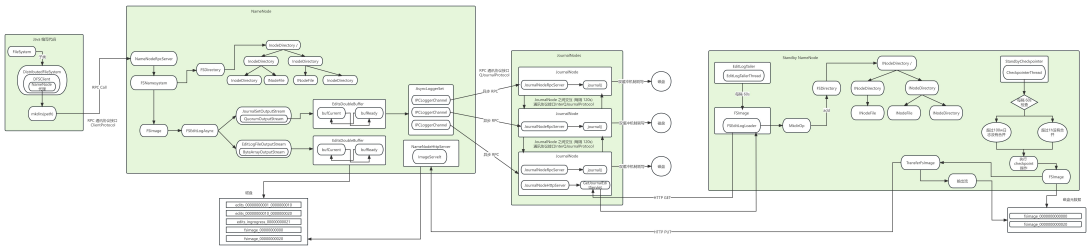
hadoop-hdfs 元数据管理源码分析

一 场景驱动案例

```
        <dependency>
            <groupId>org.apache.hadoop</groupId>
            <artifactId>hadoop-client</artifactId>
            <version>3.1.3</version>
        </dependency>
```

```
public class MkdirMain {

    public static void main(String[] args) throws Exception {

        System.setProperty("HADOOP_USER_NAME", "tanbs");

        Configuration conf = new Configuration();

        FileSystem fileSystem = FileSystem.get(conf);

        fileSystem.mkdirs(new Path("/mkdir"));

    }

}
```

二 元数据管理源码分析



2.1 创建 FileSystem

```
FileSystem fileSystem = FileSystem.get(conf);
```

```
/**
     * Returns the configured FileSystem implementation.
     *
     * @param conf the configuration to use
     */
    public static FileSystem get(Configuration conf) throws IOException {
        // 往下追
        return get(
                // 解析 key = fs.defaultFS 对应的值 比如 hdfs://mycluster
                getDefaultUri(conf), conf
        );
    }
```

```
/**
     * Get a FileSystem for this URI's scheme and authority.
     * <ol>
     * <li>
     *   If the configuration has the property
     *   {@code "fs.$SCHEME.impl.disable.cache"} set to true,
     *   a new instance will be created, initialized with the supplied URI and
     *   configuration, then returned without being cached.
     * </li>
     * <li>
     *   If the there is a cached FS instance matching the same URI, it will
     *   be returned.
     * </li>
     * <li>
     *   Otherwise: a new FS instance will be created, initialized with the
     *   configuration and URI, cached and returned to the caller.
     * </li>
     * </ol>
     *
     * @throws IOException if the FileSystem cannot be instantiated.
     */
    public static FileSystem get(URI uri, Configuration conf) throws IOException {
        // hdfs
        String scheme = uri.getScheme();
        // mycluster
        String authority = uri.getAuthority();
```

```
        if (scheme == null && authority == null) {         // use default FS
            return get(conf);
        }

        if (scheme != null && authority == null) {         // no authority
            URI defaultUri = getDefaultUri(conf);
            if (scheme.equals(defaultUri.getScheme())       // if scheme matches default
                    && defaultUri.getAuthority() != null) {    // & default has authority
                return get(defaultUri, conf);                  // return default
            }
        }

        // fs.hdfs.impl.disable.cache
        String disableCacheName = String.format("fs.%s.impl.disable.cache", scheme);
        if (conf.getBoolean(disableCacheName, false)) {
            LOGGER.debug("Bypassing cache to create filesystem {}", uri);
            return createFileSystem(uri, conf);
        }

        // 往下追 (最终返回 DistributedFileSystem 对象)
        return CACHE.get(uri, conf);
    }
```

```
        FileSystem get(URI uri, Configuration conf) throws IOException {
            Key key = new Key(uri, conf);
            // 往下追
            return getInternal(uri, conf, key);
        }
```

```
/**
     * Get the FS instance if the key maps to an instance, creating and
     * initializing the FS if it is not found.
     * If this is the first entry in the map and the JVM is not shutting down,
     * this registers a shutdown hook to close filesystems, and adds this
     * FS to the {@code toAutoClose} set if {@code "fs.automatic.close"}
     * is set in the configuration (default: true).
     *
     * @param uri    filesystem URI
     * @param conf configuration
     * @param key    key to store/retrieve this FileSystem in the cache
     * @return a cached or newly instantiated FileSystem.
```

```
             * @throws IOException
             */
            private FileSystem getInternal(URI uri, Configuration conf, Key key)
                        throws IOException {
                  FileSystem fs;
                  synchronized (this) {
                        fs = map.get(key);
                  }
                  if (fs != null) {
                        return fs;
                  }

                  // 创建 DistributedFileSystem
                  fs = createFileSystem(uri, conf);

                  synchronized (this) { // refetch the lock again
                        FileSystem oldfs = map.get(key);
                        if (oldfs != null) { // a file system is created while lock is releasing
                              fs.close(); // close the new file system
                              return oldfs;    // return the old file system
                        }

                        // now insert the new file system into the map
                        if (map.isEmpty()
                                    && !ShutdownHookManager.get().isShutdownInProgress()) {
                              ShutdownHookManager.get().addShutdownHook(clientFinalizer,
SHUTDOWN_HOOK_PRIORITY);
                        }
                        fs.key = key;
                        map.put(key, fs);
                        if (conf.getBoolean(
                                    FS_AUTOMATIC_CLOSE_KEY, FS_AUTOMATIC_CLOSE_DEFAULT)) {
                              toAutoClose.add(key);
                        }
                        return fs;
                  }
            }
```

```
/**
      * Create and initialize a new instance of a FileSystem.
      *
      * @param uri    URI containing the FS schema and FS details
      * @param conf configuration to use to look for the FS instance declaration
      *                   and to pass to the {@link FileSystem#initialize(URI, Configuration)}.
```

```
     * @return the initialized filesystem.
     * @throws IOException problems loading or initializing the FileSystem
     */
    private static FileSystem createFileSystem(URI uri, Configuration conf)
            throws IOException {
        Tracer tracer = FsTracer.get(conf);
        try (TraceScope scope = tracer.newScope("FileSystem#createFileSystem")) {
            scope.addKVAnnotation("scheme", uri.getScheme());
            // 返回 DistributedFileSystem.class
            Class<?> clazz = getFileSystemClass(uri.getScheme(), conf);
            // 创建 DistributedFileSystem
            FileSystem fs = (FileSystem) ReflectionUtils.newInstance(clazz, conf);
            // 调用 DistributedFileSystem.initialize()
            fs.initialize(uri, conf);
            return fs;
        }
    }
```

2.1.1 创建 DistributedFileSystem

```
/** Create an object for the given class and initialize it from conf
     *
     * @param theClass class of which an object is created
     * @param conf Configuration
     * @return a new object
     */
    @SuppressWarnings("unchecked")
    public static <T> T newInstance(Class<T> theClass, Configuration conf) {
        T result;
        try {
            Constructor<T> meth = (Constructor<T>) CONSTRUCTOR_CACHE.get(theClass);
            if (meth == null) {
                meth = theClass.getDeclaredConstructor(EMPTY_ARRAY);
                meth.setAccessible(true);
                CONSTRUCTOR_CACHE.put(theClass, meth);
            }
            // 调用 DistributedFileSystem 无参构造
            result = meth.newInstance();
        } catch (Exception e) {
            throw new RuntimeException(e);
        }
```

```
        // null
        setConf(result, conf);

        // 返回 DistributedFileSystem 对象
        return result;
    }
```

```
    public DistributedFileSystem() {
    }
```

2.1.2 初始化 DistributedFileSystem

```
@Override
    public void initialize(URI uri, Configuration conf) throws IOException {
        // 调用父类
        super.initialize(uri, conf);
        // 设置 配置对象
        setConf(conf);

        // mycluster
        String host = uri.getHost();
        if (host == null) {
            throw new IOException("Incomplete HDFS URI, no host: "+ uri);
        }

        // 创建 DFSClient (底层创建 NameNode 代理对象 通讯协议接口为 ClientProtocol)
        this.dfs = new DFSClient(uri, conf, statistics);

        // hdfs://mycluster
        this.uri = URI.create(uri.getScheme()+"://"+uri.getAuthority());
        this.workingDir = getHomeDirectory();

        storageStatistics = (DFSOpsCountStatistics) GlobalStorageStatistics.INSTANCE
                .put(DFSOpsCountStatistics.NAME,
                    new StorageStatisticsProvider() {
                        @Override
                        public StorageStatistics provide() {
                            return new DFSOpsCountStatistics();
                        }
                    });
    }
```

2.1.2.1 创建 DFSClient

```
/**
     * Same as this(nameNodeUri, null, conf, stats);
     * @see #DFSClient(URI, ClientProtocol, Configuration, FileSystem.Statistics)
     */
    public DFSClient(URI nameNodeUri, Configuration conf,
                     FileSystem.Statistics stats) throws IOException {
        // 往下追
        this(nameNodeUri, null, conf, stats);
    }
```

```
/**
     * Create a new DFSClient connected to the given nameNodeUri or rpcNamenode.
     * If HA is enabled and a positive value is set for
     *                                                                {@link
HdfsClientConfigKeys#DFS_CLIENT_TEST_DROP_NAMENODE_RESPONSE_NUM_KEY}
     * in the configuration, the DFSClient will use
     * {@link LossyRetryInvocationHandler} as its RetryInvocationHandler.
     * Otherwise one of nameNodeUri or rpcNamenode must be null.
     */
    @VisibleForTesting
    public DFSClient(URI nameNodeUri, ClientProtocol rpcNamenode,
                     Configuration conf, FileSystem.Statistics stats) throws IOException {
        // Copy only the required DFSClient configuration
        this.tracer = FsTracer.get(conf);

        // 创建 DfsClientConf (里面封装了很多参数)
        this.dfsClientConf = new DfsClientConf(conf);

        this.conf = conf;
        this.stats = stats;

        // 返回 StandardSocketFactory 对象
        this.socketFactory = NetUtils.getSocketFactory(conf, ClientProtocol.class);

        this.dtpReplaceDatanodeOnFailure = ReplaceDatanodeOnFailure.get(conf);

        // 512
        this.smallBufferSize = DFSUtilClient.getSmallBufferSize(conf);
        // 0
```

```
this.dtpReplaceDatanodeOnFailureReplication = (short) conf
        .getInt(HdfsClientConfigKeys.BlockWrite.ReplaceDatanodeOnFailure.
                MIN_REPLICATION,
            HdfsClientConfigKeys.BlockWrite.ReplaceDatanodeOnFailure.
                MIN_REPLICATION_DEFAULT);
if (LOG.isDebugEnabled()) {
    LOG.debug(
        "Sets " + HdfsClientConfigKeys.BlockWrite.ReplaceDatanodeOnFailure.
            MIN_REPLICATION + " to "
            + dtpReplaceDatanodeOnFailureReplication);
}
this.ugi = UserGroupInformation.getCurrentUser();

// hdfs://mycluster
this.namenodeUri = nameNodeUri;

// 客户端 ID
this.clientName = "DFSClient_" + dfsClientConf.getTaskId() + "_" +
        ThreadLocalRandom.current().nextInt() + "_" +
        Thread.currentThread().getId();
// 0
int numResponseToDrop = conf.getInt(
        DFS_CLIENT_TEST_DROP_NAMENODE_RESPONSE_NUM_KEY,
        DFS_CLIENT_TEST_DROP_NAMENODE_RESPONSE_NUM_DEFAULT);
ProxyAndInfo<ClientProtocol> proxyInfo = null;
AtomicBoolean nnFallbackToSimpleAuth = new AtomicBoolean(false);

if (numResponseToDrop > 0) {
    // This case is used for testing.
    LOG.warn(DFS_CLIENT_TEST_DROP_NAMENODE_RESPONSE_NUM_KEY
            + " is set to " + numResponseToDrop
            + ", this hacked client will proactively drop responses");
    proxyInfo = NameNodeProxiesClient.createProxyWithLossyRetryHandler(conf,
            nameNodeUri, ClientProtocol.class, numResponseToDrop,
            nnFallbackToSimpleAuth);
}

if (proxyInfo != null) {
    this.dtService = proxyInfo.getDelegationTokenService();
    this.namenode = proxyInfo.getProxy();
} else if (rpcNamenode != null) {
    // This case is used for testing.
    Preconditions.checkArgument(nameNodeUri == null);
    this.namenode = rpcNamenode;
```

```
                dtService = null;
            } else {
                // 默认来到这
                Preconditions.checkArgument(nameNodeUri != null,
                        "null URI");
                // 获取 NameNode 代理 (通讯协议接口为 ClientProtocol) 返回
ProxyAndInfo
                proxyInfo = NameNodeProxiesClient.createProxyWithClientProtocol(
                        conf,
                        nameNodeUri,
                        nnFallbackToSimpleAuth);
                this.dtService = proxyInfo.getDelegationTokenService();
                // 真正 NameNode 代理对象
                this.namenode = proxyInfo.getProxy();
            }

            String localInterfaces[] =
                    conf.getTrimmedStrings(DFS_CLIENT_LOCAL_INTERFACES);
            localInterfaceAddrs = getLocalInterfaceAddrs(localInterfaces);
            if (LOG.isDebugEnabled() && 0 != localInterfaces.length) {
                LOG.debug("Using local interfaces [" +
                        Joiner.on(',').join(localInterfaces) + "] with addresses [" +
                        Joiner.on(',').join(localInterfaceAddrs) + "]");
            }

            Boolean readDropBehind =
                    (conf.get(DFS_CLIENT_CACHE_DROP_BEHIND_READS) == null) ?
                            null : conf.getBoolean(DFS_CLIENT_CACHE_DROP_BEHIND_READS,
false);
            Long readahead = (conf.get(DFS_CLIENT_CACHE_READAHEAD) == null) ?
                    null : conf.getLong(DFS_CLIENT_CACHE_READAHEAD, 0);
            this.serverDefaultsValidityPeriod =
                    conf.getLong(DFS_CLIENT_SERVER_DEFAULTS_VALIDITY_PERIOD_MS_KEY,
                            DFS_CLIENT_SERVER_DEFAULTS_VALIDITY_PERIOD_MS_DEFAULT);
            Boolean writeDropBehind =
                    (conf.get(DFS_CLIENT_CACHE_DROP_BEHIND_WRITES) == null) ?
                            null                                                    :
conf.getBoolean(DFS_CLIENT_CACHE_DROP_BEHIND_WRITES, false);
            this.defaultReadCachingStrategy =
                    new CachingStrategy(readDropBehind, readahead);
            this.defaultWriteCachingStrategy =
                    new CachingStrategy(writeDropBehind, readahead);
            this.clientContext = ClientContext.get(
                    conf.get(DFS_CLIENT_CONTEXT, DFS_CLIENT_CONTEXT_DEFAULT),
```

```
                dfsClientConf, conf);

        if (dfsClientConf.getHedgedReadThreadpoolSize() > 0) {
            this.initThreadsNumForHedgedReads(dfsClientConf.
                    getHedgedReadThreadpoolSize());
        }

        this.initThreadsNumForStripedReads(dfsClientConf.
                getStripedReadThreadpoolSize());
        this.saslClient = new SaslDataTransferClient(
                conf, DataTransferSaslUtil.getSaslPropertiesResolver(conf),
                TrustedChannelResolver.getInstance(conf), nnFallbackToSimpleAuth);
    }
```

