Memory Management

You can specify the total memory (RAM) size used for internal caching and compacting of records. This caching happens before the records are written to state stores or forwarded downstream to other nodes.

The record caches are implemented slightly different in the DSL and Processor API.

Record caches in the DSL

You can specify the total memory (RAM) size of the record cache for an instance of the processing topology. It is leveraged by the following `KTable` instances:

- Source `KTable`: `KTable` instances that are created via `StreamsBuilder#table()` or `StreamsBuilder#globalTable()`.
- Aggregation `KTable`: instances of `KTable` that are created as a result ofaggregations.

For such `KTable` instances, the record cache is used for:

- Internal caching and compacting of output records before they are written by the underlying statefulprocessor node to its internal state stores.
- Internal caching and compacting of output records before they are forwarded from the underlying statefulprocessor node to any of its downstream processor nodes.

Use the following example to understand the behaviors with and without record caching. In this example, the input is a `KStream<String, Integer>` with the records `<K,V>: <A, 1>, <D, 5>, <A, 20>, <A, 300>`. The focus in this example is on the records with key == `A`.

- An aggregation computes the sum of record values, grouped by key, for the input and returns a `KTable<String, Integer>`.

  - **Without caching**: a sequence of output records is emitted for key `A` that represent changes in the resulting aggregation table. The parentheses (`()`) denote changes, the left number is the new aggregate value and the right number is the old aggregate value: `<A, (1, null)>, <A, (21, 1)>, <A, (321, 21)>`.
  - **With caching**: a single output record is emitted for key `A` that would likely be compacted in the cache, leading to a single output record of `<A, (321, null)>`. This record is written to the aggregation's internal state store and forwarded to any downstream operations.

The cache size is specified through the `cache.max.bytes.buffering` parameter, which is a global setting per processing topology:

```
// Enable record cache of size 10 MB.
Properties streamsConfiguration = new Properties();
streamsConfiguration.put(StreamsConfig.CACHE_MAX_BYTES_BUFFERING_CONFIG, 10 * 1024 * 1024L);
```

This parameter controls the number of bytes allocated for caching. Specifically, for a processor topology instance wit`T` threads and `C` bytes allocated for caching, each thread will have an even `C/T` bytes to construct its own cache and use as it sees fit among its tasks. This means that there are as many caches as there are threads, but no sharing of caches across threads happens.

The basic API for the cache is made of `put()` and `get()` calls. Records are evicted using a simple LRU scheme after the cache size is reached. The first time a keyed record `R1 = <K1, V1>` finishes processing at a node, it is marked as dirty in the cache. Any other keyed record `R2 = <K1, V2>` with the same key `K1` that is processed on that node during that time will overwrite `<K1, V1>`, this is referred to as "being compacted". This has the same effect as Kafka's log compaction, but happens earlier, while the records are still in memory, and within your client-side application, rather than on the server-side (i.e. the Apache Kafka® broker). After flushing, `R2` is forwarded to the next processing node and then written to the local state store.

The semantics of caching is that data is flushed to the state store and forwarded to the next downstream processor node whenever t

of `commit.interval.ms` or `cache.max.bytes.buffering` (cache pressure) hits. Both `commit.interval.ms` and `cache.max.bytes.buffering` are global parameters. As such, it is not possible to specify different parameters for individual nodes.

Here are example settings for both parameters based on desired scenarios.

- To turn off caching the cache size can be set to zero:

```
// Disable record cache
Properties streamsConfiguration = new Properties();
streamsConfiguration.put(StreamsConfig.CACHE_MAX_BYTES_BUFFERING_CONFIG, 0);
```

Turning off caching might result in high write traffic for the underlying RocksDB store. With default settings caching is enabled within Kafka Streams but RocksDB caching is disabled. Thus, to avoid high write traffic it is recommended to enable RocksDB caching if Kafka Streams caching is turned off.

