深入理解Spark 2.1 Core（十一）：Shuffle Reduce 端的原理与源码分析

http://blog.csdn.net/u011239443/article/details/56843264

在《深入理解Spark 2.1 Core （九）：迭代计算和Shuffle的原理与源码分析 》我们讲解了，以传统Hadoop MapReduce类似的从HDFS中读取数据，再到`rdd.HadoopRDD.compute`便可以调用函数`f`，即`map`中的函数的过程。在《深入理解Spark 2.1 Core （十）：Shuffle map端的原理与源码分析》 我们深入讲解了`sorter.insertAll(records)`，即如何对数据进行排序并写入内存缓冲区。

我们曾经在《深入理解Spark 2.1 Core （一）：RDD的原理与源码分析 》讲解过：

> 为了有效地实现容错，RDD提供了一种高度受限的共享内存，即RDD是只读的，并且只能通过其他RDD上的批量操作来创建（注：还可以由外部存储系数据集创建，如HDFS）

可知，我们在第九，第十篇博文所讲的是传统Hadoop MapReduce类似的，在最初从HDFS中读取数据生成`HadoopRDD`的过程。而RDD可以通过其他RDD上的批量操作来创建，所以这里的`HadoopRDD`对于下一个生成的`ShuffledRDD`可以视为`Map`端，当然下一个生成的`ShuffledRDD`可以被下下个`ShuffledRDD`视为`Map`端。反过来说，下一个`ShuffledRDD`可以被`HadoopRDD`视作`Reduce`端。

这篇博文，我们就来讲下`Shuffle`的`Reduce`端。其实在`RDD`迭代部分和第九篇博文类似，不同的是，这里调用的是`rdd.ShuffledRDD.compute`：

```
override def compute(split: Partition, context: TaskContext): Iterator[(K, C)] = {
// 得到依赖
  val dep = dependencies.head.asInstanceOf[ShuffleDependency[K, V, C]]
  // 调用getReader，传入dep.shuffleHandle 分区 上下文
  // 得到Reader，调用read()
  // 得到迭代器
   SparkEnv.get.shuffleManager.getReader(dep.shuffleHandle, split.index, split.index + 1, context)
    .read()
    .asInstanceOf[Iterator[(K, C)]]
}
```

这里调用的是`shuffle.sort.SortShuffleManager`的`getReader`：

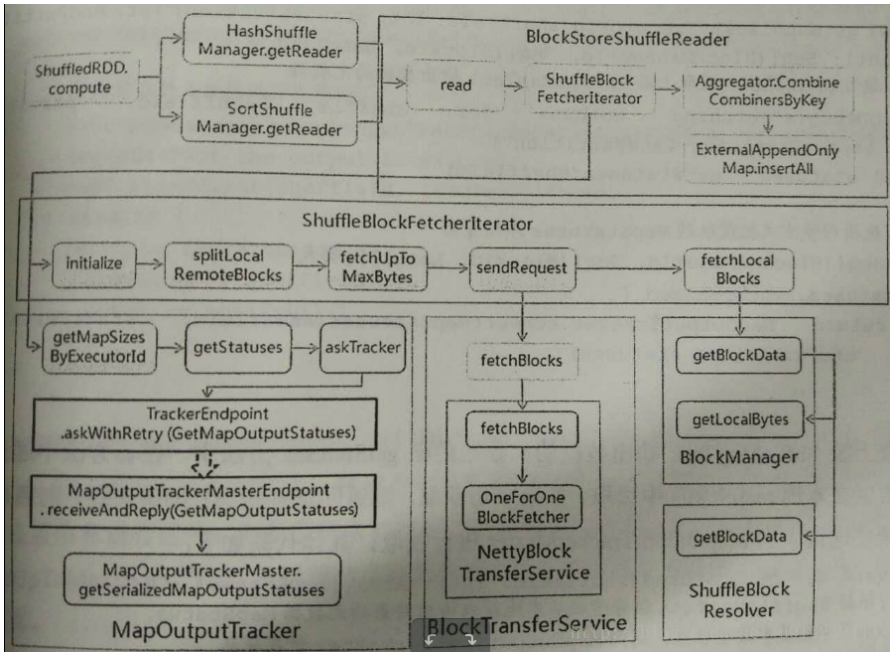
```
override def getReader[K, C](
    handle: ShuffleHandle,
    startPartition: Int,
    endPartition: Int,
    context: TaskContext): ShuffleReader[K, C] = {
    // 生成返回 BlockStoreShuffleReader
  new BlockStoreShuffleReader(
    handle.asInstanceOf[BaseShuffleHandle[K, _, C]], startPartition, endPartition, context)
}
```