2.1.2.1.1 创建 NameNode 代理 (通讯协议接口 ClientProtocol)

```
/**
     * Creates the namenode proxy with the ClientProtocol. This will handle
     * creation of either HA- or non-HA-enabled proxy objects, depending upon
     * if the provided URI is a configured logical URI.
     *
     * @param conf                      the configuration containing the required IPC
     *                                  properties, client failover configurations, etc.
     * @param nameNodeUri               the URI pointing either to a specific NameNode
     *                                  or to a logical nameservice.
     * @param fallbackToSimpleAuth set to true or false during calls to indicate
     *                                  if a secure client falls back to simple auth
     * @return an object containing both the proxy and the associated
     * delegation token service it corresponds to
     * @throws IOException if there is an error creating the proxy
     * @see {@link NameNodeProxies#createProxy(Configuration, URI, Class)}.
     */
    public static ProxyAndInfo<ClientProtocol> createProxyWithClientProtocol(
            Configuration conf, URI nameNodeUri, AtomicBoolean fallbackToSimpleAuth)
            throws IOException {
        // 默认返回 null
        AbstractNNFailoverProxyProvider<ClientProtocol> failoverProxyProvider =
                createFailoverProxyProvider(conf,
                        nameNodeUri,
                        ClientProtocol.class,
                        true,
                        fallbackToSimpleAuth);
```

```
        if (failoverProxyProvider == null) {
            // 获取 NameNode 地址 比如 hj101:8020
            InetSocketAddress nnAddr = DFSUtilClient.getNNAddress(nameNodeUri);
            Text dtService = SecurityUtil.buildTokenService(nnAddr);
            // 创建 ClientProtocol 代理对象 (代理对象底层连接 NameNode Rpc 代理)
            ClientProtocol proxy = createNonHAProxyWithClientProtocol(
                    nnAddr,
                    conf,
                    UserGroupInformation.getCurrentUser(),
                    true, fallbackToSimpleAuth);
            // 封装 ClientProtocol 代理对象 为 ProxyAndInfo
            return new ProxyAndInfo<>(proxy, dtService, nnAddr);
        } else {
            return createHAProxy(conf, nameNodeUri, ClientProtocol.class,
                    failoverProxyProvider);
        }
    }
```

```
    public static ClientProtocol createNonHAProxyWithClientProtocol(
            InetSocketAddress address, Configuration conf, UserGroupInformation ugi,
            boolean withRetries, AtomicBoolean fallbackToSimpleAuth)
            throws IOException {
        // 往下追
        return createProxyWithAlignmentContext(address,
                conf, ugi,
                withRetries,
                fallbackToSimpleAuth,
                null);
    }
```

```
public static ClientProtocol createProxyWithAlignmentContext(
            InetSocketAddress address, Configuration conf, UserGroupInformation ugi,
            boolean withRetries, AtomicBoolean fallbackToSimpleAuth,
            AlignmentContext alignmentContext)
            throws IOException {
        // 设置通信协议接口 (ClientProtocol)
        RPC.setProtocolEngine(conf, ClientNamenodeProtocolPB.class,
                ProtobufRpcEngine.class);

        final RetryPolicy defaultPolicy =
                RetryUtils.getDefaultRetryPolicy(
                        conf,
                        HdfsClientConfigKeys.Retry.POLICY_ENABLED_KEY,
                        HdfsClientConfigKeys.Retry.POLICY_ENABLED_DEFAULT,
```

```
                                HdfsClientConfigKeys.Retry.POLICY_SPEC_KEY,
                                HdfsClientConfigKeys.Retry.POLICY_SPEC_DEFAULT,
                                SafeModeException.class.getName());

        // 1
        final long version = RPC.getProtocolVersion(ClientNamenodeProtocolPB.class);
        // ClientNamenodeProtocolPB  代理
        ClientNamenodeProtocolPB proxy = RPC.getProtocolProxy(
                ClientNamenodeProtocolPB.class,
                version, address, ugi, conf,
                NetUtils.getDefaultSocketFactory(conf),
                org.apache.hadoop.ipc.Client.getTimeout(conf), defaultPolicy,
                fallbackToSimpleAuth, alignmentContext).getProxy();

        // true
        if (withRetries) { // create the proxy with retries
            Map<String, RetryPolicy> methodNameToPolicyMap = new HashMap<>();
            ClientProtocol translatorProxy =
                    new ClientNamenodeProtocolTranslatorPB(proxy);
            // hadoop-rpc  标配操作
            return (ClientProtocol) RetryProxy.create(
                    ClientProtocol.class,
                    new DefaultFailoverProxyProvider<>(ClientProtocol.class,
                            translatorProxy),
                    methodNameToPolicyMap,
                    defaultPolicy);
        } else {
            return new ClientNamenodeProtocolTranslatorPB(proxy);
        }
    }
```

2.2 执行创建目录

```
/**
     * Call {@link #mkdirs(Path, FsPermission)} with default permission.
     *
     * @param f path
     * @return true if the directory was created
     * @throws IOException IO failure
     */
    public boolean mkdirs(Path f) throws IOException {
```

```
            // 往下追
            return mkdirs(f, FsPermission.getDirDefault());
        }
```

```
/**
         * Make the given file and all non-existent parents into
         * directories. Has roughly the semantics of Unix @{code mkdir -p}.
         * Existence of the directory hierarchy is not an error.
         *
         * @param f                  path to create
         * @param permission to apply to f
         * @throws IOException IO failure
         */
        // 调用 DistributedFileSystem
        public abstract boolean mkdirs(Path f, FsPermission permission
        ) throws IOException;
```

```
/**
     * Create a directory and its parent directories.
     *
     * See {@link FsPermission#applyUMask(FsPermission)} for details of how
     * the permission is applied.
     *
     * @param f                  The path to create
     * @param permission    The permission.    See FsPermission#applyUMask for
     *                           details about how this is used to calculate the
     *                           effective permission.
     */
    @Override
    public boolean mkdirs(Path f, FsPermission permission) throws IOException {
        // 往下追
        return mkdirsInternal(f, permission, true);
    }
```

```
private boolean mkdirsInternal(Path f, final FsPermission permission,
            final boolean createParent) throws IOException {
        statistics.incrementWriteOps(1);
        storageStatistics.incrementOpCounter(OpType.MKDIRS);
        Path absF = fixRelativePart(f);
        return new FileSystemLinkResolver<Boolean>() {
            @Override
            public Boolean doCall(final Path p) throws IOException {
                // 往下追
```

```
            return dfs.mkdirs(getPathName(p), permission, createParent);
          }

          @Override
          public Boolean next(final FileSystem fs, final Path p)
              throws IOException {
            // FileSystem doesn't have a non-recursive mkdir() method
            // Best we can do is error out
            if (!createParent) {
              throw new IOException("FileSystem does not support non-recursive"
                  + "mkdir");
            }
            return fs.mkdirs(p, permission);
          }
          // 闭包结构 最终调用 doCall()
        }.resolve(this, absF);
      }
```

```
/**
       * Create a directory (or hierarchy of directories) with the given
       * name and permission.
       *
       * @param src                The path of the directory being created
       * @param permission      The permission of the directory being created.
       *                            If permission == null, use {@link FsPermission#getDirDefault()}.
       * @param createParent create missing parent directory if true
       * @return True if the operation success.
       * @see ClientProtocol#mkdirs(String, FsPermission, boolean)
       */
      public boolean mkdirs(String src, FsPermission permission,
                            boolean createParent) throws IOException {
          // 权限相关
          final FsPermission masked = applyUMaskDir(permission);
          // 往下追
          return primitiveMkdir(src, masked, createParent);
      }
```

```
/**
       * Same {{@link #mkdirs(String, FsPermission, boolean)} except
       * that the permissions has already been masked against umask.
       */
      public boolean primitiveMkdir(String src, FsPermission absPermission,
                                    boolean createParent) throws IOException {
          checkOpen();
```

```
        if (absPermission == null) {
            absPermission = applyUMaskDir(null);
        }
        LOG.debug("{}: masked={}", src, absPermission);
        try (TraceScope ignored = tracer.newScope("mkdir")) {
            // 调用 NameNodeRpcServer.mkdirs()
            return namenode.mkdirs(src, absPermission, createParent);
        } catch (RemoteException re) {
            throw re.unwrapRemoteException(AccessControlException.class,
                    InvalidPathException.class,
                    FileAlreadyExistsException.class,
                    FileNotFoundException.class,
                    ParentNotDirectoryException.class,
                    SafeModeException.class,
                    NSQuotaExceededException.class,
                    DSQuotaExceededException.class,
                    QuotaByStorageTypeExceededException.class,
                    UnresolvedPathException.class,
                    SnapshotAccessControlException.class);
        }
    }
```

2.3 调用 NameNodeRpcServer.mkdirs() 执行服务端创建目录

```
@Override // ClientProtocol
    public boolean mkdirs(String src, FsPermission masked, boolean createParent)
            throws IOException {
        checkNNStartup();
        if (stateChangeLog.isDebugEnabled()) {
            stateChangeLog.debug("*DIR* NameNode.mkdirs: " + src);
        }
        if (!checkPathLength(src)) {
            throw new IOException("mkdirs: Pathname too long.  Limit "
                    + MAX_PATH_LENGTH + " characters, " + MAX_PATH_DEPTH + " levels.");
        }
        // 往下追
        return namesystem.mkdirs(src,
                new PermissionStatus(getRemoteUser().getShortUserName(),
                        null, masked), createParent);
    }
```

```
/**
     * Create all the necessary directories
     */
    boolean mkdirs(String src, PermissionStatus permissions,
                   boolean createParent) throws IOException {
        final String operationName = "mkdirs";
        FileStatus auditStat = null;
        checkOperation(OperationCategory.WRITE);
        final FSPermissionChecker pc = getPermissionChecker();
        writeLock();
        try {
            checkOperation(OperationCategory.WRITE);
            checkNameNodeSafeMode("Cannot create directory " + src);

            // 创建目录
            auditStat = FSDirMkdirOp.mkdirs(this, pc, src, permissions,
                    createParent);

        } catch (AccessControlException e) {
            logAuditEvent(false, operationName, src);
            throw e;
        } finally {
            writeUnlock(operationName);
        }

        // 同步 EditLog (当前 hadoop-3.1.3 为异步 故忽略)
        getEditLog().logSync();
        // 审计日志相关
        logAuditEvent(true, operationName, src, null, auditStat);

        return true;
    }
```

2.3.1 创建目录

```
static FileStatus mkdirs(FSNamesystem fsn, FSPermissionChecker pc, String src,
                                    PermissionStatus permissions, boolean createParent) throws
IOException {
        // 获取 FSNamesystem
        FSDirectory fsd = fsn.getFSDirectory();

        if (NameNode.stateChangeLog.isDebugEnabled()) {
```

```
            NameNode.stateChangeLog.debug("DIR* NameSystem.mkdirs: " + src);
        }
        fsd.writeLock();
        try {
            // 检查创建目录不包含非法字符并解析其路径
            INodesInPath iip = fsd.resolvePath(pc, src, DirOp.CREATE);

            // 获取目标目录的上一 INode
            final INode lastINode = iip.getLastINode();
            if (lastINode != null && lastINode.isFile()) {
                throw new FileAlreadyExistsException("Path is not a directory: " + src);
            }

            if (lastINode == null) {
                if (fsd.isPermissionEnabled()) {
                    fsd.checkAncestorAccess(pc, iip, FsAction.WRITE);
                }

                if (!createParent) {
                    fsd.verifyParentDir(iip);
                }

                // validate that we have enough inodes. This is, at best, a
                // heuristic because the mkdirs() operation might need to
                // create multiple inodes.
                fsn.checkFsObjectLimit();

                // Ensure that the user can traversal the path by adding implicit
                // u+wx permission to all ancestor directories.
                // 返回父目录
                INodesInPath existing =
                        createParentDirectories(fsd, iip, permissions, false);
                if (existing != null) {
                    // 创建目录 返回该目录信息
                    existing = createSingleDirectory(
                            fsd, existing, iip.getLastLocalName(), permissions);
                }
                if (existing == null) {
                    throw new IOException("Failed to create directory: " + src);
                }
                iip = existing;
            }
            return fsd.getAuditFileInfo(iip);
        } finally {
```

```
            fsd.writeUnlock();
        }
    }
```

```
private static INodesInPath createSingleDirectory(FSDirectory fsd,
                                                   INodesInPath existing, byte[]
localName, PermissionStatus perm)
            throws IOException {
        assert fsd.hasWriteLock();
        // 通过父目录创建子目录
        existing = unprotectedMkdir(fsd, fsd.allocateNewInodeId(), existing,
                localName, perm, null, now());
        if (existing == null) {
            return null;
        }

        final INode newNode = existing.getLastINode();
        // Directory creation also count towards FilesCreated
        // to match count of FilesDeleted metric.
        NameNode.getNameNodeMetrics().incrFilesCreated();

        // 获取已经创建目录 path
        String cur = existing.getPath();
        // 往 EditLog 添加一条记录
        fsd.getEditLog().logMkDir(cur, newNode);

        if (NameNode.stateChangeLog.isDebugEnabled()) {
            NameNode.stateChangeLog.debug("mkdirs: created directory " + cur);
        }
        // 返回创建目录信息
        return existing;
    }
```

2.3.1.1 通过父目录创建子目录

```
/**
     * create a directory at path specified by parent
     */
    private static INodesInPath unprotectedMkdir(FSDirectory fsd, long inodeId,
                                                 INodesInPath parent, byte[] name,
PermissionStatus permission,
                                                 List<AclEntry> aclEntries, long
```

```
timestamp)
            throws QuotaExceededException, AclException, FileAlreadyExistsException {
        assert fsd.hasWriteLock();
        assert parent.getLastINode() != null;
        if (!parent.getLastINode().isDirectory()) {
            throw new FileAlreadyExistsException("Parent path is not a directory: " +
                    parent.getPath() + " " + DFSUtil.bytes2String(name));
        }
        // 创建 INodeDirectory
        final INodeDirectory dir = new INodeDirectory(inodeId, name, permission,
                timestamp);

        // 往父目录添加子目录 返回子目录信息
        INodesInPath iip =
                fsd.addLastINode(parent, dir, permission.getPermission(), true);
        if (iip != null && aclEntries != null) {
            AclStorage.updateINodeAcl(dir, aclEntries, Snapshot.CURRENT_STATE_ID);
        }
        return iip;
    }
```

```
 /**
     * Add a child to the end of the path specified by INodesInPath.
     * @param existing the INodesInPath containing all the ancestral INodes
     * @param inode the new INode to add
     * @param modes create modes
     * @param checkQuota whether to check quota
     * @return an INodesInPath instance containing the new INode
     */
    @VisibleForTesting
    public INodesInPath addLastINode(INodesInPath existing, INode inode,
                                     FsPermission modes, boolean checkQuota) throws
QuotaExceededException {
        assert existing.getLastINode() != null &&
                existing.getLastINode().isDirectory();

        final int pos = existing.length();
        // Disallow creation of /.reserved. This may be created when loading
        // editlog/fsimage during upgrade since /.reserved was a valid name in older
        // release. This may also be called when a user tries to create a file
        // or directory /.reserved.
        if (pos == 1 && existing.getINode(0) == rootDir && isReservedName(inode)) {
            throw new HadoopIllegalArgumentException(
                    "File name \"" + inode.getLocalName() + "\" is reserved and cannot "
```

```
                                    + "be created. If this is during upgrade change the name of the
"
                                    + "existing file or directory to another name before upgrading
"
                                    + "to the new release.");
            }
            // 父目录
            final INodeDirectory parent = existing.getINode(pos - 1).asDirectory();
            // The filesystem limits are not really quotas, so this check may appear
            // odd. It's because a rename operation deletes the src, tries to add
            // to the dest, if that fails, re-adds the src from whence it came.
            // The rename code disables the quota when it's restoring to the
            // original location because a quota violation would cause the the item
            // to go "poof".    The fs limits must be bypassed for the same reason.
            if (checkQuota) {
                final String parentPath = existing.getPath();
                verifyMaxComponentLength(inode.getLocalNameBytes(), parentPath);
                verifyMaxDirItems(parent, parentPath);
            }
            // always verify inode name
            verifyINodeName(inode.getLocalNameBytes());

            final QuotaCounts counts = inode
                    .computeQuotaUsage(getBlockStoragePolicySuite(),
                            parent.getStoragePolicyID(), false, Snapshot.CURRENT_STATE_ID);
            updateCount(existing, pos, counts, checkQuota);

            boolean isRename = (inode.getParent() != null);
            // 往父目录添加子目录
            final boolean added = parent.addChild(inode, true,
                    existing.getLatestSnapshotId());
            if (!added) {
                updateCountNoQuotaCheck(existing, pos, counts.negation());
                return null;
            } else {
                if (!isRename) {
                    copyINodeDefaultAcl(inode, modes);
                }
                // 缓存 Inode
                addToInodeMap(inode);
            }
            // 返回 Inode 信息
            return INodesInPath.append(existing, inode, inode.getLocalNameBytes());
        }
```

```
/**
     * Add a child inode to the directory.
     *
     * @param node INode to insert
     * @param setModTime set modification time for the parent node
     *                   not needed when replaying the addition and
     *                   the parent already has the proper mod time
     * @return false if the child with this name already exists;
     *         otherwise, return true;
     */
    public boolean addChild(INode node, final boolean setModTime,
                            final int latestSnapshotId) {
        final int low = searchChildren(node.getLocalNameBytes());
        if (low >= 0) {
            return false;
        }

        if (isInLatestSnapshot(latestSnapshotId)) {
            // create snapshot feature if necessary
            DirectoryWithSnapshotFeature sf = this.getDirectoryWithSnapshotFeature();
            if (sf == null) {
                sf = this.addSnapshotFeature(null);
            }
            return sf.addChild(this, node, setModTime, latestSnapshotId);
        }
        // 添加
        addChild(node, low);
        if (setModTime) {
            // update modification time of the parent directory
            updateModificationTime(node.getModificationTime(), latestSnapshotId);
        }
        return true;
    }
```

```
/**
     * Add the node to the children list at the given insertion point.
     * The basic add method which actually calls children.add(..).
     */
    private void addChild(final INode node, final int insertionPoint) {
        if (children == null) {
            children = new ArrayList<>(DEFAULT_FILES_PER_DIRECTORY);
        }
```

```
            node.setParent(this);
            // 添加
            children.add(-insertionPoint - 1, node);

            if (node.getGroupName() == null) {
                node.setGroup(getGroupName());
            }
        }
```

