latter is distributed since this is where the bulk of storage space is used up, and a scalable mechanism is needed here. Files themselves are chunked and each chunk is stored as a cache entry, as a byte array.

Here is a quick code snippet demonstrating usage:

```
Cache<String,byte[]> data = cacheManager.getCache("distributed");
Cache<String,GridFile.Metadata> metadata = cacheManager.getCache("replicated");
GridFilesystem fs = new GridFilesystem(data, metadata);

// Create directories
File file=fs.getFile("/tmp/testfile/stuff");
fs.mkdirs(); // creates directories /tmp/testfile/stuff

// List all files and directories under "/usr/local"
file=fs.getFile("/usr/local");
File[] files=file.listFiles();

// Create a new file
file=fs.getFile("/tmp/testfile/stuff/README.txt");
file.createNewFile();
```

Copying stuff to the grid file system:

```
InputStream in=new FileInputStream("/tmp/my-movies/dvd-image.iso");
OutputStream out=fs.getOutputStream("/grid-movies/dvd-image.iso");
byte[] buffer=new byte[20000];
int len;
while((len=in.read(buffer, 0, buffer.length)) != -1) out.write(buffer, 0, len);
in.close();
out.close();
```

Reading stuff from the grid:

```
InputStream in=in.getInput("/grid-movies/dvd-image.iso");
OutputStream out=new FileOutputStream("/tmp/my-movies/dvd-image.iso");
byte[] buffer=new byte[200000];
int len;
while((len=in.read(buffer, 0, buffer.length)) != -1) out.write(buffer, 0, len);
in.close();
out.close();
```

25.1. WebDAV demo

Infinispan ships with a demo [WebDAV](#) application that makes use of the grid file system APIs. This demo app is packaged as a [WAR](#) file which can be deployed in a servlet container, such as JBoss AS or Tomcat, and exposes the grid as a file system over WebDAV. This could then be mounted as a remote drive on your operating system.

Chapter 26. Cross site replication

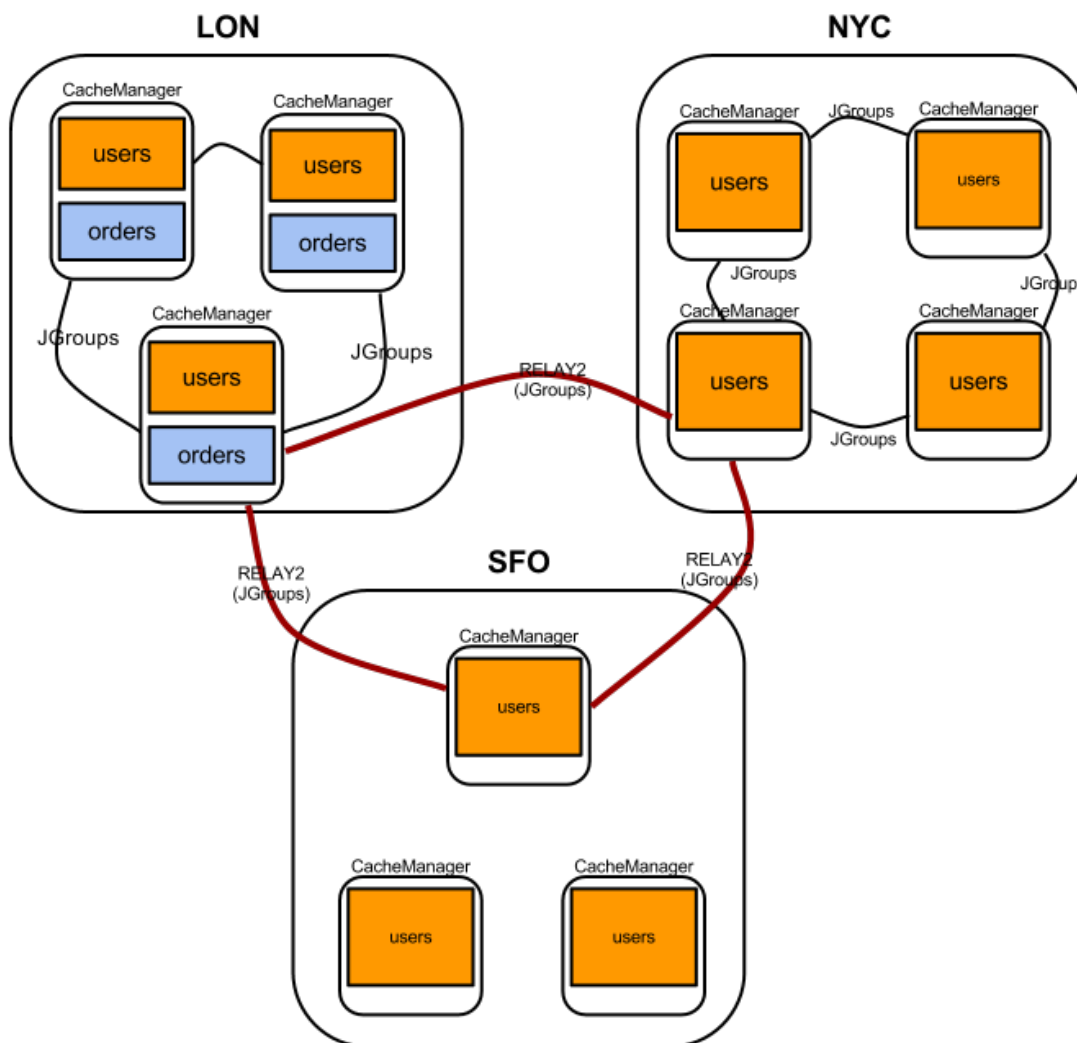
Cross site (x-site) replication allows backing up the data from one cluster to other clusters, potentially situated in different geographical location. The cross-site replication is built on top of JGroups' [RELAY2 protocol](#). [This document](#) describes the technical design of cross site replication in more detail.



