1、初始化

```java
private static final int MAXIMUM_CAPACITY = 1 << 30; //数组最大的容量，01000000 00000000 00000000 00000000
private static final int DEFAULT_CAPACITY = 16; //初始化容量
static final int MAX_ARRAY_SIZE = Integer.MAX_VALUE - 8; //
private static final int DEFAULT_CONCURRENCY_LEVEL = 16; //默认的并发级别,默认是16个tsegment所以每个segment都可以被加上一把锁
private static final float LOAD_FACTOR = 0.75f; //默认的加载因子
static final int TREEIFY_THRESHOLD = 8; //树化的阈值
static final int UNTREEIFY_THRESHOLD = 6; //树退化的阈值
static final int MIN_TREEIFY_CAPACITY = 64;//树化的最小segment长度
private static final int MIN_TRANSFER_STRIDE = 16;//扩容线程每次最少要迁移16个hash桶
private static int RESIZE_STAMP_BITS = 16; //
private static final int MAX_RESIZERS = (1 << (32 - RESIZE_STAMP_BITS)) - 1; //最多有多多少个线程可以同时对Map进行扩容
private static final int RESIZE_STAMP_SHIFT = 32 - RESIZE_STAMP_BITS; //


static final int MOVED     = -1; // hash for forwarding nodes
static final int TREEBIN   = -2; // hash for roots of trees
static final int RESERVED  = -3; // hash for transient reservations
static final int HASH_BITS = 0x7fffffff; // usable bits of normal node hash


transient volatile Node<K,V>[] table; //table数组
private transient volatile Node<K,V>[] nextTable; //resize的时候，记录下一个将使用的table;
private transient volatile long baseCount; //

private transient volatile int sizeCtl;//控制数组大小
private transient volatile int transferIndex; //扩容的时候新数组下标位置
private transient volatile int cellsBusy; //标识当前cell数组是否在初始化或扩容中的CAS标志位
private transient volatile CounterCell[] counterCells; //记录每一个segment的结点数量counterCells数组，总数值的分值分别存在每个cell中

// views
private transient KeySetView<K,V> keySet;
private transient ValuesView<K,V> values;
private transient EntrySetView<K,V> entrySet;
```

1.1 sizeCtl详解

- 未初始化：sizeCtl=0：表示没有指定初始容量。sizeCtl>0：表示初始容量。
- 初始化中：sizeCtl=-1,标记作用，告知其他线程，正在初始化
- 正常状态：sizeCtl=0.75n,扩容阈值
- 扩容中：sizeCtl < 0 : 表示有其他线程正在执行扩容
- sizeCtl = (resizeStamp(n) << RESIZE_STAMP_SHIFT)+2 表示此时只有一个线程在执行扩容；

2、ConcurrentHashMap中的Node结点

- 这个和HashMap中的Node一致；

```java
static class Node<K,V> implements Map.Entry<K,V> {
        final int hash;
        final K key;
        volatile V val;
        volatile Node<K,V> next;

        Node(int hash, K key, V val, Node<K,V> next) {
            this.hash = hash;
            this.key = key;
            this.val = val;
            this.next = next;
        }

        public final K getKey()       { return key; }
        public final V getValue()     { return val; }
        public final int hashCode()   { return key.hashCode() ^ val.hashCode();
}
        public final String toString(){ return key + "=" + val; }
        public final V setValue(V value) {
            throw new UnsupportedOperationException();
        }

        public final boolean equals(Object o) {
            Object k, v, u; Map.Entry<?,?> e;
            return ((o instanceof Map.Entry) &&
                    (k = (e = (Map.Entry<?,?>)o).getKey()) != null &&
                    (v = e.getValue()) != null &&
                    (k == key || k.equals(key)) &&
                    (v == (u = val) || v.equals(u)));
        }

        /**
         * Virtualized support for map.get(); overridden in subclasses.
         */
        Node<K,V> find(int h, Object k) {
            Node<K,V> e = this;
            if (k != null) {
                do {
                    K ek;
                    if (e.hash == h &&
                        ((ek = e.key) == k || (ek != null && k.equals(ek))))
                        return e;
                } while ((e = e.next) != null);
            }
            return null;
        }
    }
```