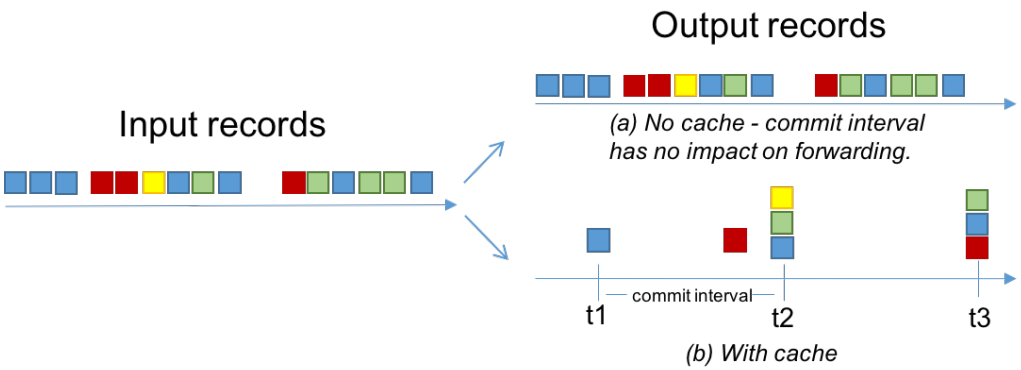
For example, the RocksDB Block Cache could be set to 100MB and Write Buffer size to 32 MB. For more information, see the RocksDB config.

- To enable caching but still have an upper bound on how long records will be cached, you can set the commit interval. In this example, it is set to 1000 milliseconds:

```
Properties streamsConfiguration = new Properties();
// Enable record cache of size 10 MB.
streamsConfiguration.put(StreamsConfig.CACHE_MAX_BYTES_BUFFERING_CONFIG, 10 * 1024 * 1024L);
// Set commit interval to 1 second.
streamsConfiguration.put(StreamsConfig.COMMIT_INTERVAL_MS_CONFIG, 1000);
```

The effect of these two configurations is described in the figure below. The records are shown using 4 keys: blue, red, yellow, and green. Assume the cache has space for only 3 keys.

- When the cache is disabled (a), all of the input records will be output.
- When the cache is enabled (b):
  - Most records are output at the end of commit intervals (e.g., at `t1` a single blue record is output, which is the final over-write of the blue key up to that time).
  - Some records are output because of cache pressure (i.e. before the end of a commit interval). For example, see the red record before `t2`. With smaller cache sizes we expect cache pressure to be the primary factor that dictates when records are output. With large cache sizes, the commit interval will be the primary factor.
  - The total number of records output has been reduced from 15 to 8.



Record caches in the Processor API

You can specify the total memory (RAM) size of the record cache for an instance of the processing topology. It is used for internal caching and compacting of output records before they are written from a stateful processor node to its state stores.

The record cache in the Processor API does not cache or compact any output records that are being forwarded downstream. This means that all downstream processor nodes can see all records, whereas the state stores see a reduced number of records. This does not impact correctness of the system, but is a performance optimization for the state stores. For example, with the Processor API you can store a record in a state store while forwarding a different value downstream.

Following from the example first shown in section State Stores, to enable caching, you can add the `withCachingEnabled` call.

```
StoreBuilder countStoreBuilder =
  Stores.keyValueStoreBuilder(
    Stores.persistentKeyValueStore("Counts"),
    Serdes.String(),
    Serdes.Long())
  .withCachingEnabled()
```

RocksDB

Each instance of RocksDB allocates off-heap memory for a block cache, index and filter blocks, and memtable (write buffer). Critical configs (for RocksDB version 4.1.0) include `block_cache_size`, `write_buffer_size` and `max_write_buffer_number`. These can be specified through the `rocksdb.config.setter` configuration.