Cross site replication needs the backup cache running in the site master node(s) (i.e. node which receives the backup and applies it). The backup cache starts automatically when it receives the first backup request.

26.1. Sample deployment

The diagram below depicts a possible setup of replicated sites, followed by a description of individual elements present in the deployment. Options are then explained at large in future paragraphs. Comments on the diagram above:



- there are 3 sites: LON, NYC and SFO.
- in each site there is a running Infinispan cluster with a (potentially) different number of

physical nodes: 3 nodes in LON, 4 nodes in NYC and 3 nodes in SFO

- the "users" cache is active in LON, NYC and SFO. Updates on the "users" cache in any of these sites gets replicated to the other sites as well
- it is possible to use different replication mechanisms between sites. E.g. One can configure SFO to backup data synchronously to NYC and asynchronously to LON
- the "users" cache can have a different configuration from one site to the other. E.g. it might be configured as distributed with numOwners=2 in the LON site, REPL in the NYC site and distributed with numOwners=1 in the SFO site
- JGroups is used for both inter-site and intra-site communication. [RELAY2](#) is used for inter-site communication
- "orders" is a site local to LON, i.e. updates to the data in "orders" don't get replicated to the remote sites The following sections discuss specific aspects of cross site replication into more detail. The foundation of the cross-site replication functionality is RELAY2 so it highly recommended to read JGroups' [RELAY2](#) documentation before moving on into cross-site. Configuration

The cross-site replication configuration spreads over the following files:

1. the backup policy for each individual cache is defined in infinispan's .xml configuration file ([infinispan.xml](#))
2. cluster's JGroups xml configuration file: [RELAY2](#) protocol needs to be added to the JGroups protocol stack ([jgroups.xml](#))
3. RELAY2 configuration file: RELAY2 has an own configuration file ([relay2.xml](#))
4. the JGroups channel that is used by RELAY2 has its own configuration file ([jgroups-relay2.xml](#))
Infinispan XML configuration file

The local site is defined in the the global configuration section. The local is the site where the node using this configuration file resides (in the example above local site is "LON").

infinispan.xml

```
<transport site="LON" />
```

The same setup can be achieved programatically:

```
GlobalConfigurationBuilder lonGc = GlobalConfigurationBuilder.defaultClusteredBuilder  
();  
lonGc.site().localSite("LON");
```

The names of the site (case sensitive) should match the name of a site as defined within JGroups' RELAY2 protocol configuration file. Besides the global configuration, each cache specifies its backup policy in the "site" element:

```
<distributed-cache name="users">
  <backups>
    <backup site="NYC" failure-policy="WARN" strategy="SYNC" timeout="12000"/>
    <backup site="SFO" failure-policy="IGNORE" strategy="ASYNC"/>
    <backup site="LON" strategy="SYNC" enabled="false"/>
  </backups>
</distributed-cache>
```

The "users" cache backs up its data to the "NYC" and "SFO" sites. Even though the "LON" appears as a backup site, it has the "enabled" attribute set to *false* so it will be ignored. For each site backup, the following configuration attributes can be specified:

- *strategy* - the strategy used for backing up data, either "SYNC" or "ASYNC". Defaults to "ASYNC"
- *failure-policy* - Decides what the system would do in case of failure during backup. Possible values are:
 - *IGNORE* - allow the local operation/transaction to succeed
 - *WARN* - same as IGNORE but also logs a warning message. Default.
 - *FAIL* - only in effect if "strategy" is "SYNC" - fails local cluster operation/transaction by throwing an exception to the user
 - *CUSTOM* - user provided, see "failurePolicyClass" below
- *failurePolicyClass* - If the 'failure-policy' is set to 'CUSTOM' then this attribute is required and should contain the fully qualified name of a class implementing `org.infinispan.xsite.CustomFailurePolicy`
- *timeout* - The timeout(milliseconds) to be used when backing up data remotely. Defaults to 10000 (10 seconds)

The same setup can be achieved programmatically:

```
ConfigurationBuilder lon = new ConfigurationBuilder();
lon.sites().addBackup()
    .site("NYC")
    .backupFailurePolicy(BackupFailurePolicy.WARN)
    .strategy(BackupConfiguration.BackupStrategy.SYNC)
    .replicationTimeout(12000)
    .sites().addInUseBackupSite("NYC")
lon.sites().addBackup()
    .site("SFO")
    .backupFailurePolicy(BackupFailurePolicy.IGNORE)
    .strategy(BackupConfiguration.BackupStrategy.ASYNC)
    .sites().addInUseBackupSite("SFO")
```