3、FowardingNode结点

```java
//A node inserted at head of bins during transfer operations.
static final class ForwardingNode<K,V> extends Node<K,V> {
        final Node<K,V>[] nextTable;
        ForwardingNode(Node<K,V>[] tab) {
```

```java
            super(MOVED, null, null, null);
            this.nextTable = tab;
        }

        Node<K,V> find(int h, Object k) {
            // loop to avoid arbitrarily deep recursion on forwarding nodes
            outer: for (Node<K,V>[] tab = nextTable;;) {
                Node<K,V> e; int n;
                if (k == null || tab == null || (n = tab.length) == 0 ||
                    (e = tabAt(tab, (n - 1) & h)) == null)
                    return null;
                for (;;) {
                    int eh; K ek;
                    if ((eh = e.hash) == h &&
                        ((ek = e.key) == k || (ek != null && k.equals(ek))))
                        return e;
                    if (eh < 0) {
                        if (e instanceof ForwardingNode) {
                            tab = ((ForwardingNode<K,V>)e).nextTable;
                            continue outer;
                        }
                        else
                            return e.find(h, k);
                    }
                    if ((e = e.next) == null)
                        return null;
                }
            }
        }
    }
```

3、扰动函数

- 在hashMap中spread函数，最后会与HASH_BITS做与运算，这是因为MAXIMUM_CAPACITY = 01000000 00000000 00000000 00000000，保证HASH值

```
HASH_BITS = OX7FFFFFFF
01111111 11111111 11111111 11111111


hash1:       00000000 00110101 11001100 01100010
hash1>>>16:  00000000 00000000 00000000 00110101
-----------------------------------------------  做异或运算
             00000000 00110101 11001100 01010111
与HASH_BITS做与运算:
             00000000 00110101 11001100 01010111
             01111111 11111111 11111111 11111111
-----------------------------------------------  做&运算
             00000000 00110101 11001100 01010111
```

```java
//ConcurrentHashMap扰动函数，
static final int spread(int h) {
        return (h ^ (h >>> 16)) & HASH_BITS; //因为MAXIMUM_CAPACITY最高位必须为0，所以计算完后还需要与HASH_BITS做与操作，将hash最高位置0，而最高位是为了帮助扩容的，因为sizeCtl < 0时最高位为1，此时正在扩容；
    }

//hashMap中的扰动函数，
static final int hash(Object key) {
        int h;
        return (key == null) ? 0 : (h = key.hashCode()) ^ (h >>> 16);
    }
```

4、构造函数

```java
public ConcurrentHashMap(int initialCapacity) {
    if (initialCapacity < 0)
        throw new IllegalArgumentException();
    int cap = ((initialCapacity >= (MAXIMUM_CAPACITY >>> 1)) ?
               MAXIMUM_CAPACITY :
               tableSizeFor(initialCapacity + (initialCapacity >>> 1) + 1)); //计算大于1.5*initialCapacity的2的幂次方
    this.sizeCtl = cap;//
}

public ConcurrentHashMap(int initialCapacity,
                         float loadFactor, int concurrencyLevel) {
    if (!(loadFactor > 0.0f) || initialCapacity < 0 || concurrencyLevel <= 0)
        throw new IllegalArgumentException();
    if (initialCapacity < concurrencyLevel)   // Use at least as many bins
        initialCapacity = concurrencyLevel;   // as estimated threads
    long size = (long)(1.0 + (long)initialCapacity / loadFactor);  //
    int cap = (size >= (long)MAXIMUM_CAPACITY) ?
        MAXIMUM_CAPACITY : tableSizeFor((int)size);
    this.sizeCtl = cap; //
}
```