2.3.1.2 往 EditLog 添加一条记录

```
/**
     * Add create directory record to edit log
     */
    public void logMkDir(String path, INode newNode) {
        PermissionStatus permissions = newNode.getPermissionStatus();
        // Mkdir 操作符记录封装
        MkdirOp op = MkdirOp.getInstance(cache.get())
                .setInodeId(newNode.getId())
                .setPath(path)
                .setTimestamp(newNode.getModificationTime())
                .setPermissionStatus(permissions);

        AclFeature f = newNode.getAclFeature();
        if (f != null) {
            op.setAclEntries(AclStorage.readINodeLogicalAcl(newNode));
        }

        XAttrFeature x = newNode.getXAttrFeature();
        if (x != null) {
            op.setXAttrs(x.getXAttrs());
        }
        // 执行添加 (调用 FSEditLogAsync.logEdit())
        logEdit(op);
    }
```

```
@Override
void logEdit(final FSEditLogOp op) {
  // 获取 Edit 对象 返回 RpcEdit
  Edit edit = getEditInstance(op);
```

```
    // 当前线程内部变量设置 RpcEdit
    THREAD_EDIT.set(edit);
    // 将 RpcEdit 添加到队列
    enqueueEdit(edit);
  }
```

2.3.1.2.1 创建 RpcEdit

```
  private Edit getEditInstance(FSEditLogOp op) {
    final Edit edit;
    final Server.Call rpcCall = Server.getCurCall().get();
    // only rpc calls not explicitly sync'ed on the log will be async.
    if (rpcCall != null && !Thread.holdsLock(this)) {
      // 创建 RpcEdit
      edit = new RpcEdit(this, op, rpcCall);
    } else {
      edit = new SyncEdit(this, op);
    }
    return edit;
  }
```

2.3.1.2.2 将 RpcEdit 添加到队列

```
private void enqueueEdit(Edit edit) {
    if (LOG.isDebugEnabled()) {
      LOG.debug("logEdit " + edit);
    }
    try {
      // not checking for overflow yet to avoid penalizing performance of
      // the common case.  if there is persistent overflow, a mutex will be
      // use to throttle contention on the queue.
      // 将 RpcEdit 添加到队列
      if (!editPendingQ.offer(edit)) {
        Preconditions.checkState(
            isSyncThreadAlive(), "sync thread is not alive");
        if (Thread.holdsLock(this)) {
          // if queue is full, synchronized caller must immediately relinquish
          // the monitor before re-offering to avoid deadlock with sync thread
          // which needs the monitor to write transactions.
          int permits = overflowMutex.drainPermits();
          try {
            do {
              this.wait(1000); // will be notified by next logSync.
```

```
                } while (!editPendingQ.offer(edit));
            } finally {
                overflowMutex.release(permits);
            }
        } else {
            // mutex will throttle contention during persistent overflow.
            overflowMutex.acquire();
            try {
                editPendingQ.put(edit);
            } finally {
                overflowMutex.release();
            }
        }
    } catch (Throwable t) {
        // should never happen!  failure to enqueue an edit is fatal
        terminate(t);
    }
}
```

2.3.2 异步同步 EditLog 到磁盘和 JournalNode

入口类：FSEditLogAsync.run()

```
@Override
public void run() {
    try {
        while (true) {
            boolean doSync;
            // 取出一个 RpcEdit
            Edit edit = dequeueEdit();
            if (edit != null) {
                // sync if requested by edit log.
                // 往下追 返回是否强制刷写 EditLog
                doSync = edit.logEdit();
                syncWaitQ.add(edit);
            } else {
                // sync when editq runs dry, but have edits pending a sync.
                doSync = !syncWaitQ.isEmpty();
            }
            if (doSync) {
                // normally edit log exceptions cause the NN to terminate, but tests
                // relying on ExitUtil.terminate need to see the exception.
```

```
                RuntimeException syncEx = null;
                try {
                    // 刷写 EditLog
                    logSync(getLastWrittenTxId());
                } catch (RuntimeException ex) {
                    syncEx = ex;
                }
                while ((edit = syncWaitQ.poll()) != null) {
                    edit.logSyncNotify(syncEx);
                }
            }
        }
    } catch (InterruptedException ie) {
        LOG.info(Thread.currentThread().getName() + " was interrupted, exiting");
    } catch (Throwable t) {
        terminate(t);
    }
}
```

2.3.2.1 返回是否强制刷写 EditLog

```
// return whether edit log wants to sync.
    boolean logEdit() {
        // 往下追
        return log.doEditTransaction(op);
    }
```

```
synchronized boolean doEditTransaction(final FSEditLogOp op) {
            // 开启事务
            long start = beginTransaction();
            op.setTransactionId(txid);

            try {
                // 写 EditLog
                // 往本地写 EditLog 调用 EditLogFileOutputStream
                // 往 JournalNode 写 EditLog 调用 JournalSetOutputStream (JournalSet)
                editLogStream.write(op);
            } catch (IOException ex) {
                // All journals failed, it is handled in logSync.
            } finally {
                op.reset();
            }
```

```
            // 结束事务
            endTransaction(start);

            // 判断是否强制刷写 EditLog
            return shouldForceSync();
        }
```

2.3.2.1.1 开启事务

```
private long beginTransaction() {
            assert Thread.holdsLock(this);
            // get a new transactionId
            // 事务 ID 累计
            txid++;

            //
            // record the transactionId when new data was written to the edits log
            //
            TransactionId id = myTransactionId.get();
            id.txid = txid;
            return monotonicNow();
        }
```

2.3.2.1.2 写 EditLog

2.3.2.1.2.1 往本地写 EditLog 调用 EditLogFileOutputStream

```
    @Override
    public void write(FSEditLogOp op) throws IOException {
        // 往双缓冲写 EditLog
        doubleBuf.writeOp(op, getCurrentLogVersion());
    }
```

```
        public void writeOp(FSEditLogOp op, int logVersion) throws IOException {
            // 往 bufCurrent 写 EditLog
            bufCurrent.writeOp(op, logVersion);
        }
```

2.3.2.1.2.2 往 JournalNode 写 EditLog 调用 JournalSetOutputStream (JournalSet)

```
    @Override
            public void write(final FSEditLogOp op)
```

```
                throws IOException {
            mapJournalsAndReportErrors(new JournalClosure() {
                @Override
                public void apply(JournalAndStream jas) throws IOException {
                    if (jas.isActive()) {
                        // 调用 QuorumOutputStream.write
                        jas.getCurrentStream().write(op);
                    }
                }
            }, "write op");
        }
```

```
    @Override
    public void write(FSEditLogOp op) throws IOException {
        // 往双缓冲写 EditLog
        buf.writeOp(op, getCurrentLogVersion());
    }
```

```
    public void writeOp(FSEditLogOp op, int logVersion) throws IOException {
        // 往 bufCurrent 写 EditLog
        bufCurrent.writeOp(op, logVersion);
    }
```

2.3.2.1.3 结束事务

```
private void endTransaction(long start) {
        assert Thread.holdsLock(this);

        // update statistics
        long end = monotonicNow();
        numTransactions++;
        totalTimeTransactions += (end - start);
        if (metrics != null) // Metrics is non-null only when used inside name node
            metrics.addTransaction(end - start);
    }
```

2.3.2.1.4 判断是否强制刷写 EditLog

```
    /**
     * Check if should automatically sync buffered edits to
     * persistent store
     *
```

```
     * @return true if any of the edit stream says that it should sync
     */
    private boolean shouldForceSync() {
        // 往下追
        return editLogStream.shouldForceSync();
    }
```

```
/**
 * @return true if the number of buffered data exceeds the intial buffer size
 */
@Override
public boolean shouldForceSync() {
  // 往下追
  return doubleBuf.shouldForceSync();
}
```

```
    public boolean shouldForceSync() {
        // 判断 bufCurrent 大小是否大于 512 KB
        return bufCurrent.size() >= initBufferSize;
    }
```

2.3.2.2 刷写 EditLog

```
protected void logSync(long mytxid) {
        long syncStart = 0;
        boolean sync = false;
        long editsBatchedInSync = 0;
        try {
            EditLogOutputStream logStream = null;
            synchronized (this) {
                try {
                    printStatistics(false);

                    // if somebody is already syncing, then wait
                    // 已经有其他线程正在刷写 EditLog
                    while (mytxid > synctxid && isSyncRunning) {
                        try {
                            wait(1000);
                        } catch (InterruptedException ie) {
                        }
                    }
```

```
                //
                // If this transaction was already flushed, then nothing to do
                //
                if (mytxid <= synctxid) {
                    return;
                }

                // now, this thread will do the sync.    track if other edits were
                // included in the sync - ie. batched.    if this is the only edit
                // synced then the batched count is 0
                editsBatchedInSync = txid - synctxid - 1;
                syncStart = txid;
                isSyncRunning = true;
                sync = true;

                // swap buffers
                try {
                    if (journalSet.isEmpty()) {
                        throw new IOException("No journals available to flush");
                    }
                    // 双缓冲内存交换
                    editLogStream.setReadyToFlush();
                } catch (IOException e) {
                    final String msg =
                            "Could not sync enough journals to persistent storage " +
                                    "due to " + e.getMessage() + ". " +
                                    "Unsynced transactions: " + (txid - synctxid);
                    LOG.error(msg, new Exception());
                    synchronized (journalSetLock) {
                        IOUtils.cleanupWithLogger(LOG, journalSet);
                    }
                    terminate(1, msg);
                }
            } finally {
                // Prevent RuntimeException from blocking other log edit write
                doneWithAutoSyncScheduling();
            }
            //editLogStream may become null,
            //so store a local variable for flush.
            logStream = editLogStream;
        }

        // do the sync
        long start = monotonicNow();
```

```
            try {
                if (logStream != null) {
                    // 刷写 EditLog
                    logStream.flush();
                }
            } catch (IOException ex) {
                synchronized (this) {
                    final String msg =
                            "Could not sync enough journals to persistent storage. "
                                    + "Unsynced transactions: " + (txid - synctxid);
                    LOG.error(msg, new Exception());
                    synchronized (journalSetLock) {
                        IOUtils.cleanupWithLogger(LOG, journalSet);
                    }
                    terminate(1, msg);
                }
            }
            long elapsed = monotonicNow() - start;

            if (metrics != null) { // Metrics non-null only when used inside name node
                metrics.addSync(elapsed);
                metrics.incrTransactionsBatchedInSync(editsBatchedInSync);
                numTransactionsBatchedInSync.addAndGet(editsBatchedInSync);
            }

        } finally {
            // Prevent RuntimeException from blocking other log edit sync
            synchronized (this) {
                if (sync) {
                    synctxid = syncStart;
                    for (JournalManager jm : journalSet.getJournalManagers()) {
                        /**
                         * {@link FileJournalManager#lastReadableTxId} is only meaningful
                         * for file-based journals. Therefore the interface is not added to
                         * other types of {@link JournalManager}.
                         */
                        if (jm instanceof FileJournalManager) {
                            ((FileJournalManager) jm).setLastReadableTxId(syncStart);
                        }
                    }
                    isSyncRunning = false;
                }
                this.notifyAll();
            }
```

```
            }
        }
```

```
    /**
     * Flush data to persistent store.
     * Collect sync metrics.
     */
    public void flush() throws IOException {
        // 本地刷写 EditLog 往下追
        // JournalNode 刷写 EditLog 调用子类
        flush(true);
    }
```

2.3.2.2.1 本地刷写 EditLog

```
    public void flush(boolean durable) throws IOException {
        numSync++;
        long start = monotonicNow();
        // 刷写
        flushAndSync(durable);
        long end = monotonicNow();
        totalTimeSync += (end - start);
    }
```

```
/**
     * Flush ready buffer to persistent store. currentBuffer is not flushed as it
     * accumulates new log records while readyBuffer will be flushed and synced.
     */
    @Override
    public void flushAndSync(boolean durable) throws IOException {
        if (fp == null) {
            throw new IOException("Trying to use aborted output stream");
        }
        if (doubleBuf.isFlushed()) {
            LOG.info("Nothing to flush");
            return;
        }
        preallocate(); // preallocate file if necessary
        // 刷写
        doubleBuf.flushTo(fp);
        if (durable && !shouldSkipFsyncForTests && !shouldSyncWritesAndSkipFsync) {
            fc.force(false); // metadata updates not needed
        }
    }
```

```
    /**
     * Writes the content of the "ready" buffer to the given output stream,
     * and resets it. Does not swap any buffers.
     */
    public void flushTo(OutputStream out) throws IOException {
        // 往下追
        bufReady.writeTo(out); // write data to file
        bufReady.reset(); // erase all data in the buffer
    }
```

```
/** Write to a file stream */
    public void writeTo(OutputStream out) throws IOException {
        // 刷写
        buffer.writeTo(out);
    }
```

2.3.2.2.2 往 JournalNode 刷写 EditLog

```
@Override
        public void flush() throws IOException {
            mapJournalsAndReportErrors(new JournalClosure() {
                @Override
                public void apply(JournalAndStream jas) throws IOException {
                    if (jas.isActive()) {
                        // 往 JournalNode 刷写 EditLog
                        jas.getCurrentStream().flush();
                    }
                }
            }, "flush");
        }
```

```
        @Override
        protected void flushAndSync(final boolean durable) throws IOException {
            mapJournalsAndReportErrors(new JournalClosure() {
                @Override
                public void apply(JournalAndStream jas) throws IOException {
                    if (jas.isActive()) {
                        jas.getCurrentStream().flushAndSync(durable);
                    }
                }
            }, "flushAndSync");
```

```
        }
```

```
@Override
    protected void flushAndSync(boolean durable) throws IOException {
        int numReadyBytes = buf.countReadyBytes();
        if (numReadyBytes > 0) {
            int numReadyTxns = buf.countReadyTxns();
            long firstTxToFlush = buf.getFirstReadyTxId();

            assert numReadyTxns > 0;

            // Copy from our double-buffer into a new byte array. This is for
            // two reasons:
            // 1) The IPC code has no way of specifying to send only a slice of
            //       a larger array.
            // 2) because the calls to the underlying nodes are asynchronous, we
            //       need a defensive copy to avoid accidentally mutating the buffer
            //       before it is sent.
            // 计算刷写数据
            DataOutputBuffer bufToSend = new DataOutputBuffer(numReadyBytes);
            buf.flushTo(bufToSend);
            assert bufToSend.getLength() == numReadyBytes;
            byte[] data = bufToSend.getData();
            assert data.length == bufToSend.getLength();

            // 往下追
            QuorumCall<AsyncLogger, Void> qcall = loggers.sendEdits(
                        segmentTxId,
                        firstTxToFlush,
                        numReadyTxns,
                        data);
            loggers.waitForWriteQuorum(qcall, writeTimeoutMs, "sendEdits");

            // Since we successfully wrote this batch, let the loggers know. Any future
            // RPCs will thus let the loggers know of the most recent transaction, even
            // if a logger has fallen behind.
            loggers.setCommittedTxId(firstTxToFlush + numReadyTxns - 1);
        }
    }
```

```
    public QuorumCall<AsyncLogger, Void> sendEdits(
            long segmentTxId, long firstTxnId, int numTxns, byte[] data) {
        Map<AsyncLogger, ListenableFuture<Void>> calls = Maps.newHashMap();
        // 变量每个 JournalNode 连接对象
```

```
        for (AsyncLogger logger : loggers) {
            // 往下追
            ListenableFuture<Void> future =
                    logger.sendEdits(segmentTxId, firstTxnId, numTxns, data);
            calls.put(logger, future);
        }
        return QuorumCall.create(calls);
    }
```