As of 5.3.0 the memory usage across all instances can be bounded, limiting the total off-heap memory of your Kafka Streams application. To do so you must configure RocksDB to cache the index and filter blocks in the block cache, limit the memtable memory through a shared WriteBufferManager and count its memory against the block cache, and then pass the same `Cache` object to each instance. See RocksDB Memory Usage for details. An example `RocksDBConfigSetter` implementing this is shown below:

```
public static class BoundedMemoryRocksDBConfig implements RocksDBConfigSetter {

  // See #1 below
  private static org.rocksdb.Cache cache = new org.rocksdb.LRUCache(TOTAL_OFF_HEAP_MEMORY, -1, false, INDEX_FILTER_BLO
CK_RATIO);
  private static org.rocksdb.WriteBufferManager writeBufferManager = new org.rocksdb.WriteBufferManager(TOTAL_MEMTABLE
_MEMORY, cache);

  @Override
  public void setConfig(final String storeName, final Options options, final Map<String, Object> configs) {

    BlockBasedTableConfig tableConfig = (BlockBasedTableConfig) options.tableFormatConfig();

    // These three options in combination will limit the memory used by RocksDB to the size passed to the block cache (T
TAL_OFF_HEAP_MEMORY)
    tableConfig.setBlockCache(cache);
    tableConfig.setCacheIndexAndFilterBlocks(true);
    options.setWriteBufferManager(writeBufferManager);

    // These options are recommended to be set when bounding the total memory
    // See #2 below
    tableConfig.setCacheIndexAndFilterBlocksWithHighPriority(true);
    tableConfig.setPinTopLevelIndexAndFilter(true);
    // See #3 below
    tableConfig.setBlockSize(BLOCK_SIZE);
    options.setMaxWriteBufferNumber(N_MEMTABLES);
    options.setWriteBufferSize(MEMTABLE_SIZE);

    options.setTableFormatConfig(tableConfig);
  }

  @Override
  public void close(final String storeName, final Options options) {
    // Cache and WriteBufferManager should not be closed here, as the same objects are shared by every store instance.
  }
}
```

Footnotes:

1. `INDEX_FILTER_BLOCK_RATIO` can be used to set a fraction of the block cache to set aside for "high priority" (aka index and filter) blocks,

preventing them from being evicted by data blocks. See the full signature of the LRUCache constructor.
2. This must be set in order for `INDEX_FILTER_BLOCK_RATIO` to take effect (see footnote 1) as described in the RocksDB docs.
3. You may want to modify the default block size per these instructions from the RocksDB GitHub. A larger block size means index blocks will be smaller, but the cached data blocks may contain more cold data that would otherwise be evicted.

Note: While we recommend setting at least the above configs, the specific options that yield the best performance are workload dependent and you should consider experimenting with these to determine the best choices for your specific use case. Keep in mind that the optimal configs for one app may not apply to one with a different topology or input topic. In addition to the recommended configs above, you may want to consider using partitioned index filters as described by the RocksDB docs.

Other memory usage

There are other modules inside Kafka that allocate memory during runtime. They include the following:

- Producer buffering, managed by the producer config `buffer.memory`.
- Consumer buffering, currently not strictly managed, but can be indirectly controlled by fetch size, i.e. `fetch.max.bytes` and `fetch.max.wait.ms`.
- Both producer and consumer also have separate TCP send / receive buffers that are not counted as the buffering memory. These are controlled by the `send.buffer.bytes` / `receive.buffer.bytes` configs.
- Deserialized objects buffering: after `consumer.poll()` returns records, they will be deserialized to extract timestamp and buffered in the streams space. Currently this is only indirectly controlled by `buffered.records.per.partition`.

Tip

Iterators should be closed explicitly to release resources: Store iterators (e.g., `KeyValueIterator` and `WindowStoreIterator`) must be closed explicitly upon completeness to release resources such as open file handlers and in-memory read buffers, or use try-with-resources statement (available since JDK7) for this Closeable class.

Otherwise, stream application's memory usage keeps increasing when running until it hits an OOM.

Last updated on Sep 10, 2019.