5、get方法

```java
    public V get(Object key) {
        Node<K,V>[] tab; Node<K,V> e, p; int n, eh; K ek;
        int h = spread(key.hashCode()); //计算Hash值
        if ((tab = table) != null && (n = tab.length) > 0 &&
            (e = tabAt(tab, (n - 1) & h)) != null) { //找到key对应的segment下标
            if ((eh = e.hash) == h) { //
                if ((ek = e.key) == key || (ek != null && key.equals(ek))) //地址相等或者值相等
                    return e.val;
            }
```

```
            else if (eh < 0)//hash值最高为为1,
                return (p = e.find(h, key)) != null ? p.val : null;
            while ((e = e.next) != null) { //在链表中查找
                if (e.hash == h &&
                    ((ek = e.key) == key || (ek != null && key.equals(ek))))
                    return e.val;
            }
        }
        return null;
    }
```

6、putval函数（向map中添加元素）

向concurrenthashmap中添加元素时，需要保证添加的key和value均不为null;

```
 final V putVal(K key, V value, boolean onlyIfAbsent) {
        if (key == null || value == null) throw new NullPointerException();
//key、value均不能为null
        int hash = spread(key.hashCode()); //首先计算key的hash值
        int binCount = 0;
        for (Node<K,V>[] tab = table;;) { //遍历table
            Node<K,V> f; int n, i, fh;  //fh记录结点f的hash
            if (tab == null || (n = tab.length) == 0) //如果table为空，说明map还没有
申请内存空间
                tab = initTable(); //初始化table;
            else if ((f = tabAt(tab, i = (n - 1) & hash)) == null) { //如果下标位
置为空
                //如果此位置没有元素，利用cas往下标位置加，如果为空才加，否则加不了;
                if (casTabAt(tab, i, null,
                             new Node<K,V>(hash, key, value, null))) //cas操作尝试
将插入结点到此位置
                    break;                   // no lock when adding to empty bin
            }
            else if ((fh = f.hash) == MOVED) //如果当前map正在扩容，那么先协助扩容再更
新值;
                tab = helpTransfer(tab, f);
            else {
                V oldVal = null;
                synchronized (f) {//对桶的头节点加锁，某个线程在插入过程中，不允许其他线程
对桶中元素进行修改
                    if (tabAt(tab, i) == f) { //这里判断是因为为了防止添加元素后变成了
一颗树
                        if (fh >= 0) { //是普通的链表结构
                            binCount = 1;
                            for (Node<K,V> e = f;; ++binCount) { //循环遍历链表
                                K ek;
                                //如果key相等则直接替换value，然后break;
                                if (e.hash == hash &&
                                    ((ek = e.key) == key ||
                                     (ek != null && key.equals(ek)))) {
                                    oldVal = e.val;
                                    if (!onlyIfAbsent)
                                        e.val = value;
                                    break;
                                }
```

```
                                    //不相等则继续查找下一个元素
                                    Node<K,V> pred = e;
                                    //查找到末尾结点发现还是不相等，则插入新结点到末尾结点之后
                                    if ((e = e.next) == null) {
                                        pred.next = new Node<K,V>(hash, key,
                                                                  value, null);
                                        break;
                                    }
                                }
                            }
                            else if (f instanceof TreeBin) { //如果fh < 0则不是链表结
构，为树结构，
                                Node<K,V> p;
                                binCount = 2;
                                if ((p = ((TreeBin<K,V>)f).putTreeVal(hash, key,
                                                               value)) != null) {
                                    oldVal = p.val;
                                    if (!onlyIfAbsent)
                                        p.val = value;
                                }
                            }
                        }
                    }
                    if (binCount != 0) {
                        if (binCount >= TREEIFY_THRESHOLD)//如果是链表，判断链表长度是否达
到了树化的阈值，如果达到了就需要树化
                            treeifyBin(tab, i);
                        if (oldVal != null)
                            return oldVal;
                        break;
                    }
                }
            }
            addCount(1L, binCount); //
            return null;
        }
```