`shuffle.BlockStoreShuffleReader.read`：

```
override def read(): Iterator[Product2[K, C]] = {
// 实例化ShuffleBlockFetcherIterator
  val blockFetcherItr = new ShuffleBlockFetcherIterator(
    context,
    blockManager.shuffleClient,
    blockManager,
    // 通过消息发送获取 ShuffleMapTask 存储数据位置的元数据
    mapOutputTracker.getMapSizesByExecutorId(handle.shuffleId, startPartition, endPartition),
    // 设置每次传输的大小
    SparkEnv.get.conf.getSizeAsMb("spark.reducer.maxSizeInFlight", "48m") * 1024 * 1024,
    // // 设置Int的大小
    SparkEnv.get.conf.getInt("spark.reducer.maxReqsInFlight", Int.MaxValue))
```

```
13
14      // 基于配置的压缩和加密来包装流
15      val wrappedStreams = blockFetcherItr.map { case (blockId, inputStream) =>
16        serializerManager.wrapStream(blockId, inputStream)
17      }
18
19      val serializerInstance = dep.serializer.newInstance()
20
21      // 对每个流生成 k/v 迭代器
22      val recordIter = wrappedStreams.flatMap { wrappedStream =>
23        serializerInstance.deserializeStream(wrappedStream).asKeyValueIterator
24      }
25
26
27      // 每条记录读取后更新任务度量
28      val readMetrics = context.taskMetrics.createTempShuffleReadMetrics()
29      // 生成完整的迭代器
30      val metricIter = CompletionIterator[(Any, Any), Iterator[(Any, Any)]](
31        recordIter.map { record =>
32          readMetrics.incRecordsRead(1)
33          record
34        },
35        context.taskMetrics().mergeShuffleReadMetrics())
36
37      // 传入metricIter到可中断的迭代器
38      // 为了能取消迭代
39      val interruptibleIter = new InterruptibleIterator[(Any, Any)](context, metricIter)
40
41      val aggregatedIter: Iterator[Product2[K, C]] = if (dep.aggregator.isDefined) {
42      // 若需要对数据进行聚合
43        if (dep.mapSideCombine) {
44          // 若需要进行Map端（对于下一个Shuffle来说）的合并
45          val combinedKeyValuesIterator = interruptibleIter.asInstanceOf[Iterator[(K, C)]]
46          dep.aggregator.get.combineCombinersByKey(combinedKeyValuesIterator, context)
47          // 若只需要进行Reduce端（对于下一个Shuffle来说）的合并
48        } else {
49          val keyValuesIterator = interruptibleIter.asInstanceOf[Iterator[(K, Nothing)]]
50          dep.aggregator.get.combineValuesByKey(keyValuesIterator, context)
51        }
52      } else {
53        require(!dep.mapSideCombine, "Map-side combine without Aggregator specified!")
54        interruptibleIter.asInstanceOf[Iterator[Product2[K, C]]]
55      }
56
57
58      dep.keyOrdering match {
59        case Some(keyOrd: Ordering[K]) =>
60        // 若需要排序
61        // 若spark.shuffle.spill设置为否的话
62        // 将不会spill到磁盘
63          val sorter =
64            new ExternalSorter[K, C, C](context, ordering = Some(keyOrd), serializer = dep.serializer)
65          sorter.insertAll(aggregatedIter)
66          context.taskMetrics().incMemoryBytesSpilled(sorter.memoryBytesSpilled)
67          context.taskMetrics().incDiskBytesSpilled(sorter.diskBytesSpilled)
68          context.taskMetrics().incPeakExecutionMemory(sorter.peakMemoryUsedBytes)
69          CompletionIterator[Product2[K, C], Iterator[Product2[K, C]]](sorter.iterator, sorter.stop())
70        case None =>
71          aggregatedIter
72      }
73    }
```