2.3.2.2.2.1 最终调用 IPCLoggerChannel.sendEdits() 发送异步 RPC

```
 @Override
    public ListenableFuture<Void> sendEdits(
            final long segmentTxId, final long firstTxnId,
            final int numTxns, final byte[] data) {
        try {
            reserveQueueSpace(data.length);
        } catch (LoggerTooFarBehindException e) {
            return Futures.immediateFailedFuture(e);
        }

        // When this batch is acked, we use its submission time in order
        // to calculate how far we are lagging.
        final long submitNanos = System.nanoTime();

        ListenableFuture<Void> ret = null;
        try {
            ret = singleThreadExecutor.submit(new Callable<Void>() {
                @Override
                public Void call() throws IOException {
                    throwIfOutOfSync();

                    long rpcSendTimeNanos = System.nanoTime();
                    try {
                        // 调用 JournalNodeRpcServer.journal()
                        getProxy().journal(createReqInfo(),
                                segmentTxId, firstTxnId, numTxns, data);
                    } catch (IOException e) {
                        QuorumJournalManager.LOG.warn(
                                "Remote journal " + IPCLoggerChannel.this + " failed to "
+
                                        "write txns " + firstTxnId + "-" + (firstTxnId +
numTxns - 1) +
                                        ". Will try to write to this JN again after the next
```

```
" +
                                                    "log roll.", e);
                                synchronized (IPCLoggerChannel.this) {
                                        outOfSync = true;
                                }
                                throw e;
                        } finally {
                                long now = System.nanoTime();
                                long rpcTime = TimeUnit.MICROSECONDS.convert(
                                                now - rpcSendTimeNanos, TimeUnit.NANOSECONDS);
                                long endToEndTime = TimeUnit.MICROSECONDS.convert(
                                                now - submitNanos, TimeUnit.NANOSECONDS);
                                metrics.addWriteEndToEndLatency(endToEndTime);
                                metrics.addWriteRpcLatency(rpcTime);
                                if (rpcTime / 1000 > WARN_JOURNAL_MILLIS_THRESHOLD) {
                                        QuorumJournalManager.LOG.warn(
                                                        "Took " + (rpcTime / 1000) + "ms to send a batch of "
+
                                                                        numTxns + " edits (" + data.length + "
bytes) to " +
                                                                        "remote journal " +
IPCLoggerChannel.this);
                                }
                        }
                        synchronized (IPCLoggerChannel.this) {
                                highestAckedTxId = firstTxnId + numTxns - 1;
                                lastAckNanos = submitNanos;
                        }
                        return null;
                }
        });
    } finally {
        if (ret == null) {
            // it didn't successfully get submitted,
            // so adjust the queue size back down.
            unreserveQueueSpace(data.length);
        } else {
            // It was submitted to the queue, so adjust the length
            // once the call completes, regardless of whether it
            // succeeds or fails.
            Futures.addCallback(ret, new FutureCallback<Void>() {
                @Override
                public void onFailure(Throwable t) {
                    unreserveQueueSpace(data.length);
```

```
                        }

                        @Override
                        public void onSuccess(Void t) {
                            unreserveQueueSpace(data.length);
                        }
                    }, MoreExecutors.directExecutor());
                }
            }
            return ret;
        }
```

2.3.2.2.2.1.1 调用 JournalNodeRpcServer.journal()

```
    @Override
    public void journal(RequestInfo reqInfo,
                        long segmentTxId, long firstTxnId,
                        int numTxns, byte[] records) throws IOException {
        jn.getOrCreateJournal(reqInfo.getJournalId(), reqInfo.getNameServiceId())
                .journal(reqInfo, segmentTxId, firstTxnId, numTxns, records);
    }
```

2.4 NameNode 异步 RPC 发送 EditLog 给 JournalNode

入口类:JournalNodeRpcServer.journal()

```
@Override
    public void journal(RequestInfo reqInfo,
                        long segmentTxId, long firstTxnId,
                        int numTxns, byte[] records) throws IOException {
        // 接收 NameNode 异步 RPC 发送 EditLog 元数据

        // 创建 Journal 对象
        jn.getOrCreateJournal(
                        reqInfo.getJournalId(),
                        reqInfo.getNameServiceId()
                )
                // 执行接收 RPC 发送的 EditLog 元数据请求
                .journal(reqInfo, segmentTxId, firstTxnId, numTxns, records);
    }
```

2.4.1 创建 Journal 对象

```
    public Journal getOrCreateJournal(String jid,
                                      String nameServiceId)
            throws IOException {
        // 往下追
        return getOrCreateJournal(jid, nameServiceId, StartupOption.REGULAR);
    }
```

```
synchronized Journal getOrCreateJournal(String jid,
                                        String nameServiceId,
                                        StartupOption startOpt)
            throws IOException {
        QuorumJournalManager.checkJournalId(jid);

        Journal journal = journalsById.get(jid);
        if (journal == null) {
            // 获取 JournalNode 存储元数据目录
            File logDir = getLogDir(jid, nameServiceId);

            // Initializing journal in directory /opt/app/hadoop-3.1.3/data/jn/mycluster
            LOG.info("Initializing journal in directory " + logDir);

            // 创建 Journal
            journal = new Journal(conf, logDir, jid, startOpt, new ErrorReporter());
            // 缓存
            journalsById.put(jid, journal);

            // Start SyncJouranl thread, if JournalNode Sync is enabled
            if (conf.getBoolean(
                    DFSConfigKeys.DFS_JOURNALNODE_ENABLE_SYNC_KEY,
                    DFSConfigKeys.DFS_JOURNALNODE_ENABLE_SYNC_DEFAULT)) {

                // 开启同步线程 同步 JournalNode 之间的相关信息
                startSyncer(journal, jid, nameServiceId);
            }
        } else if (journalSyncersById.get(jid) != null &&
                !journalSyncersById.get(jid).isJournalSyncerStarted() &&
                !journalsById.get(jid).getTriedJournalSyncerStartedwithnsId() &&
                nameServiceId != null) {
            startSyncer(journal, jid, nameServiceId);
        }
```

```
            return journal;
        }
```

2.4.1.1 执行创建 Journal 对象

```
Journal(Configuration conf, File logDir, String journalId,
            StartupOption startOpt, StorageErrorReporter errorReporter)
            throws IOException {

        this.conf = conf;

        // 创建 JNStorage
        storage = new JNStorage(conf, logDir, startOpt, errorReporter);

        // mycluster
        this.journalId = journalId;

        refreshCachedData();

        // FileJournalManager
        this.fjm = storage.getJournalManager();

        this.cache = createCache();

        this.metrics = JournalMetrics.create(this);

        // 扫描最新的 EditLog 文件
        EditLogFile latest = scanStorageForLatestEdits();

        if (latest != null) {
            updateHighestWrittenTxId(latest.getLastTxId());
        }
    }
```

2.4.1.1 启动同步线程 (同步 JournalNode 之间相关信息确保一致性)

```
        private void startSyncer(Journal journal, String jid, String nameServiceId) {
            JournalNodeSyncer jSyncer = journalSyncersById.get(jid);
            if (jSyncer == null) {
```

```
                // 创建 JournalNodeSyncer
                jSyncer = new JournalNodeSyncer(this, journal, jid, conf, nameServiceId);
                // 缓存
                journalSyncersById.put(jid, jSyncer);
            }
            // 启动 JournalNodeSyncer 执行 JournalNode 之间同步相关信息
            jSyncer.start(nameServiceId);
        }
```

2.4.1.1.1 创建 JournalNodeSyncer

```
JournalNodeSyncer(JournalNode jouranlNode, Journal journal, String jid,
        Configuration conf, String nameServiceId) {
    // 赋值操作
    this.jn = jouranlNode;
    this.journal = journal;
    this.jid = jid;
    this.nameServiceId = nameServiceId;
    this.jnStorage = journal.getStorage();
    this.conf = conf;

    // 120s
    journalSyncInterval = conf.getLong(
            DFSConfigKeys.DFS_JOURNALNODE_SYNC_INTERVAL_KEY,
            DFSConfigKeys.DFS_JOURNALNODE_SYNC_INTERVAL_DEFAULT);
    // 30
    logSegmentTransferTimeout = conf.getInt(
            DFSConfigKeys.DFS_EDIT_LOG_TRANSFER_TIMEOUT_KEY,
            DFSConfigKeys.DFS_EDIT_LOG_TRANSFER_TIMEOUT_DEFAULT);
    throttler = getThrottler(conf);
    metrics = journal.getMetrics();
    journalSyncerStarted = false;
  }
```

2.4.1.1.2 启动线程

```
public void start(String nsId) {
    if (nsId != null) {
        // mycluster
        this.nameServiceId = nsId;
        journal.setTriedJournalSyncerStartedwithnsId(true);
    }
```

```
    if (!journalSyncerStarted && // 获取其他 JournalNode 代理
                getOtherJournalNodeProxies()
    ) {
      // Starting SyncJournal daemon for journal mycluster
      LOG.info("Starting SyncJournal daemon for journal " + jid);
      // 启动同步 JournalNode EditLog 线程
      startSyncJournalsDaemon();
      journalSyncerStarted = true;
    }

  }
```

2.4.1.1.2.1 获取其他 JournalNode 代理

```
private boolean getOtherJournalNodeProxies() {
    // 获取其他 JournalNode 地址
    List<InetSocketAddress> otherJournalNodes = getOtherJournalNodeAddrs();
    if (otherJournalNodes == null || otherJournalNodes.isEmpty()) {
      LOG.warn("Other JournalNode addresses not available. Journal Syncing " +
          "cannot be done");
      return false;
    }
    for (InetSocketAddress addr : otherJournalNodes) {
      try {
        // 添加其他 JournalNode 代理
        otherJNProxies.add(new JournalNodeProxy(addr));
      } catch (IOException e) {
        LOG.warn("Could not add proxy for Journal at addresss " + addr, e);
      }
    }
    if (otherJNProxies.isEmpty()) {
      LOG.error("Cannot sync as there is no other JN available for sync.");
      return false;
    }
    numOtherJNs = otherJNProxies.size();
    return true;
  }
```

2.4.1.1.2.1.1 创建 JournalNodeProxy

```
JournalNodeProxy(InetSocketAddress jnAddr) throws IOException {
      final Configuration confCopy = new Configuration(conf);
```

```
        this.jnAddr = jnAddr;
        // 获取其他 JournalNode 的代理
        this.jnProxy = SecurityUtil.doAsLoginUser(
            new PrivilegedExceptionAction<InterQJournalProtocol>() {
              @Override
              public InterQJournalProtocol run() throws IOException {
                // 设置 JournalNode 之间内部通讯协议接口 InterQJournalProtocol
                RPC.setProtocolEngine(confCopy, InterQJournalProtocolPB.class,
                    ProtobufRpcEngine.class);
                // 获取其他 JournalNode 的代理
                InterQJournalProtocolPB interQJournalProtocolPB = RPC.getProxy(
                    InterQJournalProtocolPB.class,
                    RPC.getProtocolVersion(InterQJournalProtocolPB.class),
                    jnAddr, confCopy);
                return new InterQJournalProtocolTranslatorPB(
                    interQJournalProtocolPB);
              }
            });
    }
```

2.4.1.1.2.2 执行启动线程 (创建 EditLog 存储目录)

```
private void startSyncJournalsDaemon() {
    // 创建线程并启动
    syncJournalDaemon = new Daemon(() -> {
      // Wait for journal to be formatted to create edits.sync directory
      while(!journal.isFormatted()) {
        try {
          Thread.sleep(journalSyncInterval);
        } catch (InterruptedException e) {
          LOG.error("JournalNodeSyncer daemon received Runtime exception.", e);
          Thread.currentThread().interrupt();
          return;
        }
      }
      // 创建 JournalNode 同步 EditLog 目录
      if (!createEditsSyncDir()) {
        LOG.error("Failed to create directory for downloading log " +
            "segments: %s. Stopping Journal Node Sync.",
            journal.getStorage().getEditsSyncDir());
        return;
      }
      while(shouldSync) {
        try {
```

```
            if (!journal.isFormatted()) {
              LOG.warn("Journal cannot sync. Not formatted.");
            } else {
              // 执行 同步 JournalNode 相关的信息
              syncJournals();
            }
          } catch (Throwable t) {
            if (!shouldSync) {
              if (t instanceof InterruptedException) {
                LOG.info("Stopping JournalNode Sync.");
                Thread.currentThread().interrupt();
                return;
              } else {
                LOG.warn("JournalNodeSyncer received an exception while " +
                    "shutting down.", t);
              }
              break;
            } else {
              if (t instanceof InterruptedException) {
                LOG.warn("JournalNodeSyncer interrupted", t);
                Thread.currentThread().interrupt();
                return;
              }
            }
            LOG.error(
                "JournalNodeSyncer daemon received Runtime exception. ", t);
          }
          try {
            // 120s
            Thread.sleep(journalSyncInterval);
          } catch (InterruptedException e) {
            if (!shouldSync) {
              LOG.info("Stopping JournalNode Sync.");
            } else {
              LOG.warn("JournalNodeSyncer interrupted", e);
            }
            Thread.currentThread().interrupt();
            return;
          }
        }
      });
      syncJournalDaemon.start();
    }
```

2.4.2 执行接收 RPC 发送的 EditLog 元数据请求 (写磁盘)

```
/**
     * Write a batch of edits to the journal.
     * {@see QJournalProtocol#journal(RequestInfo, long, long, int, byte[])}
     */
    synchronized void journal(RequestInfo reqInfo,
        long segmentTxId, long firstTxnId,
        int numTxns, byte[] records) throws IOException {
      checkFormatted();
      checkWriteRequest(reqInfo);

      // If numTxns is 0, it's actually a fake send which aims at updating
      // committedTxId only. So we can return early.
      if (numTxns == 0) {
        return;
      }

      checkSync(curSegment != null,
          "Can't write, no segment open" + " ; journal id: " + journalId);

      if (curSegmentTxId != segmentTxId) {
        // Sanity check: it is possible that the writer will fail IPCs
        // on both the finalize() and then the start() of the next segment.
        // This could cause us to continue writing to an old segment
        // instead of rolling to a new one, which breaks one of the
        // invariants in the design. If it happens, abort the segment
        // and throw an exception.
        JournalOutOfSyncException e = new JournalOutOfSyncException(
            "Writer out of sync: it thinks it is writing segment " + segmentTxId
                + " but current segment is " + curSegmentTxId
                + " ; journal id: " + journalId);
        abortCurSegment();
        throw e;
      }

      checkSync(nextTxId == firstTxnId,
          "Can't write txid " + firstTxnId + " expecting nextTxId=" + nextTxId
              + " ; journal id: " + journalId);

      long lastTxnId = firstTxnId + numTxns - 1;
      if (LOG.isTraceEnabled()) {
        LOG.trace("Writing txid " + firstTxnId + "-" + lastTxnId +
```

```
            " ; journal id: " + journalId);
    }
    if (cache != null) {
      // 缓存 EditLog
      cache.storeEdits(records, firstTxnId, lastTxnId, curSegmentLayoutVersion);
    }

    // If the edit has already been marked as committed, we know
    // it has been fsynced on a quorum of other nodes, and we are
    // "catching up" with the rest. Hence we do not need to fsync.
    boolean isLagging = lastTxnId <= committedTxnId.get();
    boolean shouldFsync = !isLagging;

    // 往双缓存写 EditLog
    curSegment.writeRaw(records, 0, records.length);
    // 交换双缓存
    curSegment.setReadyToFlush();
    StopWatch sw = new StopWatch();
    sw.start();
    // 刷写缓存 EditLog 到磁盘
    curSegment.flush(shouldFsync);
    sw.stop();

    long nanoSeconds = sw.now();
    metrics.addSync(
        TimeUnit.MICROSECONDS.convert(nanoSeconds, TimeUnit.NANOSECONDS));
    long milliSeconds = TimeUnit.MILLISECONDS.convert(
        nanoSeconds, TimeUnit.NANOSECONDS);

    if (milliSeconds > WARN_SYNC_MILLIS_THRESHOLD) {
      LOG.warn("Sync of transaction range " + firstTxnId + "-" + lastTxnId +
                  " took " + milliSeconds + "ms" + " ; journal id: " + journalId);
    }

    if (isLagging) {
      // This batch of edits has already been committed on a quorum of other
      // nodes. So, we are in "catch up" mode. This gets its own metric.
      metrics.batchesWrittenWhileLagging.incr(1);
    }

    metrics.batchesWritten.incr(1);
    metrics.bytesWritten.incr(records.length);
    metrics.txnsWritten.incr(numTxns);
```

```
        updateHighestWrittenTxId(lastTxnId);
        nextTxId = lastTxnId + 1;
        lastJournalTimestamp = Time.now();
    }
```