6.1 initTable申请内存空间

- initTable是在多线程情况下，假设同时有多个线程尝试initTable；
- 首先每个线程都会判断table是否为null，如果为空就会尝试初始化table;
- 如果当前sizeCtl < 0，那么说明table正在被其他线程创建，此线程就通过Thread.yield()函数挂起，让出cpu的执行权；
- 如果说sizeCtl>=0，那么当前table还没有被初始化，当前线程尝试CAS修改sizeCtl的内存值，如果修改失败就重新进入循环；
- 如果当前线程修改sizeCtl内存值成功，说明当前线程获取到了初始化table的权限，尝试为table申请内存空间；
- 在申请前还要再次判断tab是否为空，
- 判断sizeCtl是否大于0，不大于0就使用默认的初始化容量；
- 申请内存空间；
- 将sizeCtl赋值为0.75初始化容量大小；

```
//初始化表的过程
    private final Node<K,V>[] initTable() {
        Node<K,V>[] tab; int sc;
```

```
        while ((tab = table) == null || tab.length == 0) { //如果表为空
            if ((sc = sizeCtl) < 0) //判断sizeCtl大小，我们根据sizeCtl来申请具体大小的
内存空间
                Thread.yield(); // lost initialization race; just spin
            else if (U.compareAndSwapInt(this, SIZECTL, sc, -1)) { //SIZECTL表示
sizeCtl的偏移量//通过CAS
                try {
                    if ((tab = table) == null || tab.length == 0) { //第二次还需要
判断是为了避免重复初始化;
                        int n = (sc > 0) ? sc : DEFAULT_CAPACITY;
                        @SuppressWarnings("unchecked")
                        Node<K,V>[] nt = (Node<K,V>[])new Node<?,?>[n];
                        table = tab = nt;
                        sc = n - (n >>> 2); //0.75n
                    }
                } finally {
                    sizeCtl = sc; //记录扩容阈值
                }
                break;
            }
        }
        return tab;
    }
```

6.2 CAS过程

o: 传入的对象;

offset: 偏移量

expected: 期待值;

x: 如果o对象offset处值为expected，那么将其修改为x;

```
compareAndSwapInt(Object o, long offset, int expected, int x);
```

6.3 treeifyBin函数树化过程

```
 private final void treeifyBin(Node<K,V>[] tab, int index) {
        Node<K,V> b; int n, sc;
        if (tab != null) {
            if ((n = tab.length) < MIN_TREEIFY_CAPACITY) //如果table最大长度小于64，
则不会树化，而是选择扩容
                tryPresize(n << 1); //扩容到原来的两倍

            //这里才会进行树化操作，因为是多线程情况下，所以一旦某个线程在树化，就会对Index位
置的桶加锁，其他线程无法树化
            else if ((b = tabAt(tab, index)) != null && b.hash >= 0) {
                synchronized (b) {
                    if (tabAt(tab, index) == b) {
                        TreeNode<K,V> hd = null, tl = null;
                        //循环将链表结构转换为树结构，这里不是真正的树化过程，只是通过
TreeNode的next指针将树连接起来
                        for (Node<K,V> e = b; e != null; e = e.next) {
                            TreeNode<K,V> p =
```

```
                            new TreeNode<K,V>(e.hash, e.key, e.val,
                                              null, null);
                        if ((p.prev = tl) == null)
                            hd = p;
                        else
                            tl.next = p;
                        tl = p;
                    }
                    //调用TreeBin实现真正的树化过程，并且将树的根结点存放到index下标
的桶中
                    setTabAt(tab, index, new TreeBin<K,V>(hd));
                }
            }
        }
    }
}

//扩容过程,这里传入的size是原数组大小扩容为2倍的值
private final void tryPresize(int size) {
        //首先判断扩容后数组大小是否超过了MAXIMUM_CAPACITY，大于的化调整为
MAXIMUM_CAPACITY
        //否则，调用tableSizeFor调整为2的幂次方
        int c = (size >= (MAXIMUM_CAPACITY >>> 1)) ? MAXIMUM_CAPACITY :
            tableSizeFor(size + (size >>> 1) + 1);
        int sc; //记录sizeCtl
        while ((sc = sizeCtl) >= 0) {//自旋尝试扩容
            Node<K,V>[] tab = table; int n;
            //如果数组为null，或者数组长度为0，说明数组还没有初始化呢，那么进行初始化操作
            if (tab == null || (n = tab.length) == 0) {
                n = (sc > c) ? sc : c;//n为sizeCtl和c较大值
                //尝试CAS将sizeCtl的值替换为-1，也就是一个标记为，如果为-1说明有线程正在扩
容，CAS成功，说明当前线程获得了扩容权限
                if (U.compareAndSwapInt(this, SIZECTL, sc, -1)) {
                    try {
                        //双重判断，当前线程进入后再判断一次table是否为空，为空才会申请内存
                        if (table == tab) {
                            @SuppressWarnings("unchecked")
                            Node<K,V>[] nt = (Node<K,V>[])new Node<?,?>[n];
                            table = nt;
                            sc = n - (n >>> 2);
                        }
                    } finally {
                        //sizeCtl = 0.75*capacity;
                        sizeCtl = sc;
                    }
                }
            }
            //数组不为空，扩容值小于sizeCtl或者大于最大容量，直接Break;
            else if (c <= sc || n >= MAXIMUM_CAPACITY)
                break;
            //table不为空的扩容过程
            else if (tab == table) {
                int rs = resizeStamp(n);
                if (sc < 0) {
                    Node<K,V>[] nt;

                    //sc右移动16位后和rs判读是否值相等
                    if ((sc >>> RESIZE_STAMP_SHIFT) != rs || sc == rs + 1 ||
```