The "users" cache above doesn't know on which cache on the remote sites its data is being replicated. By default the remote site writes the backup data to a cache having the same name as

the originator, i.e. "users". This behaviour can be overridden with an "backupFor" element. For example the following configuration in SFO makes the "usersLONBackup" cache act as the backup cache for the "users" cache defined above in the LON site:

infinispan.xml

```
<infinispan>
  <cache-container default-cache="">
    <distributed-cache name="usersLONBackup">
      <backup-for remote-cache="users" remote-site="LON"/>
    </distributed-cache>
  </cache-container>
</infinispan>
```

The same setup can be achieved programatically:

```
ConfigurationBuilder cb = new ConfigurationBuilder();
cb.sites().backupFor().remoteCache("users").remoteSite("LON");
```

26.1.1. Local cluster's jgroups .xml configuration

This is the configuration file for the local (intra-site) infinispan cluster. It is referred from the infinispan configuration file, see "configurationFile" below:

infinispan.xml

```
<infinispan>
  <jgroups>
    <stack-file name="external-file" path="jgroups.xml"/>
  </jgroups>
  <cache-container>
    <transport stack="external-file" />
  </cache-container>

  ...

</infinispan>
```

In order to allow inter-site calls, the RELAY2 protocol needs to be added to the protocol stack defined in the jgroups configuration (see attached [jgroups.xml](#) for an example).

26.1.2. RELAY2 configuration file

The RELAY2 configuration file is linked from the jgroups.xml (see attached [relay2.xml](#)). It defines the sites seen by this cluster and also the JGroups configuration file that is used by RELAY2 in order to communicate with the remote sites.

26.2. Data replication

For both transactional and non-transactional caches, the backup calls are performed in parallel with local cluster calls, e.g. if we write data to node N1 in LON then replication to the local nodes N2 and N3 and remote backup sites SFO and NYC happen in parallel.

26.2.1. Non transactional caches

In the case of non-transactional caches the replication happens during each operation. Given that data is sent in parallel to backups and local caches, it is possible for the operations to succeed locally and fail remotely, or the other way, causing inconsistencies

26.2.2. Transactional caches

For synchronous transactional caches, Infinispan internally uses a two phase commit protocol: lock acquisition during the 1st phase (prepare) and apply changes during the 2nd phase (commit). For asynchronous caches the two phases are merged, the "apply changes" message being sent asynchronously to the owners of data. This 2PC protocol maps to 2PC received from the JTA transaction manager. For transactional caches, both optimistic and pessimistic, the backup to remote sites happens during the prepare and commit phase only.

Synchronous local cluster with async backup

In this scenario the backup call happens during local commit phase(2nd phase). That means that if the local prepare fails, no remote data is being sent to the remote backup.

Synchronous local cluster with sync backup

In this case there are two backup calls:

- during prepare a message is sent across containing all the modifications that happened within this transaction
- if the remote backup cache is transactional then a transaction is started remotely and all these modifications are being written within this transaction's scope. The transaction is not committed yet (see below)
- if the remote backup cache is not transactional, then the changes are applied remotely
- during the commit/rollback, a commit/rollback message is sent across
- if the remote backups cache is transactional then the transaction started at the previous phase is committed/rolled back
- if the remote backup is not transactional then this call is ignored

Both the local and the backup call(if the "backupFailurePolicy" is set to "FAIL") can veto transaction's prepare outcome

Asynchronous local cluster

In the case of asynchronous local clusters, the backup data is sent during the commit phase. If the

backup call fails and the "backupFailurePolicy" is set to "FAIL" then the user is notified through an exception.

26.3. Taking a site offline

If backing up to a site fails for a certain number of times during a time interval, then it is possible to automatically mark that site as offline. When a site is marked as offline the local site won't try to backup data to it anymore. In order to be taken online a system administrator intervention being required.

26.3.1. Configuration

The taking offline of a site can be configured as follows:

infinispan.xml

```
<replicated-cache name="bestEffortBackup">
  ...
  <backups>
    <backup site="NYC" strategy="SYNC" failure-policy="FAIL">
      <take-offline after-failures="500" min-wait="10000"/>
    </backup>
  </backups>
  ...
</replicated-cache>
```

The *take-offline* element under the *backup* configures the taking offline of a site:

- *after-failures* - the number of failed backup operations after which this site should be taken offline. Defaults to 0 (never). A negative value would mean that the site will be taken offline after *minTimeToWait*
- *min-wait* - the number of milliseconds in which a site is not marked offline even if it is unreachable for 'afterFailures' number of times. If smaller or equal to 0, then only *afterFailures* is considered.

The equivalent programmatic configuration is:

```
lon.sites().addBackup()
    .site("NYC")
    .backupFailurePolicy(BackupFailurePolicy.FAIL)
    .strategy(BackupConfiguration.BackupStrategy.SYNC)
    .takeOffline()
        .afterFailures(500)
        .minTimeToWait(10000);
```

26.3.2. Taking a site back online

In order to bring a site back online after being taken offline, one can use the JMX console and invoke the "bringSiteOnline(siteName)" operation on the *XSiteAdmin* managed bean. At the moment this method would need to be invoked on all the nodes within the site(further releases will overcome this limitation).