2.5 Standby NameNode 拉取 JournalNode EditLog 元数据信息

入口类：EditLogTailer.EditLogTailerThread.run()

```
@Override
            public void run() {
                SecurityUtil.doAsLoginUserOrFatal(
                        new PrivilegedAction<Object>() {
                            @Override
                            public Object run() {
                                // 执行
                                doWork();
                                return null;
                            }
                        });
            }
```

```
private void doWork() {
                long currentSleepTimeMs = sleepTimeMs;
                while (shouldRun) {
                    long editsTailed = 0;
                    try {
                        // There's no point in triggering a log roll if the Standby hasn't
                        // read any more transactions since the last time a roll was
                        // triggered.
                        // 触发 EditLog 文件滚动判断
                        boolean triggeredLogRoll = false;
                        if (// 超过 120s 没有更新
                                tooLongSinceLastLoad() &&
                                        lastRollTriggerTxId < lastLoadedTxnId) {
                            // 触发 Active EditLog 滚动
                            triggerActiveLogRoll();
                            triggeredLogRoll = true;
                        }
                        /**
                         * Check again in case someone calls {@link EditLogTailer#stop} while
```

```
                 * we're triggering an edit log roll, since ipc.Client catches and
                 * ignores {@link InterruptedException} in a few places. This fixes
                 * the bug described in HDFS-2823.
                 */
                if (!shouldRun) {
                    break;
                }
                // Prevent reading of name system while being modified. The full
                // name system lock will be acquired to further block even the block
                // state updates.
                namesystem.cpLockInterruptibly();
                long startTime = Time.monotonicNow();
                try {
                    NameNode.getNameNodeMetrics().addEditLogTailInterval(
                            startTime - lastLoadTimeMs);
                    // 往下追
                    editsTailed = doTailEdits();
                } finally {
                    namesystem.cpUnlock();
                    NameNode.getNameNodeMetrics().addEditLogTailTime(
                            Time.monotonicNow() - startTime);
                }
                // Update NameDirSize Metric
                if (triggeredLogRoll) {
                    namesystem.getFSImage().getStorage().updateNameDirSize();
                }
            } catch (EditLogInputException elie) {
                LOG.warn("Error while reading edits from disk. Will try again.", elie);
            } catch (InterruptedException ie) {
                // interrupter should have already set shouldRun to false
                continue;
            } catch (Throwable t) {
                LOG.fatal("Unknown error encountered while tailing edits. " +
                        "Shutting down standby NN.", t);
                terminate(1, t);
            }

            try {
                if (editsTailed == 0 && maxSleepTimeMs > 0) {
                    // If no edits were tailed, apply exponential backoff
                    // before tailing again. Double the current sleep time on each
                    // empty response, but don't exceed the max. If the sleep time
                    // was configured as 0, start the backoff at 1 ms.
                    currentSleepTimeMs = Math.min(maxSleepTimeMs,
```

```
                                        (currentSleepTimeMs == 0 ? 1 : currentSleepTimeMs) *
2);
                            } else {
                                currentSleepTimeMs = sleepTimeMs; // reset to initial sleep time
                            }
                            // 睡眠
                            EditLogTailer.this.sleep(currentSleepTimeMs);
                        } catch (InterruptedException e) {
                            LOG.warn("Edit log tailer interrupted", e);
                        }
                    }
                }
            }
```

2.5.1 触发 EditLog 文件滚动判断

```
    /**
     * @return true if the configured log roll period has elapsed.
     */
    private boolean tooLongSinceLastLoad() {
        // 120s >= 0
        return logRollPeriodMs >= 0 &&
                (monotonicNow() - lastRollTimeMs) > logRollPeriodMs;
    }
```

2.5.1.1 触发 Active NameNode EditLog 滚动

```
    /**
     * Trigger the active node to roll its logs.
     */
    @VisibleForTesting
    void triggerActiveLogRoll() {
        LOG.info("Triggering log roll on remote NameNode");
        Future<Void> future = null;
        try {
            // 发送 RPC 请求给 Active NameNode 滚动 EditLog
            future = rollEditsRpcExecutor.submit(
                    // 发送 RPC 请求
                    getNameNodeProxy()
            );
```

```
                future.get(rollEditsTimeoutMs, TimeUnit.MILLISECONDS);
                lastRollTimeMs = monotonicNow();
                lastRollTriggerTxId = lastLoadedTxnId;
            } catch (ExecutionException e) {
                LOG.warn("Unable to trigger a roll of the active NN", e);
            } catch (TimeoutException e) {
                if (future != null) {
                    future.cancel(true);
                }
                LOG.warn(String.format(
                        "Unable to finish rolling edits in %d ms", rollEditsTimeoutMs));
            } catch (InterruptedException e) {
                LOG.warn("Unable to trigger a roll of the active NN", e);
            }
        }
```

```
/**
     * NameNodeProxy factory method.
     *
     * @return a Callable to roll logs on remote NameNode.
     */
    @VisibleForTesting
    Callable<Void> getNameNodeProxy() {
        return new MultipleNameNodeProxy<Void>() {
            @Override
            protected Void doWork() throws IOException {
                // 调用 NameNodeRpcServer.rollEditLog() (通讯协议接口 NamenodeProtocol)
                cachedActiveProxy.rollEditLog();
                return null;
            }
        };
    }
```

2.5.2 执行拉取 JournalNode EditLog 数据 (HTTP GET 方式)

```
@VisibleForTesting
    public long doTailEdits() throws IOException, InterruptedException {
        // Write lock needs to be interruptible here because the
        // transitionToActive RPC takes the write lock before calling
        // tailer.stop() -- so if we're not interruptible, it will
        // deadlock.
```

```
namesystem.writeLockInterruptibly();
try {
    // 获取 FSImage
    FSImage image = namesystem.getFSImage();

    long lastTxnId = image.getLastAppliedTxId();

    if (LOG.isDebugEnabled()) {
        LOG.debug("lastTxnId: " + lastTxnId);
    }
    Collection<EditLogInputStream> streams;
    long startTime = Time.monotonicNow();
    try {
        // 选择 JournalNode 流
        streams = editLog.selectInputStreams(lastTxnId + 1, 0,
                null, inProgressOk, true);
    } catch (IOException ioe) {
        // This is acceptable. If we try to tail edits in the middle of an edits
        // log roll, i.e. the last one has been finalized but the new inprogress
        // edits file hasn't been started yet.
        LOG.warn("Edits tailer failed to find any streams. Will try again " +
                "later.", ioe);
        return 0;
    } finally {
        NameNode.getNameNodeMetrics().addEditLogFetchTime(
                Time.monotonicNow() - startTime);
    }
    if (LOG.isDebugEnabled()) {
        LOG.debug("edit streams to load from: " + streams.size());
    }

    // Once we have streams to load, errors encountered are legitimate cause
    // for concern, so we don't catch them here. Simple errors reading from
    // disk are ignored.
    long editsLoaded = 0;
    try {
        // 从 streams 拉取 EditLog
        editsLoaded = image.loadEdits(
                streams, namesystem, maxTxnsPerLock, null, null);
    } catch (EditLogInputException elie) {
        editsLoaded = elie.getNumEditsLoaded();
        throw elie;
    } finally {
        if (editsLoaded > 0 || LOG.isDebugEnabled()) {
```

```
                    LOG.debug(String.format("Loaded %d edits starting from txid %d ",
                            editsLoaded, lastTxnId));
                }
                NameNode.getNameNodeMetrics().addNumEditLogLoaded(editsLoaded);
            }

            if (editsLoaded > 0) {
                lastLoadTimeMs = monotonicNow();
            }
            lastLoadedTxnId = image.getLastAppliedTxId();
            return editsLoaded;
        } finally {
            namesystem.writeUnlock();
        }
    }
```

2.5.2.1 选择 JournalNode 流

```
/**
     * Select a list of input streams.
     *
     * @param fromTxId               first transaction in the selected streams
     * @param toAtLeastTxId      the selected streams must contain this transaction
     * @param recovery               recovery context
     * @param inProgressOk       set to true if in-progress streams are OK
     * @param onlyDurableTxns set to true if streams are bounded
     *                                   by the durable TxId
     */
    public Collection<EditLogInputStream> selectInputStreams(long fromTxId,
                                                             long      toAtLeastTxId,
MetaRecoveryContext recovery, boolean inProgressOk,
                                                             boolean
onlyDurableTxns) throws IOException {

        List<EditLogInputStream> streams = new ArrayList<EditLogInputStream>();
        synchronized (journalSetLock) {
            Preconditions.checkState(journalSet.isOpen(), "Cannot call " +
                    "selectInputStreams() on closed FSEditLog");
            // 往下追
            selectInputStreams(streams, fromTxId, inProgressOk, onlyDurableTxns);
        }
```

```
        try {
            checkForGaps(streams, fromTxId, toAtLeastTxId, inProgressOk);
        } catch (IOException e) {
            if (recovery != null) {
                // If recovery mode is enabled, continue loading even if we know we
                // can't load up to toAtLeastTxId.
                LOG.error("Exception while selecting input streams", e);
            } else {
                closeAllStreams(streams);
                throw e;
            }
        }
        return streams;
    }
```

```
@Override
    public void selectInputStreams(Collection<EditLogInputStream> streams,
                                   long fromTxId, boolean inProgressOk, boolean
onlyDurableTxns)
            throws IOException {
        // 往下追
        journalSet.selectInputStreams(
                streams, fromTxId,
                inProgressOk, onlyDurableTxns);
    }
```

```
/**
     * In this function, we get a bunch of streams from all of our JournalManager
     * objects.  Then we add these to the collection one by one.
     *
     * @param streams           The collection to add the streams to.  It may or
     *                          may not be sorted-- this is up to the caller.
     * @param fromTxId          The transaction ID to start looking for streams at
     * @param inProgressOk      Should we consider unfinalized streams?
     * @param onlyDurableTxns   Set to true if streams are bounded by the durable
     *                          TxId. A durable TxId is the committed txid in QJM
     *                          or the largest txid written into file in FJM
     */
    @Override
    public void selectInputStreams(Collection<EditLogInputStream> streams,
                                   long fromTxId, boolean inProgressOk, boolean
onlyDurableTxns) {
```

```
        final PriorityQueue<EditLogInputStream> allStreams =
                new PriorityQueue<EditLogInputStream>(64,
                        EDIT_LOG_INPUT_STREAM_COMPARATOR);
        // 遍历每个 JournalNode
        for (JournalAndStream jas : journals) {
            if (jas.isDisabled()) {
                LOG.info("Skipping jas " + jas + " since it's disabled");
                continue;
            }
            try {
                // 往下追
                jas.getManager()
                        // 调用 QuorumJournalManager
                        .selectInputStreams(allStreams, fromTxId,
                        inProgressOk, onlyDurableTxns);
            } catch (IOException ioe) {
                LOG.warn("Unable to determine input streams from " + jas.getManager() +
                        ". Skipping.", ioe);
            }
        }
        chainAndMakeRedundantStreams(streams, allStreams, fromTxId);
    }
```

2.5.2.1.1 调用 QuorumJournalManager.selectInputStreams() 进行选择

```
@Override
    public void selectInputStreams(Collection<EditLogInputStream> streams,
                                   long fromTxnId, boolean inProgressOk,
                                   boolean onlyDurableTxns) throws IOException {
        // Some calls will use inProgressOK to get in-progress edits even if
        // the cache used for RPC calls is not enabled; fall back to using the
        // streaming mechanism to serve such requests
        if (inProgressOk && inProgressTailingEnabled) {
            if (LOG.isDebugEnabled()) {
                LOG.debug("Tailing edits starting from txn ID " + fromTxnId +
                        " via RPC mechanism");
            }
            try {
                Collection<EditLogInputStream> rpcStreams = new ArrayList<>();
                selectRpcInputStreams(rpcStreams, fromTxnId, onlyDurableTxns);
                streams.addAll(rpcStreams);
                return;
            } catch (IOException ioe) {
                LOG.warn("Encountered exception while tailing edits >= " + fromTxnId +
```

```
                                    " via RPC; falling back to streaming.", ioe);
                }
            }
            // 选择流式输入流
            selectStreamingInputStreams(streams, fromTxnId, inProgressOk,
                    onlyDurableTxns);
        }
```

```
/**
         * Select input streams from the journals, specifically using the streaming
         * mechanism optimized for resiliency / bulk load.
         */
        private void selectStreamingInputStreams(
                Collection<EditLogInputStream> streams, long fromTxnId,
                boolean inProgressOk, boolean onlyDurableTxns) throws IOException {
            // 通过 RPC Request 请求获取 JournalNode EditLog 清单
            QuorumCall<AsyncLogger, RemoteEditLogManifest> q =
                    loggers.getEditLogManifest(fromTxnId, inProgressOk);
            Map<AsyncLogger, RemoteEditLogManifest> resps =
                    loggers.waitForWriteQuorum(q, selectInputStreamsTimeoutMs,
                            "selectStreamingInputStreams");

            LOG.debug("selectStreamingInputStream manifests:\n" +
                    Joiner.on("\n").withKeyValueSeparator(": ").join(resps));

            final PriorityQueue<EditLogInputStream> allStreams =
                    new PriorityQueue<EditLogInputStream>(64,
                            JournalSet.EDIT_LOG_INPUT_STREAM_COMPARATOR);
            for (Map.Entry<AsyncLogger, RemoteEditLogManifest> e : resps.entrySet()) {
                AsyncLogger logger = e.getKey();
                RemoteEditLogManifest manifest = e.getValue();
                long committedTxnId = manifest.getCommittedTxnId();

                for (RemoteEditLog remoteLog : manifest.getLogs()) {
                    // 构建拉取 JournalNode EditLog URL (HTTP 方式)
                    URL url = logger.buildURLToFetchLogs(remoteLog.getStartTxId());

                    long endTxId = remoteLog.getEndTxId();

                    // If it's bounded by durable Txns, endTxId could not be larger
                    // than committedTxnId. This ensures the consistency.
                    // We don't do the following for finalized log segments, since all
                    // edits in those are guaranteed to be committed.
                    if (onlyDurableTxns && inProgressOk && remoteLog.isInProgress()) {
```

```
                        endTxId = Math.min(endTxId, committedTxnId);
                        if (endTxId < remoteLog.getStartTxId()) {
                            LOG.warn("Found endTxId (" + endTxId + ") that is less than " +
                                    "the startTxId (" + remoteLog.getStartTxId() +
                                    ") - setting it to startTxId.");
                            endTxId = remoteLog.getStartTxId();
                        }
                    }

                    // 创建 HTTP 拉取 JournalNode EditLog 输入流 返回 EditLogFileInputStream
                    EditLogInputStream elis = EditLogFileInputStream.fromUrl(
                            connectionFactory, url, remoteLog.getStartTxId(),
                            endTxId, remoteLog.isInProgress());
                    // 添加
                    allStreams.add(elis);
                }
            }
            // 往下追
            JournalSet.chainAndMakeRedundantStreams(streams, allStreams, fromTxnId);
        }
```

2.5.2.1.1.1 构建拉取 JournalNode EditLog URL (HTTP 方式)

```
    @Override
    public URL buildURLToFetchLogs(long segmentTxId) {
        Preconditions.checkArgument(segmentTxId > 0,
                "Invalid segment: %s", segmentTxId);
        Preconditions.checkState(hasHttpServerEndPoint(), "No HTTP/HTTPS endpoint");

        try {
            // 构建 HTTP 方式拉取 JournalNode EditLog
            String path = GetJournalEditServlet.buildPath(
                    journalId, segmentTxId, nsInfo, true);
            return new URL(httpServerURL, path);
        } catch (MalformedURLException e) {
            // should never get here.
            throw new RuntimeException(e);
        }
    }
```

```
public static String buildPath(String journalId, long segmentTxId,
        NamespaceInfo nsInfo, boolean inProgressOk) {
    // 构建 PATH
```

```
    StringBuilder path = new StringBuilder("/getJournal?");
    try {
      path.append(JOURNAL_ID_PARAM).append("=")
          .append(URLEncoder.encode(journalId, "UTF-8"));
      path.append("&" + SEGMENT_TXID_PARAM).append("=")
          .append(segmentTxId);
      path.append("&" + STORAGEINFO_PARAM).append("=")
          .append(URLEncoder.encode(nsInfo.toColonSeparatedString(), "UTF-8"));
      path.append("&" + IN_PROGRESS_OK).append("=")
          .append(inProgressOk);
    } catch (UnsupportedEncodingException e) {
      // Never get here -- everyone supports UTF-8
      throw new RuntimeException(e);
    }
    return path.toString();
  }
```