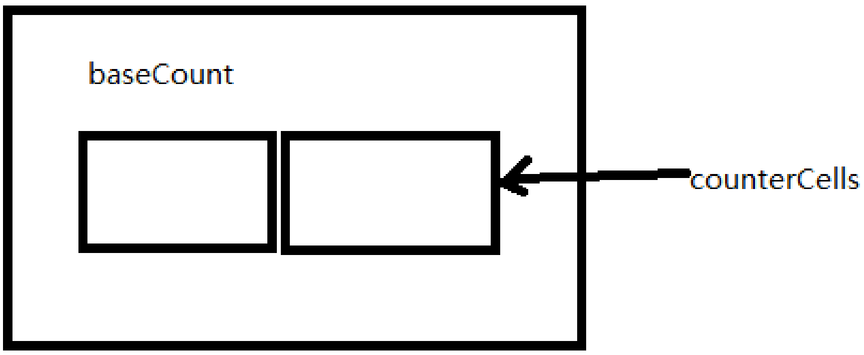
```java
                        sc == rs + MAX_RESIZERS || (nt = nextTable) == null ||
                        transferIndex <= 0)
                        break;
                    if (U.compareAndSwapInt(this, SIZECTL, sc, sc + 1))
                        transfer(tab, nt);
                }
                else if (U.compareAndSwapInt(this, SIZECTL, sc,
                                             (rs << RESIZE_STAMP_SHIFT) + 2))
                    transfer(tab, null);
            }
        }
    }



TreeBin(TreeNode<K,V> b) {
            super(TREEBIN, null, null, null);
            this.first = b; //first取b的头节点
            TreeNode<K,V> r = null; //r记录根结点
            //循环遍历树结点，
            for (TreeNode<K,V> x = b, next; x != null; x = next) {
                next = (TreeNode<K,V>)x.next;
                x.left = x.right = null;
                if (r == null) {//如果开始r为空，那么r = x;
                    x.parent = null;
                    x.red = false;
                    r = x;
                }
                //
                else {
                    K k = x.key;
                    int h = x.hash;
                    Class<?> kc = null;
                    for (TreeNode<K,V> p = r;;) {//p指向已经树化的那部分结点
                        int dir, ph;
                        K pk = p.key;
                        if ((ph = p.hash) > h)//判断ph的hash值和h的hash值，大于dir =
-1:
                            dir = -1;
                        else if (ph < h) //小于 ， dir = 1;
                            dir = 1;
                        //如果ph == h也就是hash值相等，那么调用tieBreakOrder判断需要插
入左子树还是右子树
                        else if ((kc == null &&
                                  (kc = comparableClassFor(k)) == null) ||
                                 (dir = compareComparables(kc, k, pk)) == 0)
                            dir = tieBreakOrder(k, pk);
                            TreeNode<K,V> xp = p;
                        //如果dir <= 0, 并且p.left为空，那么就将结点插入到左子树。
                        // 如果dir > 0, 并且p.right为空，那么就将结点插入到右子树。
                        if ((p = (dir <= 0) ? p.left : p.right) == null) {
                            x.parent = xp;
                            if (dir <= 0)
                                xp.left = x;
                            else
                                xp.right = x;
                            //插值完成后，可能会破坏红黑树的特性，这里需要平衡一次
                            r = balanceInsertion(r, x);
```