26.4. State Transfer between sites



This feature is available since Infinispan 7.0.0.Alpha2

When a new site is bough back online, it is necessary to re-sync the site with the most recent updates. This feature allows state to be transferred from one site to another.

The state transfer is triggered manually by a system administrator (or other responsible entity) via JMX. The operation can be found over the *XSiteAdminOperations* managed bean and it is named `pushState(String)`. The system administrator should invoke this operation in the provider site (i.e. the site that will send the state) and set the name of the consumer site (i.e. the site that will receive the state). The figure below shows where to find the `pushState(String)` operation using JConsole:

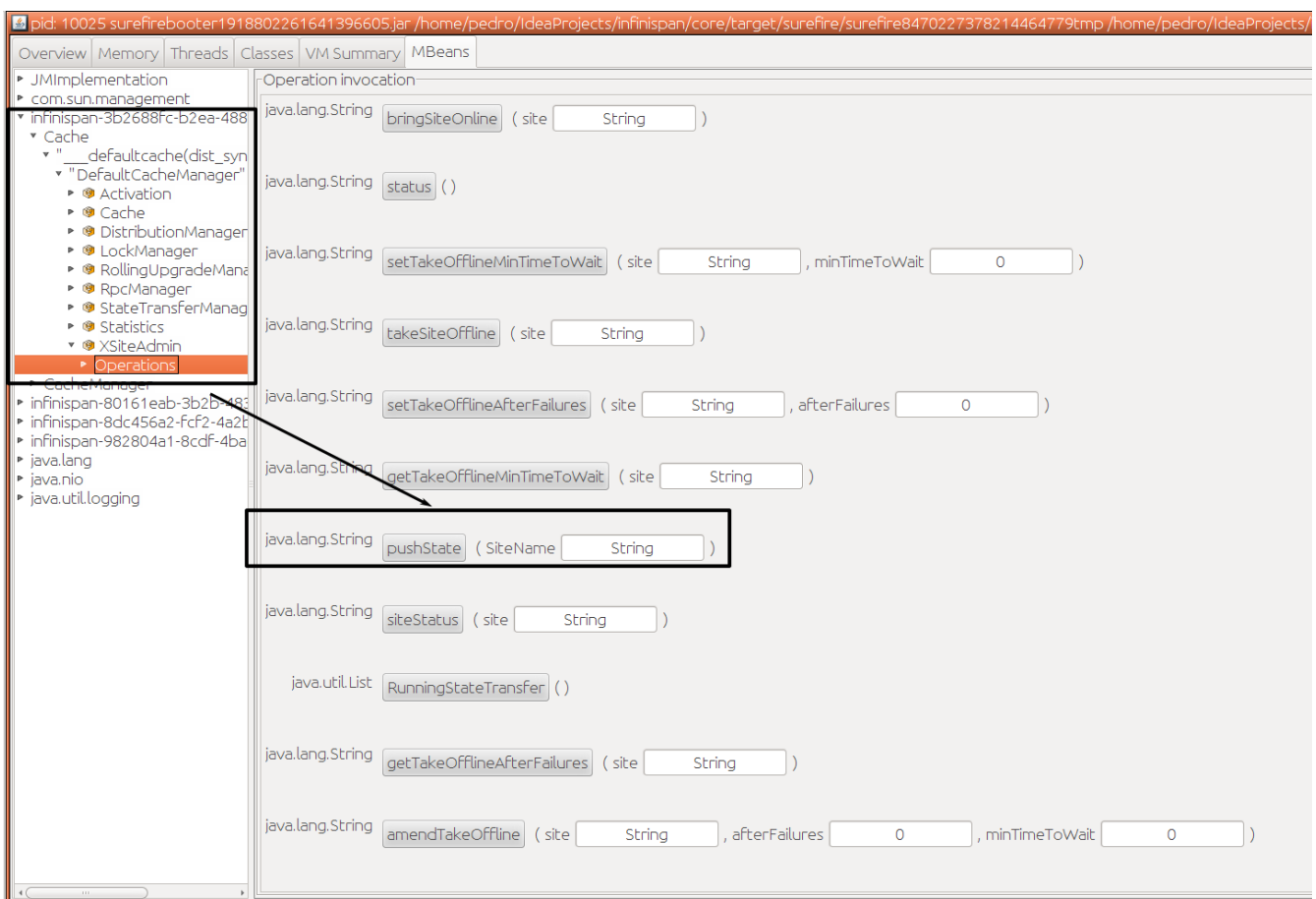


Figure 30. Pushing state via JConsole



The `pushState(siteName)` operation will automatically bring the new site online. The system administrator does not need to bring the site online first.



The receiver site can only receive state from a single site.

The consumer site can be in any state (online or offline) in respect to the provider site and the system administrator can trigger the push state at any time. The system will ignore multiple invocations if the provider site is already pushing state to the consumer site.