类调用关系图：



下面我们来深入讲解下实例化`ShuffleBlockFetcherIterator`的过程:

```
// 实例化ShuffleBlockFetcherIterator
  val blockFetcherItr = new ShuffleBlockFetcherIterator(
    context,
    blockManager.shuffleClient,
    blockManager,
    // 通过消息发送获取 ShuffleMapTask 存储数据位置的元数据
    mapOutputTracker.getMapSizesByExecutorId(handle.shuffleId, startPartition, endPartition),
    // 设置每次传输的大小
    SparkEnv.get.conf.getSizeAsMb("spark.reducer.maxSizeInFlight", "48m") * 1024 * 1024,
    // // 设置Int的大小
    SparkEnv.get.conf.getInt("spark.reducer.maxReqsInFlight", Int.MaxValue))
```

获取元数据

mapOutputTracker.getMapSizesByExecutorId

首先我们会调用`mapOutputTracker.getMapSizesByExecutorId`：

```
def getMapSizesByExecutorId(shuffleId: Int, startPartition: Int, endPartition: Int)
    : Seq[(BlockManagerId, Seq[(BlockId, Long)])] = {
  logDebug(s"Fetching outputs for shuffle $shuffleId, partitions $startPartition-$endPartition")
  // 得到元数据
  val statuses = getStatuses(shuffleId)
  // 返回格式为：
  // Seq[BlockManagerId,Seq[(shuffle block id, shuffle block size)]]
  statuses.synchronized {
    return MapOutputTracker.convertMapStatuses(shuffleId, startPartition, endPartition, statuses)
  }
}
```

mapOutputTracker.getStatuses

```
private def getStatuses(shuffleId: Int): Array[MapStatus] = {
// 尝试从本地获取数据
  val statuses = mapStatuses.get(shuffleId).orNull
  if (statuses == null) {
  // 若本地无数据
```

```
      logInfo("Don't have map outputs for shuffle " + shuffleId + ", fetching them")
      val startTime = System.currentTimeMillis
      var fetchedStatuses: Array[MapStatus] = null
      fetching.synchronized {
        // 若以及有其他人也准备远程获取这数据的话
        // 则等待
        while (fetching.contains(shuffleId)) {
          try {
            fetching.wait()
          } catch {
            case e: InterruptedException =>
          }
        }

        // 尝试直接获取数据
        fetchedStatuses = mapStatuses.get(shuffleId).orNull
        if (fetchedStatuses == null) {
          // 若还是不得不远程获取，
          // 则将shuffleId加入fetching
          fetching += shuffleId
        }
      }

      if (fetchedStatuses == null) {
        logInfo("Doing the fetch; tracker endpoint = " + trackerEndpoint)
        try {
        // 远程获取
          val fetchedBytes = askTracker[Array[Byte]](GetMapOutputStatuses(shuffleId))
          // 反序列化
          fetchedStatuses = MapOutputTracker.deserializeMapStatuses(fetchedBytes)
          logInfo("Got the output locations")
          // 将数据加入mapStatuses
          mapStatuses.put(shuffleId, fetchedStatuses)
        } finally {
          fetching.synchronized {
            fetching -= shuffleId
            fetching.notifyAll()
          }
        }
      }
      logDebug(s"Fetching map output statuses for shuffle $shuffleId took " +
        s"${System.currentTimeMillis - startTime} ms")

      if (fetchedStatuses != null) {
      // 若直接获取，则直接返回
        return fetchedStatuses
      } else {
        logError("Missing all output locations for shuffle " + shuffleId)
        throw new MetadataFetchFailedException(
          shuffleId, -1, "Missing all output locations for shuffle " + shuffleId)
      }
    } else {
    // 若直接获取，则直接返回
      return statuses
    }
  }
```