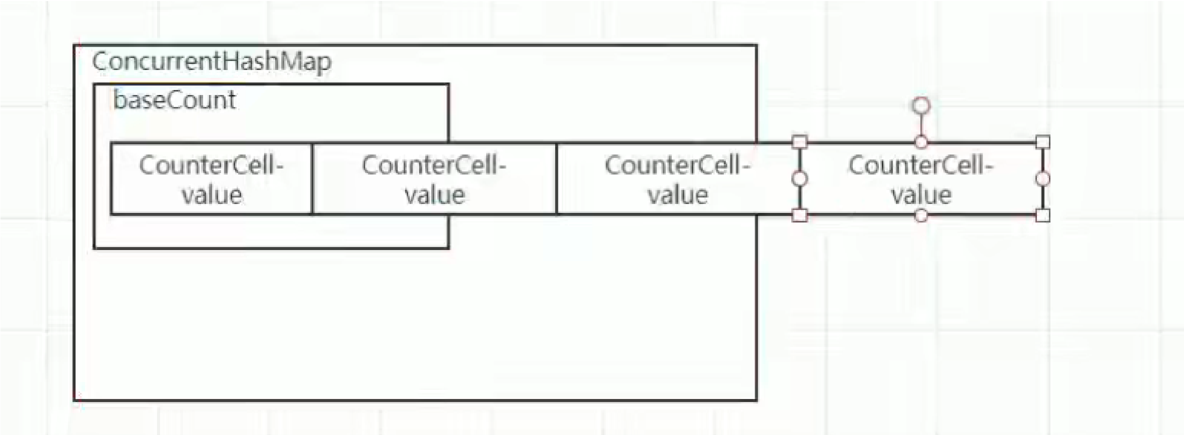
```java
                        break;
                    }
                }
            }
        }
        this.root = r;
        assert checkInvariants(root);
    }

/**
  * 用这个方法来比较两个对象，返回值要么大于0，要么小于0，不会为0
  * 也就是说这一步一定能确定要插入的节点要么是树的左节点，要么是右节点，不然就无继续满足二叉树结构了
  * 先比较两个对象的类名，类名是字符串对象，就按字符串的比较规则
  * 如果两个对象是同一个类型，那么调用本地方法为两个对象生成hashCode值，再进行比较，hashCode相等的话返回-1
  */
static int tieBreakOrder(Object a, Object b) {
    int d;
    if (a == null || b == null ||
        (d = a.getClass().getName().
         compareTo(b.getClass().getName())) == 0)
        d = (System.identityHashCode(a) <= System.identityHashCode(b) ?
             -1 : 1);
    return d;
}

//平衡过程和HashMap的一样的，因为能够进入这个函数的时候，当前线程已经对桶加了锁，所以这里面不需要加锁考虑并发问题
 static <K,V> TreeNode<K,V> balanceInsertion(TreeNode<K,V> root,
                                                    TreeNode<K,V> x) {
            x.red = true;
            for (TreeNode<K,V> xp, xpp, xppl, xppr;;) {
                if ((xp = x.parent) == null) {
                    x.red = false;
                    return x;
                }
                else if (!xp.red || (xpp = xp.parent) == null)
                    return root;
                if (xp == (xppl = xpp.left)) {
                    if ((xppr = xpp.right) != null && xppr.red) {
                        xppr.red = false;
                        xp.red = false;
                        xpp.red = true;
                        x = xpp;
                    }
                    else {
                        if (x == xp.right) {
                            root = rotateLeft(root, x = xp);
                            xpp = (xp = x.parent) == null ? null : xp.parent;
                        }
                        if (xp != null) {
                            xp.red = false;
                            if (xpp != null) {
                                xpp.red = true;
                                root = rotateRight(root, xpp);
                            }
                        }
```

```java
                    }
                }
                else {
                    if (xppl != null && xppl.red) {
                        xppl.red = false;
                        xp.red = false;
                        xpp.red = true;
                        x = xpp;
                    }
                    else {
                        if (x == xp.left) {
                            root = rotateRight(root, x = xp);
                            xpp = (xp = x.parent) == null ? null : xp.parent;
                        }
                        if (xp != null) {
                            xp.red = false;
                            if (xpp != null) {
                                xpp.red = true;
                                root = rotateLeft(root, xpp);
                            }
                        }
                    }
                }
            }
        }
```