It is worth to refer that it is not necessary to consumer site to be in an empty state. But be aware, the existing keys can be overwritten but they are never deleted. In other words, if a key K does not exist in the provider site but it exists in consumer site, it will not be deleted. In other way, if a key K exists in both sites, it will be overwritten in the consumer site.

26.4.1. Handling join/leave nodes

The current implementation automatically handles the topology changes in producer or consumer site. Also, the cross-site state transfer can run in parallel with a local site state transfer.

26.4.2. Handling broken link between sites

A System Administrator action is needed if the link between the producer and consumer site is broken during the cross-site state transfer (data consistency is not ensured in consumer site). The producer site retries for a while before giving up. Then, it gets back to normal state. However, the consumer site is not able to get back to normal state and, here, an action from System Administrator is needed. The System Administrator should use the operation `cancelReceiveState(String siteName)` to bring the consumer site to normal state.

26.4.3. System Administrator Operations

A set of operations can be performed to control the cross-site state transfer:

- `pushState(String siteName)` - It starts the cross-site state transfer to the site name specified;
- `cancelPushState(String siteName)` - It cancels the cross-site state transfer to the site name specified;
- `getRunningStateTransfer()` - It returns a list of site name to which this site is pushing the state;
- `getSendingSiteName()` - It returns the site name that is pushing state to this site;
- `cancelReceiveState(String siteName)` - It restores the site to normal state. Should be used when the link between the sites is broken during the state transfer (as described above);
- `getPushStateStatus()` - It returns the status of completed cross-site state transfer;
- `clearPushStateStatus()` - It clears the status of completed cross-site state transfer.

For more technical information, you can check the Cross Site design document (See [Reference](#)).

26.4.4. Configuration

State transfer between sites cannot be enabled or disabled but it allows to tune some parameters. The values shown below are the default values:


```

<replicated-cache name="xSiteStateTransfer">
  ...
  <backups>
    <backup site="NYC" strategy="SYNC" failure-policy="FAIL">
      <state-transfer chunk-size="512" timeout="1200000" max-retries="30" wait-
time="2000" />
    </backup>
  </backups>
  ...
</replicated-cache>

```

The equivalent programmatic configuration is:

```

lon.sites().addBackup()
    .site("NYC")
    .backupFailurePolicy(BackupFailurePolicy.FAIL)
    .strategy(BackupConfiguration.BackupStrategy.SYNC)
    .stateTransfer()
        .chunkSize(512)
        .timeout(1200000)
        .maxRetries(30)
        .waitingTimeBetweenRetries(2000);

```

Below, it is the parameters description:

- *chunk-size* - The number of keys to batch before sending them to the consumer site. A negative or a zero value is **not** a valid value. Default value is 512 keys.
- *timeout* - The time (in milliseconds) to wait for the consumer site acknowledge the reception and appliance of a state chunk. A negative or zero value is **not** a valid value. Default value is 20 minutes.
- *max-retries* - The maximum number of retries when a push state command fails. A negative or a zero value means that the command will not retry in case of failure. Default value is 30.
- *wait-time* - The waiting time (in milliseconds) between each retry. A negative or a zero value is **not** a valid value. Default value is 2 seconds.

26.5. Reference

[This document](#) describes the technical design of cross site replication in more detail.

Chapter 27. Rolling upgrades

Rolling upgrades is the process by which an Infinispan installation is upgraded without a service shutdown. In the case of Infinispan library/embedded mode, it refers to an installation to the nodes where Infinispan is running in library/embedded mode. For Infinispan servers, it refers to the server side components, not the client side. The upgrade could involve hardware change, or software change, such as upgrading the Infinispan version in use.

Rolling upgrades can be done in Infinispan installations using Infinispan in embedded or library mode, or in server mode. Here are the instructions for each use case:

27.1. Rolling upgrades for Infinispan library/embedded mode

Rolling upgrades for Infinispan library/embedded mode are done taking advantage of the Command-Line Interface (CLI) that Infinispan provides in order to interact with a remote Infinispan cluster. When a new cluster is started, it will get the data from the existing cluster using the CLI, so the existing cluster must be ready to receive CLI requests. Please check the [Command-Line Interface \(CLI\) chapter](#) for information on how to set up a cluster to receive CLI requests.



Rolling upgrades for Infinispan library/embedded mode are only supported for caches using standard JDK types as keys. Custom keys are not currently supported. Custom value types are supported, using JSON as the format to ship them between source and target cluster.