2.5.2.1.2 创建 HTTP 拉取 JournalNode EditLog 输入流 返回 EditLogFileInputStream

```
  /**
   * Open an EditLogInputStream for the given URL.
   *
   * @param connectionFactory
   *          the URLConnectionFactory used to create the connection.
   * @param url
   *          the url hosting the log
   * @param startTxId
   *          the expected starting txid
   * @param endTxId
   *          the expected ending txid
   * @param inProgress
   *          whether the log is in-progress
   * @return a stream from which edits may be read
   */
  public static EditLogInputStream fromUrl(
      URLConnectionFactory connectionFactory, URL url, long startTxId,
      long endTxId, boolean inProgress) {
    // 创建 EditLogFileInputStream
    return new EditLogFileInputStream(new URLLog(connectionFactory, url),
        startTxId, endTxId, inProgress);
  }
```

```
  private EditLogFileInputStream(LogSource log,
      long firstTxId, long lastTxId,
      boolean isInProgress) {
    //
    this.log = log;
    this.firstTxId = firstTxId;
    this.lastTxId = lastTxId;
    this.isInProgress = isInProgress;
    this.maxOpSize = DFSConfigKeys.DFS_NAMENODE_MAX_OP_SIZE_DEFAULT;
  }
```

2.5.2.2 从 streams 拉取 EditLog

```
public long loadEdits(Iterable<EditLogInputStream> editStreams,
      FSNamesystem target, long maxTxnsToRead,
      StartupOption startOpt, MetaRecoveryContext recovery)
      throws IOException {
    LOG.debug("About to load edits:\n  " + Joiner.on("\n  ").join(editStreams));
    StartupProgress prog = NameNode.getStartupProgress();
    prog.beginPhase(Phase.LOADING_EDITS);

    long prevLastAppliedTxId = lastAppliedTxId;
    long remainingReadTxns = maxTxnsToRead;
    try {
      // 创建 FSEditLogLoader
      FSEditLogLoader loader = new FSEditLogLoader(target, lastAppliedTxId);

      // Load latest edits
      for (EditLogInputStream editIn : editStreams) {
        LogAction logAction = loadEditLogHelper.record();
        if (logAction.shouldLog()) {
          String logSuppressed = "";
          if (logAction.getCount() > 1) {
            logSuppressed = "; suppressed logging for " +
                (logAction.getCount() - 1) + " edit reads";
          }
          LOG.info("Reading " + editIn + " expecting start txid #" +
              (lastAppliedTxId + 1) + logSuppressed);
        }
        try {
          // 执行
          remainingReadTxns -= loader.loadFSEdits(editIn, lastAppliedTxId + 1,
```

```
                        remainingReadTxns, startOpt, recovery);
            } finally {
                // Update lastAppliedTxId even in case of error, since some ops may
                // have been successfully applied before the error.
                lastAppliedTxId = loader.getLastAppliedTxId();
            }
            // If we are in recovery mode, we may have skipped over some txids.
            if (editIn.getLastTxId() != HdfsServerConstants.INVALID_TXID
                && recovery != null) {
                lastAppliedTxId = editIn.getLastTxId();
            }
            if (remainingReadTxns <= 0) {
                break;
            }
        }
    } finally {
        FSEditLog.closeAllStreams(editStreams);
    }
    prog.endPhase(Phase.LOADING_EDITS);
    return lastAppliedTxId - prevLastAppliedTxId;
}
```

2.5.2.2.1 创建 FSEditLogLoader

```
public FSEditLogLoader(FSNamesystem fsNamesys, long lastAppliedTxId) {
    // 往下追
    this(fsNamesys, lastAppliedTxId, new Timer());
}
```

```
@VisibleForTesting
FSEditLogLoader(FSNamesystem fsNamesys, long lastAppliedTxId, Timer timer) {
    this.fsNamesys = fsNamesys;
    this.blockManager = fsNamesys.getBlockManager();
    this.lastAppliedTxId = lastAppliedTxId;
    this.timer = timer;
}
```

2.5.2.2.2 执行拉取

```
/**
     * Load an edit log, and apply the changes to the in-memory structure
     * This is where we apply edits that we've been writing to disk all
```

```
   * along.
   */
  long loadFSEdits(EditLogInputStream edits, long expectedStartingTxId,
      long maxTxnsToRead,
      StartupOption startOpt, MetaRecoveryContext recovery) throws IOException {

    StartupProgress prog = NameNode.getStartupProgress();
    Step step = createStartupProgressStep(edits);
    prog.beginStep(Phase.LOADING_EDITS, step);

    fsNamesys.writeLock();
    try {
      long startTime = timer.monotonicNow();
      LogAction preLogAction = loadEditsLogHelper.record("pre", startTime);

      if (preLogAction.shouldLog()) {
        FSImage.LOG.info("Start loading edits file " + edits.getName()
            + " maxTxnsToRead = " + maxTxnsToRead +
            LogThrottlingHelper.getLogSupressionMessage(preLogAction));
      }
      // 加载 (返回 EditLog 个数)
      long numEdits = loadEditRecords(edits, false, expectedStartingTxId,
          maxTxnsToRead, startOpt, recovery);

      long endTime = timer.monotonicNow();

      LogAction postLogAction = loadEditsLogHelper.record("post", endTime,
          numEdits, edits.length(), endTime - startTime);

      if (postLogAction.shouldLog()) {
        FSImage.LOG.info("Loaded " + postLogAction.getCount()
            + " edits file(s) (the last named " + edits.getName()
            + ") of total size " + postLogAction.getStats(1).getSum()
            + ", total edits " + postLogAction.getStats(0).getSum()
            + ", total load time " + postLogAction.getStats(2).getSum()
            + " ms");
      }
      return numEdits;
    } finally {
      edits.close();
      fsNamesys.writeUnlock("loadFSEdits");
      prog.endStep(Phase.LOADING_EDITS, step);
    }
  }
```

```
long loadEditRecords(EditLogInputStream in, boolean closeOnExit,
        long expectedStartingTxId, long maxTxnsToRead, StartupOption startOpt,
        MetaRecoveryContext recovery) throws IOException {

    EnumMap<FSEditLogOpCodes, Holder<Integer>> opCounts =
        new EnumMap<FSEditLogOpCodes, Holder<Integer>>(FSEditLogOpCodes.class);

    if (LOG.isTraceEnabled()) {
        LOG.trace("Acquiring write lock to replay edit log");
    }

    fsNamesys.writeLock();
    FSDirectory fsDir = fsNamesys.dir;
    fsDir.writeLock();

    long recentOpcodeOffsets[] = new long[4];
    Arrays.fill(recentOpcodeOffsets, -1);

    long expectedTxId = expectedStartingTxId;
    long numEdits = 0;
    long lastTxId = in.getLastTxId();
    long numTxns = (lastTxId - expectedStartingTxId) + 1;

    StartupProgress prog = NameNode.getStartupProgress();
    Step step = createStartupProgressStep(in);
    prog.setTotal(Phase.LOADING_EDITS, step, numTxns);
    Counter counter = prog.getCounter(Phase.LOADING_EDITS, step);

    long lastLogTime = timer.monotonicNow();
    long lastInodeId = fsNamesys.dir.getLastInodeId();

    try {
        while (true) {
            try {
                FSEditLogOp op;
                try {
                    // 调用 GetJournalEditServlet.doGet() 的输出流 (这里是输入流)
                    // 真正读取 JournalNode 的 EditLogFile
                    op = in.readOp();
                    if (op == null) {
                        break;
                    }
                } catch (Throwable e) {
```

```
        // Handle a problem with our input
        check203UpgradeFailure(in.getVersion(true), e);
        String errorMessage =
          formatEditLogReplayError(in, recentOpcodeOffsets, expectedTxId);
        FSImage.LOG.error(errorMessage, e);
        if (recovery == null) {
           // We will only try to skip over problematic opcodes when in
           // recovery mode.
          throw new EditLogInputException(errorMessage, e, numEdits);
        }
        MetaRecoveryContext.editLogLoaderPrompt(
            "We failed to read txId " + expectedTxId,
            recovery, "skipping the bad section in the log");
        in.resync();
        continue;
      }

      recentOpcodeOffsets[(int)(numEdits % recentOpcodeOffsets.length)] =
        in.getPosition();
      if (op.hasTransactionId()) {
        if (op.getTransactionId() > expectedTxId) {
          MetaRecoveryContext.editLogLoaderPrompt("There appears " +
              "to be a gap in the edit log.  We expected txid " +
              expectedTxId + ", but got txid " +
              op.getTransactionId() + ".", recovery, "ignoring missing " +
              " transaction IDs");
        } else if (op.getTransactionId() < expectedTxId) {
          MetaRecoveryContext.editLogLoaderPrompt("There appears " +
              "to be an out-of-order edit in the edit log.  We " +
              "expected txid " + expectedTxId + ", but got txid " +
              op.getTransactionId() + ".", recovery,
              "skipping the out-of-order edit");
          continue;
        }
      }
      try {
        if (LOG.isTraceEnabled()) {
          LOG.trace("op=" + op + ", startOpt=" + startOpt
              + ", numEdits=" + numEdits + ", totalEdits=" + totalEdits);
        }
        // 将读取的 EditLog 更新到内存
        long inodeId = applyEditLogOp(op, fsDir, startOpt,
            in.getVersion(true), lastInodeId);
```

```
                if (lastInodeId < inodeId) {
                    lastInodeId = inodeId;
                }
            } catch (RollingUpgradeOp.RollbackException e) {
                throw e;
            } catch (Throwable e) {
                LOG.error("Encountered exception on operation " + op, e);
                if (recovery == null) {
                    throw e instanceof IOException? (IOException)e: new IOException(e);
                }

                MetaRecoveryContext.editLogLoaderPrompt("Failed to " +
                  "apply edit log operation " + op + ": error " +
                  e.getMessage(), recovery, "applying edits");
            }
            // Now that the operation has been successfully decoded and
            // applied, update our bookkeeping.
            incrOpCount(op.opCode, opCounts, step, counter);
            if (op.hasTransactionId()) {
                lastAppliedTxId = op.getTransactionId();
                expectedTxId = lastAppliedTxId + 1;
            } else {
                expectedTxId = lastAppliedTxId = expectedStartingTxId;
            }
            // log progress
            if (op.hasTransactionId()) {
                long now = timer.monotonicNow();
                if (now - lastLogTime > REPLAY_TRANSACTION_LOG_INTERVAL) {
                    long deltaTxId = lastAppliedTxId - expectedStartingTxId + 1;
                    int percent = Math.round((float) deltaTxId / numTxns * 100);
                    LOG.info("replaying edit log: " + deltaTxId + "/" + numTxns
                          + " transactions completed. (" + percent + "%)");
                    lastLogTime = now;
                }
            }
            numEdits++;
            totalEdits++;
            if(numEdits >= maxTxnsToRead) {
                break;
            }
        } catch (RollingUpgradeOp.RollbackException e) {
            LOG.info("Stopped at OP_START_ROLLING_UPGRADE for rollback.");
            break;
        } catch (MetaRecoveryContext.RequestStopException e) {
```

```
                MetaRecoveryContext.LOG.warn("Stopped reading edit log at " +
                    in.getPosition() + "/"    + in.length());
                break;
              }
            }
          } finally {
            fsNamesys.dir.resetLastInodeId(lastInodeId);
            if(closeOnExit) {
              in.close();
            }
            fsDir.writeUnlock();
            fsNamesys.writeUnlock("loadEditRecords");

            if (LOG.isTraceEnabled()) {
              LOG.trace("replaying edit log finished");
            }

            if (FSImage.LOG.isDebugEnabled()) {
              dumpOpCounts(opCounts);
              FSImage.LOG.debug("maxTxnsToRead = " + maxTxnsToRead
                  + " actual edits read = " + numEdits);
            }
            assert numEdits <= maxTxnsToRead || numEdits == 1 :
              "should read at least one txn, but not more than the configured max";
          }
          return numEdits;
        }
```

2.5.2.2.2.1 调用 GetJournalEditServlet.doGet()

```
@Override
    public void doGet(final HttpServletRequest request,
        final HttpServletResponse response) throws ServletException, IOException {
      FileInputStream editFileIn = null;
      try {
        final ServletContext context = getServletContext();
        final Configuration conf = (Configuration) getServletContext()
            .getAttribute(JspHelper.CURRENT_CONF);
        final String journalId = request.getParameter(JOURNAL_ID_PARAM);
        final String inProgressOkStr = request.getParameter(IN_PROGRESS_OK);
        final boolean inProgressOk;
        if (inProgressOkStr != null &&
            inProgressOkStr.equalsIgnoreCase("false")) {
          inProgressOk = false;
```

```
} else {
    inProgressOk = true;
}
QuorumJournalManager.checkJournalId(journalId);
// 获取 JNStorage
final JNStorage storage = JournalNodeHttpServer
        .getJournalFromContext(context, journalId).getStorage();

// Check security
if (!checkRequestorOrSendError(conf, request, response)) {
    return;
}

// Check that the namespace info is correct
if (!checkStorageInfoOrSendError(storage, request, response)) {
    return;
}

long segmentTxId = ServletUtil.parseLongParam(request,
        SEGMENT_TXID_PARAM);

// 获取 FileJournalManager
FileJournalManager fjm = storage.getJournalManager();
File editFile;

synchronized (fjm) {
    // Synchronize on the FJM so that the file doesn't get finalized
    // out from underneath us while we're in the process of opening
    // it up.
    // 获取 EditLogFile
    EditLogFile elf = fjm.getLogFile(segmentTxId, inProgressOk);
    if (elf == null) {
        response.sendError(HttpServletResponse.SC_NOT_FOUND,
                "No edit log found starting at txid " + segmentTxId);
        return;
    }
    editFile = elf.getFile();
    ImageServlet.setVerificationHeadersForGet(response, editFile);
    ImageServlet.setFileNameHeaders(response, editFile);

    // 构建输入流读取 EditLog
    editFileIn = new FileInputStream(editFile);
}
```

```
        // null
        DataTransferThrottler throttler = ImageServlet.getThrottler(conf);

        // send edits
        // 发送 EditLog (流拷贝)
        TransferFsImage.copyFileToStream(response.getOutputStream(), editFile,
              editFileIn, throttler);

      } catch (Throwable t) {
        String errMsg = "getedit failed. " + StringUtils.stringifyException(t);
        response.sendError(HttpServletResponse.SC_INTERNAL_SERVER_ERROR, errMsg);
        throw new IOException(errMsg);
      } finally {
        IOUtils.closeStream(editFileIn);
      }
    }
```