mapOutputTracker.askTracker

向`trackerEndpoint`发送消息`GetMapOutputStatuses(shuffleId)`

```
  protected def askTracker[T: ClassTag](message: Any): T = {
    try {
      trackerEndpoint.askWithRetry[T](message)
```

```
    } catch {
      case e: Exception =>
        logError("Error communicating with MapOutputTracker", e)
        throw new SparkException("Error communicating with MapOutputTracker", e)
    }
  }
```

MapOutputTrackerMasterEndpoint.receiveAndReply

```
    case GetMapOutputStatuses(shuffleId: Int) =>
      val hostPort = context.senderAddress.hostPort
      logInfo("Asked to send map output locations for shuffle " + shuffleId + " to " + hostPort)
      val mapOutputStatuses = tracker.post(new GetMapOutputMessage(shuffleId, context))
```

可以看到，这里并不是直接返回消息，而是调用`tracker.post`：

```
  def post(message: GetMapOutputMessage): Unit = {
    mapOutputRequests.offer(message)
  }
```

向`mapOutputRequests`加入`GetMapOutputMessage(shuffleId, context)`消息。这里的`mapOutputRequests`是链式阻塞队列。

```
  private val mapOutputRequests = new LinkedBlockingQueue[GetMapOutputMessage]
```

MapOutputTrackerMaster.MessageLoop.run

`MessageLoop`启一个线程不断的参数从`mapOutputRequests`读取数据：

```
  private class MessageLoop extends Runnable {
    override def run(): Unit = {
      try {
        while (true) {
          try {
            val data = mapOutputRequests.take()
             if (data == PoisonPill) {
              mapOutputRequests.offer(PoisonPill)
              return
            }
            val context = data.context
            val shuffleId = data.shuffleId
            val hostPort = context.senderAddress.hostPort
            logDebug("Handling request to send map output locations for shuffle " + shuffleId +
              " to " + hostPort)
              // 若读到数据
              // 则序列化
            val mapOutputStatuses = getSerializedMapOutputStatuses(shuffleId)
            // 返回数据
            context.reply(mapOutputStatuses)
          } catch {
            case NonFatal(e) => logError(e.getMessage, e)
          }
        }
      } catch {
        case ie: InterruptedException => // exit
      }
    }
  }
```

MapOutputTracker.convertMapStatuses

我们回到`mapOutputTracker.getMapSizesByExecutorId`中返回的`MapOutputTracker.convertMapStatuses`：

```
private def convertMapStatuses(
    shuffleId: Int,
    startPartition: Int,
    endPartition: Int,
    statuses: Array[MapStatus]): Seq[(BlockManagerId, Seq[(BlockId, Long)])] = {
  assert (statuses != null)
  val splitsByAddress = new HashMap[BlockManagerId, ArrayBuffer[(BlockId, Long)]]
  for ((status, mapId) <- statuses.zipWithIndex) {
    if (status == null) {
      val errorMessage = s"Missing an output location for shuffle $shuffleId"
      logError(errorMessage)
      throw new MetadataFetchFailedException(shuffleId, startPartition, errorMessage)
    } else {
      for (part <- startPartition until endPartition) {
      // 返回的Seq中的结构是status.location，Seq[ShuffleBlockId,SizeForBlock]
        splitsByAddress.getOrElseUpdate(status.location, ArrayBuffer()) +=
          ((ShuffleBlockId(shuffleId, mapId, part), status.getSizeForBlock(part)))
      }
    }
  }
  // 对Seq根据status.location进行排序
  splitsByAddress.toSeq
}
```