27.1.1. Steps

1. Start a new cluster (*Target Cluster*) with the new version of Infinispan, using either different network settings or JGroups cluster name so that the old cluster (*Source Cluster*) and the new one don't overlap.
2. For each cache to be migrated, the *Target Cluster* is configured with a Command-Line Interface cache loader which will retrieve data from the source cluster, with these settings:
3. *connection*: JMX connection string to use to connect to *Source Cluster*. The connection string specifies how to connect to one of the source cluster members. Connection to one of the nodes is enough, there's no need to specify connection information for all nodes in the *Source Cluster*. The connection URL contains cache name information and this name must coincide with the name of the cache on the Source Cluster. The URL might change depending on the set up, check the Command-Line Interface chapter for more information. Here is a sample connection value:
`jmx://1.1.1.1:4444/MyCacheManager/myCache`
4. Configure clients to point to the *Target Cluster* instead of the *Source Cluster* , and one by one, restart each client node. Gradually, all requests will be handled by the *Target Cluster* rather than the *Source Cluster* . The *Target Cluster* will lazily load data from the *Source Cluster* on demand via the Command-Line Interface cache loader.
5. Once all connections have switched to using the *Target Cluster* the keyset on the *Source Cluster* must be dumped. This can be achieved either via a JMX operation or via the CLI:

6. JMX: invoke the *recordKnownGlobalKeyset* operation on the *RollingUpgradeManager* MBean on the *Source Cluster* for all of the caches that need to be migrated
7. CLI: invoke the *upgrade --dumpkeys* command on the *Source Cluster* for all of the caches that need to be migrated (additionally the *--all* switch can be used to dump all caches in the cluster)
8. At this point the *Target Cluster* needs to fetch all remaining data from the *Source Cluster* :
9. JMX: invoke the *synchronizeData* operation specifying the "cli" parameter on the *RollingUpgradeManager* MBean on the *Target Cluster* for all of the caches that need to be migrated
10. CLI: invoke the *upgrade --synchronize=cli* command on the *Target Cluster* for all of the caches that need to be migrated (additionally the *--all* switch can be used to synchronize all caches in the cluster)
11. Once the above operation is complete, the *CLInterfaceLoader* on the *Target Cluster* must be disabled as follows:
12. JMX: invoke the *disconnectSource* operation specifying the "cli" parameter on the *RollingUpgradeManager* MBean on the *Target Cluster* for all of the caches that have been migrated
13. CLI: invoke the *upgrade --disconnectsource=cli* command on the *Target Cluster* for all of the caches that have been migrated (additionally the *--all* switch can be used to disconnect all caches in the cluster)
14. The *Source Cluster* can be decommissioned now.

27.2. Rolling upgrades for Infinispan Servers

This process is used for installations making use of Infinispan as a remote grid, via Hot Rod. This assumes an upgrade of the Infinispan grid, and *not* the client application.

In the following description we will refer to the *Source* and *Target* clusters, where the *Source* cluster is the old cluster which is currently in use and the *Target* cluster is the new cluster to which the data will be migrated to.

27.3. Steps

1. Start a new cluster (*Target Cluster*) with the new version of Infinispan, using either different network settings or JGroups cluster name so that the old cluster (*Source Cluster*) and the new one don't overlap.
2. For each cache to be migrated, the *Target Cluster* is configured with a *RemoteCacheStore* with the following settings:
 - a. *servers* should point to the *Source Cluster*
 - b. *remoteCacheName* must coincide with the name of the cache on the *Source Cluster*
 - c. *hotRodWrapping* must be enabled (*true*)
 - d. *read-only* should be true

Configure clients to point to the *Target Cluster* instead of the *Source Cluster* , and one by one, restart each client node. Gradually, all requests will be handled by the *Target Cluster* rather than the *Source Cluster* . The *Target Cluster* will lazily load data from the *Source Cluster* on demand via the *RemoteCacheStore*.

4. If the *Source Cluster* version is **older than 8.2**, its keyset must be dumped. This can be achieved either via a JMX operation or via the CLI:
 - a. JMX: invoke the *recordKnownGlobalKeyset* operation on the *RollingUpgradeManager* MBean on the *Source Cluster* for all of the caches that need to be migrated
 - b. CLI: invoke the *upgrade --dumpkeys* command on the *Source Cluster* for all of the caches that need to be migrated (additionally the *--all* switch can be used to dump all caches in the cluster)
5. At this point the *Target Cluster* needs to fetch all remaining data from the *Source Cluster* . This can be achieved either via a JMX operation or via the CLI:
 - a. JMX: invoke the *synchronizeData* operation specifying the "hotrod" parameter on the *RollingUpgradeManager* MBean on the *Target Cluster* for all of the caches that need to be migrated
 - b. CLI: invoke the *upgrade --synchronize=hotrod* command on the *Target Cluster* for all of the caches that need to be migrated (additionally the *--all* switch can be used to synchronize all caches in the cluster)
6. Once the above operation is complete, the *RemoteCacheStore* on the *Target Cluster* must be disabled either via JMX or CLI:
 - a. JMX: invoke the *disconnectSource* operation specifying the "hotrod" parameter on the *RollingUpgradeManager* MBean on the *Target Cluster* for all of the caches that have been migrated
 - b. CLI: invoke the *upgrade --disconnectsource=hotrod* command on the *Target Cluster* for all of the caches that have been migrated (additionally the *--all* switch can be used to disconnect all caches in the cluster)
7. The *Source Cluster* can be decommissioned now.