2.5.2.2.2.2 将读取的 EditLog 更新到内存

```
@SuppressWarnings("deprecation")
private long applyEditLogOp(FSEditLogOp op, FSDirectory fsDir,
      StartupOption startOpt, int logVersion, long lastInodeId) throws IOException {
    long inodeId = HdfsConstants.GRANDFATHER_INODE_ID;
    if (LOG.isTraceEnabled()) {
      LOG.trace("replaying edit log: " + op);
    }
    final boolean toAddRetryCache = fsNamesys.hasRetryCache() && op.hasRpcIds();

    switch (op.opCode) {
    case OP_ADD: {
      AddCloseOp addCloseOp = (AddCloseOp)op;
      final String path =
          renameReservedPathsOnUpgrade(addCloseOp.path, logVersion);
      if (FSNamesystem.LOG.isDebugEnabled()) {
        FSNamesystem.LOG.debug(op.opCode + ": " + path +
            " numblocks : " + addCloseOp.blocks.length +
            " clientHolder " + addCloseOp.clientName +
            " clientMachine " + addCloseOp.clientMachine);
      }
      // There are 3 cases here:
      // 1. OP_ADD to create a new file
      // 2. OP_ADD to update file blocks
      // 3. OP_ADD to open file for append (old append)
```

```
// See if the file already exists (persistBlocks call)
INodesInPath iip = fsDir.getINodesInPath(path, DirOp.WRITE);
INodeFile oldFile = INodeFile.valueOf(iip.getLastINode(), path, true);
if (oldFile != null && addCloseOp.overwrite) {
   // This is OP_ADD with overwrite
   FSDirDeleteOp.deleteForEditLog(fsDir, iip, addCloseOp.mtime);
   iip = INodesInPath.replace(iip, iip.length() - 1, null);
   oldFile = null;
}
INodeFile newFile = oldFile;
if (oldFile == null) { // this is OP_ADD on a new file (case 1)
   // versions > 0 support per file replication
   // get name and replication
   final short replication = fsNamesys.getBlockManager()
         .adjustReplication(addCloseOp.replication);
   assert addCloseOp.blocks.length == 0;

   // add to the file tree
   inodeId = getAndUpdateLastInodeId(addCloseOp.inodeId, logVersion, lastInodeId);
   newFile = FSDirWriteFileOp.addFileForEditLog(fsDir, inodeId,
         iip.getExistingINodes(), iip.getLastLocalName(),
         addCloseOp.permissions, addCloseOp.aclEntries,
         addCloseOp.xAttrs, replication, addCloseOp.mtime,
         addCloseOp.atime, addCloseOp.blockSize, true,
         addCloseOp.clientName, addCloseOp.clientMachine,
         addCloseOp.storagePolicyId, addCloseOp.erasureCodingPolicyId);
   assert newFile != null;
   iip = INodesInPath.replace(iip, iip.length() - 1, newFile);
   fsNamesys.leaseManager.addLease(addCloseOp.clientName, newFile.getId());

   // add the op into retry cache if necessary
   if (toAddRetryCache) {
      HdfsFileStatus stat =
            FSDirStatAndListingOp.createFileStatusForEditLog(fsDir, iip);
      fsNamesys.addCacheEntryWithPayload(addCloseOp.rpcClientId,
            addCloseOp.rpcCallId, stat);
   }
} else { // This is OP_ADD on an existing file (old append)
   if (!oldFile.isUnderConstruction()) {
      // This is case 3: a call to append() on an already-closed file.
      if (FSNamesystem.LOG.isDebugEnabled()) {
         FSNamesystem.LOG.debug("Reopening an already-closed file " +
               "for append");
```

```
            }
            LocatedBlock lb = FSDirAppendOp.prepareFileForAppend(fsNamesys, iip,
                addCloseOp.clientName, addCloseOp.clientMachine, false, false,
                false);
            // add the op into retry cache if necessary
            if (toAddRetryCache) {
              HdfsFileStatus stat =
                  FSDirStatAndListingOp.createFileStatusForEditLog(fsDir, iip);
              fsNamesys.addCacheEntryWithPayload(addCloseOp.rpcClientId,
                  addCloseOp.rpcCallId, new LastBlockWithStatus(lb, stat));
            }
          }
        }
        // Fall-through for case 2.
        // Regardless of whether it's a new file or an updated file,
        // update the block list.

        // Update the salient file attributes.
        newFile.setAccessTime(addCloseOp.atime, Snapshot.CURRENT_STATE_ID, false);
        newFile.setModificationTime(addCloseOp.mtime, Snapshot.CURRENT_STATE_ID);
        ErasureCodingPolicy ecPolicy =
            FSDirErasureCodingOp.unprotectedGetErasureCodingPolicy(
                fsDir.getFSNamesystem(), iip);
        updateBlocks(fsDir, addCloseOp, iip, newFile, ecPolicy);
        break;
      }
      ......
      case OP_MKDIR: {
        // 强制转换
        MkdirOp mkdirOp = (MkdirOp)op;
        inodeId = getAndUpdateLastInodeId(mkdirOp.inodeId, logVersion,
            lastInodeId);

        // 往下追
        FSDirMkdirOp.mkdirForEditLog(fsDir, inodeId,
            renameReservedPathsOnUpgrade(mkdirOp.path, logVersion),
            mkdirOp.permissions, mkdirOp.aclEntries, mkdirOp.timestamp);
        break;
      }
      case OP_SET_GENSTAMP_V1: {
        SetGenstampV1Op setGenstampV1Op = (SetGenstampV1Op)op;
        blockManager.getBlockIdManager().setLegacyGenerationStamp(
            setGenstampV1Op.genStampV1);
        break;
```

```
      }
     .....
      default:
         throw new IOException("Invalid operation read " + op.opCode);
      }
      return inodeId;
   }
```

```
static void mkdirForEditLog(FSDirectory fsd, long inodeId, String src,
                                        PermissionStatus permissions, List<AclEntry> aclEntries,
long timestamp)
                throws QuotaExceededException, UnresolvedLinkException, AclException,
                FileAlreadyExistsException, ParentNotDirectoryException,
                AccessControlException {
          assert fsd.hasWriteLock();
          //
          INodesInPath iip = fsd.getINodesInPath(src, DirOp.WRITE_LINK);
          final byte[] localName = iip.getLastLocalName();
          final INodesInPath existing = iip.getParentINodesInPath();
          Preconditions.checkState(existing.getLastINode() != null);
          // 往下追 (Standby NameNode 添加目录信息跟 Active NameNode 相同)
          unprotectedMkdir(fsd, inodeId, existing, localName, permissions, aclEntries,
                    timestamp);
      }
```

```
 /**
       * create a directory at path specified by parent
       */
      private static INodesInPath unprotectedMkdir(FSDirectory fsd, long inodeId,
                                                   INodesInPath parent, byte[] name,
PermissionStatus permission,
                                                   List<AclEntry> aclEntries, long
timestamp)
                throws QuotaExceededException, AclException, FileAlreadyExistsException {
          assert fsd.hasWriteLock();
          assert parent.getLastINode() != null;
          if (!parent.getLastINode().isDirectory()) {
                throw new FileAlreadyExistsException("Parent path is not a directory: " +
                          parent.getPath() + " " + DFSUtil.bytes2String(name));
          }
          // 创建 INodeDirectory
          final INodeDirectory dir = new INodeDirectory(inodeId, name, permission,
                    timestamp);
```

```
        // 往父目录添加子目录 返回子目录信息
        INodesInPath iip =
                fsd.addLastINode(parent, dir, permission.getPermission(), true);
        if (iip != null && aclEntries != null) {
            AclStorage.updateINodeAcl(dir, aclEntries, Snapshot.CURRENT_STATE_ID);
        }
        return iip;
    }
```

2.6 Standby NameNode 执行 checkpoint 并上传 Active NameNode

入口类：StandbyCheckpointer.CheckpointerThread.run()

```
@Override
        public void run() {
            // We have to make sure we're logged in as far as JAAS
            // is concerned, in order to use kerberized SSL properly.
            SecurityUtil.doAsLoginUserOrFatal(
                    new PrivilegedAction<Object>() {
                        @Override
                        public Object run() {
                            // 执行
                            doWork();
                            return null;
                        }
                    });
        }
```

```
private void doWork() {
            // 检查 checkpoint 间隔 默认 60 * 1000L
            final long checkPeriod = 1000 * checkpointConf.getCheckPeriod();

            // Reset checkpoint time so that we don't always checkpoint
            // on startup.
            lastCheckpointTime = monotonicNow();
            lastUploadTime = monotonicNow();

            while (shouldRun) {
                // 判断是否 checkpoint fsimage
                boolean needRollbackCheckpoint = namesystem.isNeedRollbackFsImage();
                if (!needRollbackCheckpoint) {
```

```
                try {
                    // 睡眠 60s
                    Thread.sleep(checkPeriod);
                } catch (InterruptedException ie) {
                }
                if (!shouldRun) {
                    break;
                }
            }
            try {
                // We may have lost our ticket since last checkpoint, log in again, just in
case
                if (UserGroupInformation.isSecurityEnabled()) {

UserGroupInformation.getCurrentUser().checkTGTAndReloginFromKeytab();
                }

                final long now = monotonicNow();
                // 获取没有 checkpoint tx 总数
                final long uncheckpointed = countUncheckpointedTxns();
                final long secsSinceLast = (now - lastCheckpointTime) / 1000;

                // if we need a rollback checkpoint, always attempt to checkpoint
                boolean needCheckpoint = needRollbackCheckpoint;

                if (needCheckpoint) {
                    LOG.info("Triggering a rollback fsimage for rolling upgrade.");
                } else if (
                    // uncheckpointed >= 100w
                        uncheckpointed >= checkpointConf.getTxnCount()
                ) {
                    LOG.info("Triggering checkpoint because there have been {} txns " +
                                    "since the last checkpoint, " +
                                    "which exceeds the configured threshold {}",
                            uncheckpointed, checkpointConf.getTxnCount());
                    needCheckpoint = true;
                } else if (
                    // secsSinceLast >= 3600s = 1h
                        secsSinceLast >= checkpointConf.getPeriod()
                ) {
                    LOG.info("Triggering checkpoint because it has been {} seconds " +
                            "since the last checkpoint, which exceeds the configured "
+
                            "interval {}", secsSinceLast, checkpointConf.getPeriod());
```

```
                    needCheckpoint = true;
                }

                if (needCheckpoint) {
                    synchronized (cancelLock) {
                        if (now < preventCheckpointsUntil) {
                            LOG.info("But skipping this checkpoint since we are about
to failover!");
                            canceledCount++;
                            continue;
                        }
                        assert canceler == null;
                        canceler = new Canceler();
                    }

                    // on all nodes, we build the checkpoint. However, we only ship the
checkpoint if have a
                    // rollback request, are the checkpointer, are outside the quiet
period.
                    final long secsSinceLastUpload = (now - lastUploadTime) / 1000;
                    boolean sendRequest =
                            // true
                            isPrimaryCheckPointer
                                    ||
                                    // secsSinceLastUpload >= 3600 * 15
                                    secsSinceLastUpload                         >=
checkpointConf.getQuietPeriod();
                    // 执行 checkpoint
                    doCheckpoint(sendRequest);

                    // reset needRollbackCheckpoint to false only when we finish a ckpt
                    // for rollback image
                    if (needRollbackCheckpoint
                            && namesystem.getFSImage().hasRollbackFSImage()) {
                        namesystem.setCreatedRollbackImages(true);
                        namesystem.setNeedRollbackFsImage(false);
                    }
                    lastCheckpointTime = now;
                    LOG.info("Checkpoint finished successfully.");
                }
            } catch (SaveNamespaceCancelledException ce) {
                LOG.info("Checkpoint was cancelled: {}", ce.getMessage());
                canceledCount++;
            } catch (InterruptedException ie) {
```

```
                        LOG.info("Interrupted during checkpointing", ie);
                        // Probably requested shutdown.
                        continue;
                    } catch (Throwable t) {
                        LOG.error("Exception in doCheckpoint", t);
                    } finally {
                        synchronized (cancelLock) {
                            canceler = null;
                        }
                    }
                }
            }
```

2.6.1 执行 checkpoint

```
private void doCheckpoint(boolean sendCheckpoint) throws InterruptedException, IOException {
        assert canceler != null;
        final long txid;
        final NameNodeFile imageType;
        // Acquire cpLock to make sure no one is modifying the name system.
        // It does not need the full namesystem write lock, since the only thing
        // that modifies namesystem on standby node is edit log replaying.
        namesystem.cpLockInterruptibly();
        try {
            assert namesystem.getEditLog().isOpenForRead() :
                    "Standby Checkpointer should only attempt a checkpoint when " +
                            "NN is in standby mode, but the edit logs are in an unexpected
state";

            // 获取 FSImage
            FSImage img = namesystem.getFSImage();

            long prevCheckpointTxId = img.getStorage().getMostRecentCheckpointTxId();
            long thisCheckpointTxId = img.getCorrectLastAppliedOrWrittenTxId();
            assert thisCheckpointTxId >= prevCheckpointTxId;
            if (thisCheckpointTxId == prevCheckpointTxId) {
                LOG.info("A checkpoint was triggered but the Standby Node has not " +
                        "received any transactions since the last checkpoint at txid {}. " +
                        "Skipping...", thisCheckpointTxId);
                return;
            }
```

```
                if (namesystem.isRollingUpgrade()
                        && !namesystem.getFSImage().hasRollbackFSImage()) {
                    // if we will do rolling upgrade but have not created the rollback image
                    // yet, name this checkpoint as fsimage_rollback
                    imageType = NameNodeFile.IMAGE_ROLLBACK;
                } else {
                    imageType = NameNodeFile.IMAGE;
                }
                // 将 fsimage+editLog 元数据写一份到磁盘 fsimage[合并结果] (这个 fsimage 将来上传给 Active NameNode)
                img.saveNamespace(namesystem, imageType, canceler);
                txid = img.getStorage().getMostRecentCheckpointTxId();
                assert txid == thisCheckpointTxId : "expected to save checkpoint at txid=" +
                        thisCheckpointTxId + " but instead saved at txid=" + txid;

                // Save the legacy OIV image, if the output dir is defined.
                String outputDir = checkpointConf.getLegacyOivImageDir();
                if (outputDir != null && !outputDir.isEmpty()) {
                    try {
                        img.saveLegacyOIVImage(namesystem, outputDir, canceler);
                    } catch (IOException ioe) {
                        LOG.warn("Exception encountered while saving legacy OIV image; "
                                + "continuing with other checkpointing steps", ioe);
                    }
                }
            } finally {
                namesystem.cpUnlock();
            }

            //early exit if we shouldn't actually send the checkpoint to the ANN
            if (!sendCheckpoint) {
                return;
            }

            // Upload the saved checkpoint back to the active
            // Do this in a separate thread to avoid blocking transition to active, but don't allow more
            // than the expected number of tasks to run or queue up
            // See HDFS-4816
            // 创建一个线程池
            ExecutorService executor = new ThreadPoolExecutor(
                    0,
                    activeNNAddresses.size(),
                    100,
```

```
                    TimeUnit.MILLISECONDS,
                    new LinkedBlockingQueue<Runnable>(activeNNAddresses.size()),
                    uploadThreadFactory);

            // for right now, just match the upload to the nn address by convention. There is no need to
            // directly tie them together by adding a pair class.
            List<Future<TransferFsImage.TransferResult>> uploads =
                    new ArrayList<Future<TransferFsImage.TransferResult>>();
            // 遍历 Active NameNode
            for (final URL activeNNAddress : activeNNAddresses) {
                Future<TransferFsImage.TransferResult> upload =
                        executor.submit(new Callable<TransferFsImage.TransferResult>() {
                            @Override
                            public TransferFsImage.TransferResult call()
                                    throws IOException, InterruptedException {

CheckpointFaultInjector.getInstance().duringUploadInProgess();
                                // 请求 NameNode 上传 fsimage (http)
                                return TransferFsImage.uploadImageFromStorage(
                                        activeNNAddress, conf, namesystem
                                                .getFSImage().getStorage(),
                                        imageType, txid, canceler);
                            }
                        });
                uploads.add(upload);
            }
            InterruptedException ie = null;
            IOException ioe = null;
            int i = 0;
            boolean success = false;
            for (; i < uploads.size(); i++) {
                // 获取请求结果
                Future<TransferFsImage.TransferResult> upload = uploads.get(i);
                try {
                    // TODO should there be some smarts here about retries nodes that are not the active NN?
                    if (upload.get() == TransferFsImage.TransferResult.SUCCESS) {
                        success = true;
                        //avoid getting the rest of the results - we don't care since we had a successful upload
                        break;
                    }
```

```
                } catch (ExecutionException e) {
                    ioe = new IOException("Exception during image upload", e);
                    break;
                } catch (InterruptedException e) {
                    ie = e;
                    break;
                }
            }
            if (ie == null && ioe == null) {
                //Update only when response from remote about success or
                lastUploadTime = monotonicNow();
                // we are primary if we successfully updated the ANN
                this.isPrimaryCheckPointer = success;
            }
            // cleaner than copying code for multiple catch statements and better than catching all
            // exceptions, so we just handle the ones we expect.
            if (ie != null || ioe != null) {

                // cancel the rest of the tasks, and close the pool
                for (; i < uploads.size(); i++) {
                    Future<TransferFsImage.TransferResult> upload = uploads.get(i);
                    // The background thread may be blocked waiting in the throttler, so
                    // interrupt it.
                    upload.cancel(true);
                }

                // shutdown so we interrupt anything running and don't start anything new
                executor.shutdownNow();
                // this is a good bit longer than the thread timeout, just to make sure all the
threads
                // that are not doing any work also stop
                executor.awaitTermination(500, TimeUnit.MILLISECONDS);

                // re-throw the exception we got, since one of these two must be non-null
                if (ie != null) {
                    throw ie;
                } else if (ioe != null) {
                    throw ioe;
                }
            }
        }
```