划分本地和远程Block

让我回到`new ShuffleBlockFetcherIterator`

storage.ShuffleBlockFetcherIterator.initialize

当我们实例化`ShuffleBlockFetcherIterator`时，会调用`initialize`：

```
private[this] def initialize(): Unit = {
  context.addTaskCompletionListener(_ => cleanup())

  // 划分本地和远程的blocks
  val remoteRequests = splitLocalRemoteBlocks()
  // 把远程请求随机的添加到队列中
  fetchRequests ++= Utils.randomize(remoteRequests)
  assert ((0 == reqsInFlight) == (0 == bytesInFlight),
    "expected reqsInFlight = 0 but found reqsInFlight = " + reqsInFlight +
    ", expected bytesInFlight = 0 but found bytesInFlight = " + bytesInFlight)

  // 发送远程请求获取blocks
  fetchUpToMaxBytes()

  val numFetches = remoteRequests.size - fetchRequests.size
  logInfo("Started " + numFetches + " remote fetches in" + Utils.getUsedTimeMs(startTime))

  // 获取本地的Blocks
  fetchLocalBlocks()
  logDebug("Got local blocks in " + Utils.getUsedTimeMs(startTime))
}
```

storage.ShuffleBlockFetcherIterator.splitLocalRemoteBlocks

```
private[this] def splitLocalRemoteBlocks(): ArrayBuffer[FetchRequest] = {
  // 是的远程请求最大长度为 maxBytesInFlight / 5
  // maxBytesInFlight： 为单次航班请求的最大字节数
  // 航班： 一批请求
  // 1/5 ： 是为了提高请求批发度，允许5个请求分别从5个节点获取数据
  val targetRequestSize = math.max(maxBytesInFlight / 5, 1L)
```

```
    logDebug("maxBytesInFlight: " + maxBytesInFlight + ", targetRequestSize: " + targetRequestSize)

    // 缓存需要远程请求的FetchRequest对象
    val remoteRequests = new ArrayBuffer[FetchRequest]

    // 总共 blocks 的数量
    var totalBlocks = 0
    // 我们从上文可知blocksByAddress是根据status.location进行排序的
    for ((address, blockInfos) <- blocksByAddress) {
      totalBlocks += blockInfos.size
      if (address.executorId == blockManager.blockManagerId.executorId) {
        // 若 executorId 相同 与本 blockManagerId.executorId,
        // 则从本地获取
        localBlocks ++= blockInfos.filter(_._2 != 0).map(_._1)
        numBlocksToFetch += localBlocks.size
      } else {
      // 否则 远程请求
      // 得到迭代器
        val iterator = blockInfos.iterator
     // 当前累计块的大小
        var curRequestSize = 0L
     // 当前累加块
     // 累加： 若向一个节点频繁的请求字节很少的Block,
     // 那么会造成网络阻塞
        var curBlocks = new ArrayBuffer[(BlockId, Long)]
        // iterator 中的block 都是同一节点的
        while (iterator.hasNext) {
          val (blockId, size) = iterator.next()
          if (size > 0) {
            curBlocks += ((blockId, size))
            remoteBlocks += blockId
            numBlocksToFetch += 1
            curRequestSize += size
          } else if (size < 0) {
            throw new BlockException(blockId, "Negative block size " + size)
          }
          if (curRequestSize >= targetRequestSize) {
            // 若累加到大于远程请求的尺寸
            // 往remoteRequests加入FetchRequest
            remoteRequests += new FetchRequest(address, curBlocks)
            curBlocks = new ArrayBuffer[(BlockId, Long)]
            logDebug(s"Creating fetch request of $curRequestSize at $address")
            curRequestSize = 0
          }
        }
        // 增加最后的请求
        if (curBlocks.nonEmpty) {
          remoteRequests += new FetchRequest(address, curBlocks)
        }
      }
    }
    logInfo(s"Getting $numBlocksToFetch non-empty blocks out of $totalBlocks blocks")
    remoteRequests
  }
```