Chapter 28. Customizing Key/Value Comparisons

28.1. The Problem of Caching Arrays

There are times when users want to store data into Infinispan caches whose default `equals()` and/or `hashCode()` implementations produce undesirable results. One of those data types are arrays. When users want to store arrays into Infinispan caches, the big majority of users want `equals()` function to be calculated based on the contents of the arrays as opposed to comparing the object reference, so if we take byte arrays as example, users would like to call up the static `java.util.Arrays.equals(byte[], byte[])` method instead of `Object.equals()`. The same thing happens with `hashCode()`. The default implementation of `Object.hashCode()` for arrays suffers from the same issue, because the result is not produced based on the contents of the array, but rather based on the object reference to the array.

28.2. Old workaround: Wrapper Classes

Until Infinispan 5.2, the way to get around these issues was by wrapping arrays, or any other object whose `equals()/hashCode()` implementations are not best suited for being stored in Infinispan caches, around another object which would override `Object.equals()` and `Object.hashCode()` to do the correct calculations. This is where classes such as [ByteArrayKey](#) originated:

```

public final class ByteArrayKey implements Serializable {

    private final byte[] data;
    private final int hashCode;

    public ByteArrayKey(byte[] data) {
        this.data = data;
        this.hashCode = 41 + Arrays.hashCode(data);
    }

    public byte[] getData() {
        return data;
    }

    @Override
    public boolean equals(Object obj) {
        if (this == obj) return true;
        if (obj == null || ByteArrayKey.class != obj.getClass()) return false;
        ByteArrayKey key = (ByteArrayKey) obj;
        return Arrays.equals(key.data, this.data);
    }

    @Override
    public int hashCode() {
        return hashCode;
    }

    @Override
    public String toString() {
        return new StringBuilder().append("ByteArrayKey").append("{")
            .append("data=").append(Util.printArray(data, true))
            .append("}").toString();
    }
}

```

The problem with these classes is that they result in extra memory consumption due to the extra objects required to support data types such as arrays and really, these classes just a workaround for the lack of ability to provide a way to pass in a function that specifies how two byte arrays are compared, or how to calculate the hash code of a given array.

28.3. New solution: Plugging Equivalence functions

Starting with Infinispan 5.3, Infinispan users can provide these functions for both keys and values implementing the new `Equivalence<T>` interface:

```

public interface Equivalence<T> extends Serializable {

```

```

/**
 * Returns a hash code value for the object passed.
 *
 * As an example, implementors can provide an alternative implementation
 * for the hash code calculation for arrays. So, instead of relying on
 * {@link Object#hashCode()}, call {@link java.util.Arrays.hashCode()}.
 *
 * @param obj instance to calculate hash code for
 * @return a hash code value for the object passed as parameter
 */
int hashCode(Object obj);

/**
 * Indicates whether the objects passed are "equal to" each other.
 *
 * As an example, implementors can provide an alternative implementation
 * for the equals for arrays. So, instead of relying on
 * {@link Object#equals(Object)}, call {@link java.util.Arrays.equals()}.
 *
 * @param obj to be compared with second parameter
 * @param otherObj to be compared with first parameter
 * @return <code>true</code> if both objects are the same;
 *         <code>false</code> otherwise
 */
boolean equals(T obj, Object otherObj);

/**
 * Returns a string representation of the given object.
 *
 * @param obj whose string representation is to be returned
 * @return a string representation of the passed object
 */
String toString(Object obj);

/**
 * Returns whether the given object is comparable. In other words, if
 * given an instance of the object, a sensible comparison can be computed
 * using {@link #compare(Object, Object)} method.
 *
 * @param obj instance to check if it's comparable
 * @return <code>true</code> if the object is comparable;
 *         <code>false</code> otherwise
 */
boolean isComparable(Object obj); // For future support for objects that are not
comparable, i.e. arrays

/**
 * Compares the two given objects for order. Returns a negative integer,
 * zero, or a positive integer as the first object is less than, equal to,
 * or greater than the second object.
 *

```

```
* @param obj first object to be compared
* @param otherObj second object to be compared
* @return a negative integer, zero, or a positive integer as the
*         first object is less than, equal to, or greater than the
*         second object
*/
int compare(Object obj, Object otherObj); // For future support for objects that
are not comparable, i.e. arrays

}
```

Implementations of these function can be pretty flexible. On one side, they could focus on a single, particular type, such as `ByteArrayEquivalence` below which expects nothing else other than byte arrays, such as in the case of Hot Rod based Infinispan remote caches:


```

package com.acme;

public class ByteArrayEquivalence implements Equivalence<byte[]> {

    public static final Equivalence<byte[]> INSTANCE = new ByteArrayEquivalence();

    @Override
    public int hashCode(Object obj) {
        return 41 + Arrays.hashCode((byte[]) obj);
    }

    @Override
    public boolean equals(byte[] obj, Object otherObj) {
        if (obj == otherObj) return true;
        if (obj == null) return false;
        if (otherObj == null || byte[].class != otherObj.getClass()) return false;
        byte[] otherByteArray = (byte[]) otherObj;
        return Arrays.equals(obj, otherByteArray);
    }

    @Override
    public String toString(Object obj) {
        return Arrays.toString((byte[]) obj);
    }

    @Override
    public boolean isComparable(Object obj) {
        return false;
    }

    @Override
    public int compare(Object obj, Object otherObj) {
        return 0; // irrelevant
    }

}