2.6.1.1 请求 NameNode 上传 fsimage (http)

```
/**
     * Requests that the NameNode download an image from this node.  Allows for
     * optional external cancelation.
     *
     * @param fsName the http address for the remote NN
     * @param conf Configuration
     * @param storage the storage directory to transfer the image from
     * @param nnf the NameNodeFile type of the image
     * @param txid the transaction ID of the image to be uploaded
     * @param canceler optional canceler to check for abort of upload
     * @throws IOException if there is an I/O error or cancellation
     */
    public static TransferResult uploadImageFromStorage(URL fsName, Configuration conf,
                                                        NNStorage storage,
NameNodeFile nnf, long txid, Canceler canceler)
            throws IOException {
        // 构建 URL (xxx/imagetransfer)
        URL url = new URL(fsName, ImageServlet.PATH_SPEC);
        long startTime = Time.monotonicNow();
        try {
            // 请求上传 fsimage
            uploadImage(url, conf, storage, nnf, txid, canceler);
        } catch (HttpPutFailedException e) {
            // translate the error code to a result, which is a bit more obvious in usage
            TransferResult result = TransferResult.getResultForCode(e.getResponseCode());
            if (result.shouldReThrowException) {
                throw e;
            }
            return result;
        }
        double xferSec = Math.max(
                ((float) (Time.monotonicNow() - startTime)) / 1000.0, 0.001);
        LOG.info("Uploaded image with txid " + txid + " to namenode at " + fsName
                + " in " + xferSec + " seconds");
        return TransferResult.SUCCESS;
    }
```

2.6.1.1.1 请求上传 fsimage

```
/*
     * Uploads the imagefile using HTTP PUT method
```

```
     */
    private static void uploadImage(URL url, Configuration conf,
                                    NNStorage storage, NameNodeFile nnf, long txId,
Canceler canceler)
            throws IOException {

        // 获取本地 Standby NameNode fsimage[合并结果] 路径文件 (文件已经打开)
        File imageFile = storage.findImageFile(nnf, txId);
        if (imageFile == null) {
            throw new IOException("Could not find image with txid " + txId);
        }

        HttpURLConnection connection = null;
        try {
            // 构建 HTTP PUT 请求参数
            URIBuilder uriBuilder = new URIBuilder(url.toURI());

            // write all params for image upload request as query itself.
            // Request body contains the image to be uploaded.
            Map<String, String> params = ImageServlet.getParamsForPutImage(storage,
                    txId, imageFile.length(), nnf);
            for (Entry<String, String> entry : params.entrySet()) {
                uriBuilder.addParameter(entry.getKey(), entry.getValue());
            }

            URL urlWithParams = uriBuilder.build().toURL();
            // 连接 NameNodeHttpServer 的 ImageServlet 容器
            connection = (HttpURLConnection) connectionFactory.openConnection(
                    urlWithParams, UserGroupInformation.isSecurityEnabled());
            // Set the request to PUT
            // 请求方式为 PUT
            connection.setRequestMethod("PUT");
            connection.setDoOutput(true);

            // 64 KB
            int chunkSize = conf.getInt(
                    DFSConfigKeys.DFS_IMAGE_TRANSFER_CHUNKSIZE_KEY,
                    DFSConfigKeys.DFS_IMAGE_TRANSFER_CHUNKSIZE_DEFAULT);
            if (imageFile.length() > chunkSize) {
                // using chunked streaming mode to support upload of 2GB+ files and to
                // avoid internal buffering.
                // this mode should be used only if more than chunkSize data is present
                // to upload. otherwise upload may not happen sometimes.
                connection.setChunkedStreamingMode(chunkSize);
```

```
            }

            setTimeout(connection);

            // set headers for verification
            ImageServlet.setVerificationHeadersForPut(connection, imageFile);

            // Write the file to output stream.
            // 执行请求 (流拷贝 调用 ImageServlet.doPut())
            writeFileToPutRequest(conf, connection, imageFile, canceler);

            int responseCode = connection.getResponseCode();
            if (responseCode != HttpURLConnection.HTTP_OK) {
                throw new HttpPutFailedException(String.format(
                        "Image uploading failed, status: %d, url: %s, message: %s",
                        responseCode, urlWithParams, connection.getResponseMessage()),
                        responseCode);
            }
        } catch (AuthenticationException | URISyntaxException e) {
            throw new IOException(e);
        } finally {
            if (connection != null) {
                connection.disconnect();
            }
        }
    }
```

```
private static void writeFileToPutRequest(Configuration conf,
                                          HttpURLConnection connection, File
imageFile, Canceler canceler)
            throws IOException {
        connection.setRequestProperty(Util.CONTENT_TYPE, "application/octet-stream");
        connection.setRequestProperty(Util.CONTENT_TRANSFER_ENCODING, "binary");
        // 获取 HTTP 输出流
        OutputStream output = connection.getOutputStream();
        FileInputStream input = new FileInputStream(imageFile);
        try {
            // 将上传的 fsimage 写入输出流
            copyFileToStream(output, imageFile, input,
                    ImageServlet.getThrottler(conf), canceler);
        } finally {
            IOUtils.closeStream(input);
            IOUtils.closeStream(output);
```

```
        }
    }
```

2.6.1.1.1.1 请求调用 ImageServlet.doPut()

```
@Override
  protected void doPut(final HttpServletRequest request,
      final HttpServletResponse response) throws ServletException, IOException {
    try {
      ServletContext context = getServletContext();
      // 获取 Active NameNode FSImage
      final FSImage nnImage = NameNodeHttpServer.getFsImageFromContext(context);
      final Configuration conf = (Configuration) getServletContext()
          .getAttribute(JspHelper.CURRENT_CONF);
      // 解析请求参数
      final PutImageParams parsedParams = new PutImageParams(request, response,
          conf);
      final NameNodeMetrics metrics = NameNode.getNameNodeMetrics();

      validateRequest(context, conf, request, response, nnImage,
          parsedParams.getStorageInfoString());

      UserGroupInformation.getCurrentUser().doAs(
          new PrivilegedExceptionAction<Void>() {

            @Override
            public Void run() throws Exception {
              // if its not the active NN, then we need to notify the caller it was was the
wrong
              // target (regardless of the fact that we got the image)
              HAServiceProtocol.HAServiceState state = NameNodeHttpServer
                  .getNameNodeStateFromContext(getServletContext());
              if (state != HAServiceProtocol.HAServiceState.ACTIVE) {
                // we need a different response type here so the client can differentiate this
                // from the failure to upload due to (1) security, or (2) other checkpoints
already
                // present
                response.sendError(HttpServletResponse.SC_EXPECTATION_FAILED,
                    "Nameode "+request.getLocalAddr()+" is currently not in a state which
can "
                        + "accept uploads of new fsimages. State: "+state);
                return null;
              }
```

```
                final long txid = parsedParams.getTxId();
                String remoteAddr = request.getRemoteAddr();

                ImageUploadRequest imageRequest = new ImageUploadRequest(txid,
remoteAddr);

                final NameNodeFile nnf = parsedParams.getNameNodeFile();

                // if the node is attempting to upload an older transaction, we ignore it
                SortedSet<ImageUploadRequest> larger =
currentlyDownloadingCheckpoints.tailSet(imageRequest);
                if (larger.size() > 0) {
                  response.sendError(HttpServletResponse.SC_CONFLICT,
                      "Another checkpointer is already in the process of uploading a" +
                          " checkpoint made up to transaction ID " + larger.last());
                  return null;
                }

                //make sure no one else has started uploading one
                if (!currentlyDownloadingCheckpoints.add(imageRequest)) {
                  response.sendError(HttpServletResponse.SC_CONFLICT,
                      "Either current namenode is checkpointing or another"
                          + " checkpointer is already in the process of "
                          + "uploading a checkpoint made at transaction ID "
                          + txid);
                  return null;
                }
                try {
                  if (nnImage.getStorage().findImageFile(nnf, txid) != null) {
                    response.sendError(HttpServletResponse.SC_CONFLICT,
                        "Either current namenode has checkpointed or "
                            + "another checkpointer already uploaded an "
                            + "checkpoint for txid " + txid);
                    return null;
                  }

                  InputStream stream = request.getInputStream();
                  try {
                    long start = monotonicNow();
                    MD5Hash downloadImageDigest = TransferFsImage
                            // 处理 Standby NameNode 上传 fsimage 请求
                        .handleUploadImageRequest(
                                request,
                                txid,
```

```
                                    nnImage.getStorage(),
                                        stream,
                                    parsedParams.getFileSize(), getThrottler(conf));

                                // fsimage 文件重命名
                                nnImage.saveDigestAndRenameCheckpointImage(nnf, txid,
                                    downloadImageDigest);
                                // Metrics non-null only when used inside name node
                                if (metrics != null) {
                                  long elapsed = monotonicNow() - start;
                                  metrics.addPutImage(elapsed);
                                }
                                // Now that we have a new checkpoint, we might be able to
                                // remove some old ones.
                                nnImage.purgeOldStorage(nnf);
                              } finally {
                                // remove the request once we've processed it, or it threw an error, so we
                                // aren't using it either
                                currentlyDownloadingCheckpoints.remove(imageRequest);

                                stream.close();
                              }
                            } finally {
                              nnImage.removeFromCheckpointing(txid);
                            }
                            return null;
                          }

                        });
            } catch (Throwable t) {
              String errMsg = "PutImage failed. " + StringUtils.stringifyException(t);
              response.sendError(HttpServletResponse.SC_GONE, errMsg);
              throw new IOException(errMsg);
            }
          }
```

2.6.1.1.1.1.1 请求上传 fsimage 落盘到 Active NameNode 磁盘

```
static MD5Hash handleUploadImageRequest(HttpServletRequest request,
                                        long imageTxId, Storage dstStorage,
InputStream stream,
                                        long advertisedSize, DataTransferThrottler
throttler) throws IOException {
```

```
            // 获取  image file
            String fileName = NNStorage.getCheckpointImageFileName(imageTxId);

            // 找到要存储  image files
            List<File> dstFiles = dstStorage.getFiles(NameNodeDirType.IMAGE, fileName);
            if (dstFiles.isEmpty()) {
                throw new IOException("No targets in destination storage!");
            }

            MD5Hash advertisedDigest = parseMD5Header(request);
            // 往下追
            MD5Hash hash = Util.receiveFile(fileName,
                    dstFiles, dstStorage,
                    true,
                    advertisedSize, advertisedDigest,
                    fileName, stream, throttler);
            LOG.info("Downloaded file " + dstFiles.get(0).getName() + " size "
                    + dstFiles.get(0).length() + " bytes.");
            return hash;
        }
```

```
/**
     * Receives file at the url location from the input stream and puts them in
     * the specified destination storage location.
     */
    public static MD5Hash receiveFile(String url, List<File> localPaths,
                                      Storage dstStorage, boolean getChecksum, long advertisedSize,
                                      MD5Hash advertisedDigest, String fsImageName, InputStream stream,
                                      DataTransferThrottler throttler) throws
            IOException {
        long startTime = Time.monotonicNow();
        Map<FileOutputStream, File> streamPathMap = new HashMap<>();
        StringBuilder xferStats = new StringBuilder();
        double xferCombined = 0;
        if (localPaths != null) {
            // If the local paths refer to directories, use the server-provided header
            // as the filename within that directory
            List<File> newLocalPaths = new ArrayList<>();
            for (File localPath : localPaths) {
                if (localPath.isDirectory()) {
                    if (fsImageName == null) {
```

```
                        throw new IOException("No filename header provided by server");
                    }
                    newLocalPaths.add(new File(localPath, fsImageName));
                } else {
                    newLocalPaths.add(localPath);
                }
            }
            localPaths = newLocalPaths;
        }


        long received = 0;
        MessageDigest digester = null;
        if (getChecksum) {
            digester = MD5Hash.getDigester();
            stream = new DigestInputStream(stream, digester);
        }
        boolean finishedReceiving = false;
        int num = 1;

        List<FileOutputStream> outputStreams = Lists.newArrayList();

        try {
            if (localPaths != null) {
                for (File f : localPaths) {
                    try {
                        if (f.exists()) {
                            LOG.warn("Overwriting existing file " + f
                                    + " with file downloaded from " + url);
                        }
                        FileOutputStream fos = new FileOutputStream(f);
                        outputStreams.add(fos);
                        streamPathMap.put(fos, f);
                    } catch (IOException ioe) {
                        LOG.warn("Unable to download file " + f, ioe);
                        // This will be null if we're downloading the fsimage to a file
                        // outside of an NNStorage directory.
                        if (dstStorage != null &&
                                (dstStorage instanceof StorageErrorReporter)) {
                            ((StorageErrorReporter) dstStorage).reportErrorOnFile(f);
                        }
                    }
                }
```

```
                if (outputStreams.isEmpty()) {
                    throw new IOException(
                            "Unable to download to any storage directory");
                }
            }

            // 4096
            byte[] buf = new byte[IO_FILE_BUFFER_SIZE];
            while (num > 0) {
                // 读取 image
                num = stream.read(buf);
                if (num > 0) {
                    received += num;
                    for (FileOutputStream fos : outputStreams) {
                        // 写入 outputStreams
                        fos.write(buf, 0, num);
                    }
                    if (throttler != null) {
                        throttler.throttle(num);
                    }
                }
            }
            finishedReceiving = true;
            double xferSec = Math.max(
                    ((float) (Time.monotonicNow() - startTime)) / 1000.0, 0.001);
            long xferKb = received / 1024;
            xferCombined += xferSec;
            xferStats.append(
                    String.format(" The file download took %.2fs at %.2f KB/s.",
                            xferSec, xferKb / xferSec));
        } finally {
            stream.close();
            for (FileOutputStream fos : outputStreams) {
                long flushStartTime = Time.monotonicNow();
                fos.getChannel().force(true);
                fos.close();
                double writeSec = Math.max(((float)
                        (flushStartTime - Time.monotonicNow())) / 1000.0, 0.001);
                xferCombined += writeSec;
                xferStats.append(String
                        .format(" Synchronous (fsync) write to disk of " +
                                streamPathMap.get(fos).getAbsolutePath() +
                                " took %.2fs.", writeSec));
            }
```

```
            // Something went wrong and did not finish reading.
            // Remove the temporary files.
            if (!finishedReceiving) {
                deleteTmpFiles(localPaths);
            }

            if (finishedReceiving && received != advertisedSize) {
                // only throw this exception if we think we read all of it on our end
                // -- otherwise a client-side IOException would be masked by this
                // exception that makes it look like a server-side problem!
                deleteTmpFiles(localPaths);
                throw new IOException("File " + url + " received length " + received +
                        " is not of the advertised size " + advertisedSize +
                        ". Fsimage name: " + fsImageName + " lastReceived: " + num);
            }
        }
        xferStats.insert(0, String.format("Combined time for file download and" +
                " fsync to all disks took %.2fs.", xferCombined));
        LOG.info(xferStats.toString());

        if (digester != null) {
            MD5Hash computedDigest = new MD5Hash(digester.digest());

            if (advertisedDigest != null &&
                    !computedDigest.equals(advertisedDigest)) {
                deleteTmpFiles(localPaths);
                throw new IOException("File " + url + " computed digest " +
                        computedDigest + " does not match advertised digest " +
                        advertisedDigest);
            }
            return computedDigest;
        } else {
            return null;
        }
    }
```

2.6.1.1.1.1.2 Active NameNode fsimage 文件重命名

```
/**
     * This is called by the 2NN after having downloaded an image, and by
     * the NN after having received a new image from the 2NN. It
     * renames the image from fsimage_N.ckpt to fsimage_N and also
     * saves the related .md5 file into place.
```

```
   */
  public synchronized void saveDigestAndRenameCheckpointImage(NameNodeFile nnf,
      long txid, MD5Hash digest) throws IOException {
    // Write and rename MD5 file
    List<StorageDirectory> badSds = Lists.newArrayList();

    for (StorageDirectory sd : storage.dirIterable(NameNodeDirType.IMAGE)) {
      File imageFile = NNStorage.getImageFile(sd, nnf, txid);
      try {
        MD5FileUtils.saveMD5File(imageFile, digest);
      } catch (IOException ioe) {
        badSds.add(sd);
      }
    }
    storage.reportErrorsOnDirectories(badSds);

    CheckpointFaultInjector.getInstance().afterMD5Rename();

    // Rename image from tmp file
    //  重命名
    renameCheckpoint(txid, NameNodeFile.IMAGE_NEW, nnf, false);
    // So long as this is the newest image available,
    // advertise it as such to other checkpointers
    // from now on
    if (txid > storage.getMostRecentCheckpointTxId()) {
      storage.setMostRecentCheckpointInfo(txid, Time.now());
    }

    // Create a version file in any new storage directory.
    initNewDirs();
  }
```