获取Block

storage.ShuffleBlockFetcherIterator.fetchUpToMaxBytes

我们回到`storage.ShuffleBlockFetcherIterator.initialize`的`fetchUpToMaxBytes()`来深入讲解下如何获取远程的`Block`：

```
  private def fetchUpToMaxBytes(): Unit = {
    // Send fetch requests up to maxBytesInFlight
```

```
    // 单次航班请求数要小于最大航班请求数
    // 单次航班字节数数要小于最大航班字节数
    while (fetchRequests.nonEmpty &&
      (bytesInFlight == 0 ||
        (reqsInFlight + 1 <= maxReqsInFlight &&
          bytesInFlight + fetchRequests.front.size <= maxBytesInFlight))) {
      sendRequest(fetchRequests.dequeue())
    }
  }
```

storage.ShuffleBlockFetcherIterator.sendRequest

```
  private[this] def sendRequest(req: FetchRequest) {
    logDebug("Sending request for %d blocks (%s) from %s".format(
      req.blocks.size, Utils.bytesToString(req.size), req.address.hostPort))
    bytesInFlight += req.size
    reqsInFlight += 1

    // 可根据blockID查询block大小
    val sizeMap = req.blocks.map { case (blockId, size) => (blockId.toString, size) }.toMap
    val remainingBlocks = new HashSet[String]() ++= sizeMap.keys
    val blockIds = req.blocks.map(_._1.toString)

    val address = req.address
    // 关于shuffleClient.fetchBlocks我们会在之后的博文讲解
    shuffleClient.fetchBlocks(address.host, address.port, address.executorId, blockIds.toArray,
      new BlockFetchingListener {
      // 请求成功
        override def onBlockFetchSuccess(blockId: String, buf: ManagedBuffer): Unit = {
          ShuffleBlockFetcherIterator.this.synchronized {
            if (!isZombie) {
              buf.retain()
              remainingBlocks -= blockId
              results.put(new SuccessFetchResult(BlockId(blockId), address, sizeMap(blockId), buf,
                remainingBlocks.isEmpty))
              logDebug("remainingBlocks: " + remainingBlocks)
            }
          }
          logTrace("Got remote block " + blockId + " after " + Utils.getUsedTimeMs(startTime))
        }

      // 请求失败
        override def onBlockFetchFailure(blockId: String, e: Throwable): Unit = {
          logError(s"Failed to get block(s) from ${req.address.host}:${req.address.port}", e)
          results.put(new FailureFetchResult(BlockId(blockId), address, e))
        }
      }
    )
  }
```

storage.ShuffleBlockFetcherIterator.fetchLocalBlocks

我们再回过头来看获取本地blocks：

```
  private[this] def fetchLocalBlocks() {
  // 获取迭代器
    val iter = localBlocks.iterator
    while (iter.hasNext) {
      val blockId = iter.next()
      try {
      // 遍历获取数据
      // blockManager.getBlockData 会在后续博文讲解
        val buf = blockManager.getBlockData(blockId)
```

```
        shuffleMetrics.incLocalBlocksFetched(1)
        shuffleMetrics.incLocalBytesRead(buf.size)
        buf.retain()
        results.put(new SuccessFetchResult(blockId, blockManager.blockManagerId, 0, buf, false))
      } catch {
        case e: Exception =>
          logError(s"Error occurred while fetching local blocks", e)
          results.put(new FailureFetchResult(blockId, blockManager.blockManagerId, e))
          return
      }
    }
  }
```