```

Or you could have implementations that support multiple different types, in case you store varied information, for example [AnyServerEquivalence](#) which supports both arrays and normal objects:

```

public class AnyServerEquivalence implements Equivalence<Object> {

    private static boolean isByteArray(Object obj) {
        return byte[].class == obj.getClass();
    }

    @Override
    public int hashCode(Object obj) {
        if (isByteArray(obj)) {
            return 41 + Arrays.hashCode((byte[]) obj);
        } else {
            return obj.hashCode();
        }
    }

    @Override
    public boolean equals(Object obj, Object otherObj) {
        if (obj == otherObj)
            return true;
        if (obj == null || otherObj == null)
            return false;
        if (isByteArray(obj) && isByteArray(otherObj))
            return Arrays.equals((byte[]) obj, (byte[]) otherObj);
        return obj.equals(otherObj);
    }

    @Override
    public String toString(Object obj) {
        if (isByteArray(obj))
            return Arrays.toString((byte[]) obj);
        else
            return obj.toString();
    }

    @Override
    public boolean isComparable(Object obj) {
        return obj instanceof Comparable;
    }

    @Override
    @SuppressWarnings("unchecked")
    public int compare(Object obj, Object otherObj) {
        return ((Comparable<Object>) obj).compareTo(otherObj);
    }
}

```

28.3.1. Configuring Equivalence functions

Using XML

The way to configure Infinispan with these Equivalence implementations is by adding them to the `<data-container />` XML element. For example, if we wanted to have byte array based keys, but the values would be normal objects, we'd define:

```
<dataContainer keyEquivalence="com.acme.ByteArrayEquivalence" />
```

If you were trying to store both byte arrays as keys and values, you'd configure `valueEquivalence` attribute in `<dataContainer />` XML element:

```
<dataContainer keyEquivalence="com.acme.ByteArrayEquivalence" valueEquivalence="com.acme.ByteArrayEquivalence" />
```

If no key or value equivalence is configured, they default to [org.infinispan.commons.equivalence.AnyEquivalence](https://github.com/infinispan/infinispan-commons/blob/master/infinispan-commons/src/main/java/org/infinispan/commons/equivalence/AnyEquivalence.java), which behaves like any standard java object, delegating the `equals/hashCode()` calls to the objects themselves.

Using Programmatic Configuration

Key and/or value equivalence could also have been configured programmatically, for example:

```
EmbeddedCacheManager cacheManager = ...;
ConfigurationBuilder builder = new ConfigurationBuilder();
builder.dataContainer()
    .keyEquivalence(com.acme.ByteArrayEquivalence.INSTANCE)
    .valueEquivalence(com.acme.ByteArrayEquivalence.INSTANCE);
cacheManager.defineConfiguration("myCache", builder.build());
```

28.3.2. Byte array storage example

Assuming you've configured both `keyEquivalence` (via XML, or programmatically) to be `com.acme.ByteArrayEquivalence`, you should now be able to write code like this and get the assertion to succeed. If `keyEquivalence` has not been configured correctly, this test will fail:

```
Cache<byte[], byte[]> cache = ...
byte[] key = {1, 2, 3};
byte[] value = {4, 5, 6};
cache.put(key, value);

byte[] expectedValue = {4, 5, 6};
byte[] lookupKey = {1, 2, 3};
assert Arrays.equals(expectedValue, cache.get(lookupKey));
```

28.3.3. Other methods in Equivalence interface

Finally, Equivalence defines some extra methods, such as `toString(Object obj)` , `isComparable(Object obj)` and `compare(Object obj, Object otherObj)` , which again can be used to provide different implementations to the ones provided for the JDK. For example, the `toString()` method can be used to provide a different String representation of the object, which is again useful for arrays since the default JDK implementation does not print the array contents. The comparable functions are not yet used by Infinispan but they've been defined in order to help with potential future support of tree-based storage in inner data structures.

Chapter 29. Functional Map API

Infinispan 8 introduces a new 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.

29.1. 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.

29.2. 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.

29.3. 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.commons.api.functional.FunctionalMap.*;
import org.infinispan.functional.impl.*;

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.

29.4. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;

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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import org.infinispan.commons.api.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.

29.4.1. 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 section](#) to find out more.

29.5. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.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 (see [functional listeners section](#) for more information) 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");
```

29.5.1. 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 section](#) to find out more).
- `remove()` method removes the cache entry, including both value and metadata parameters associated with this key.

29.6. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.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.

29.6.1. 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](#)

29.7. 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 [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 view](#) 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import org.infinispan.commons.api.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.

29.8. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import org.infinispan.commons.api.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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import org.infinispan.commons.api.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.

29.9. 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](#).

29.9.1. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import org.infinispan.commons.api.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();
```

29.9.2. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;
import
org.infinispan.commons.api.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();

```

29.10. 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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.functional.FunctionalMap.*;

WriteOnlyMap<String, String> writeOnlyMap = ...

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

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

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

```
import org.infinispan.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.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.commons.api.functional.EntryView.*;
import org.infinispan.commons.api.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));
```

29.11. 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 wanting 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...etc.