7、扩容过程

7.1 addCount判断是否需要扩容





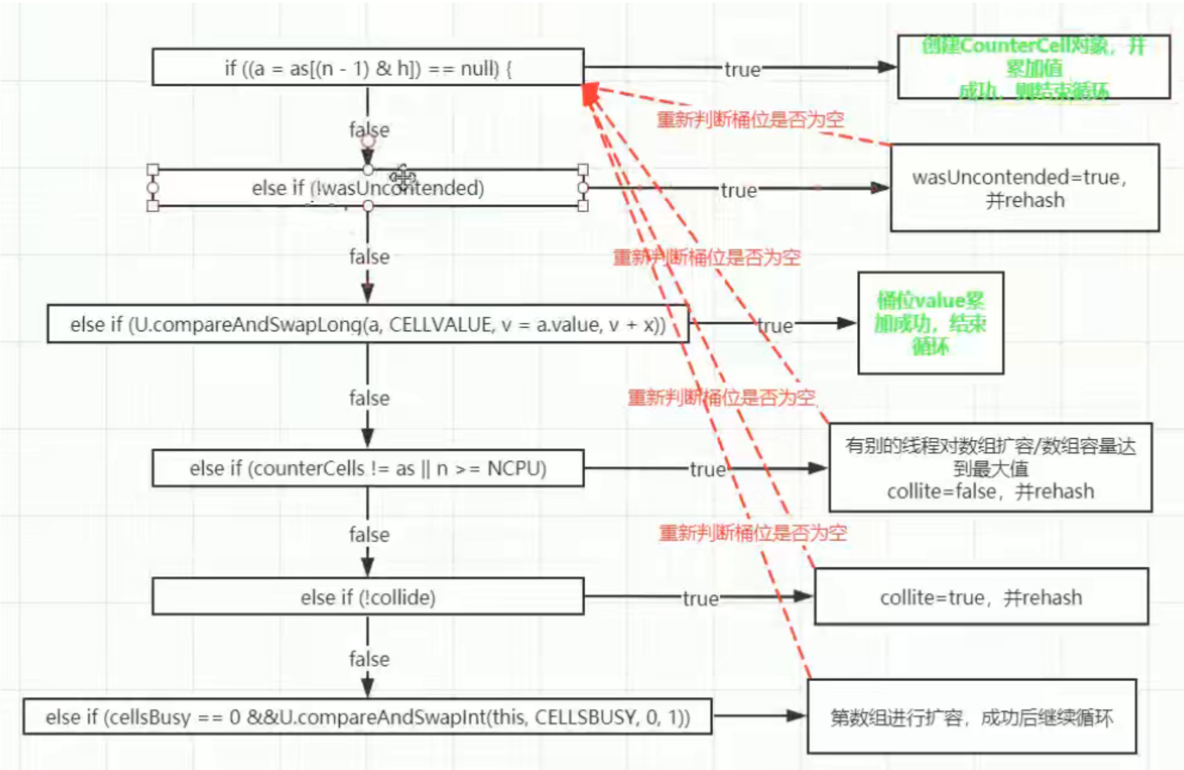
- 首先尝试对baseCount进行加操作，如果没有加成功则找对应的桶下标的CounterCell做加一操作；
- 这里之之所以需要使用counterCells是因为多个线程尝试对baseCount增加压力过大，使用counterCells数组分担压力，最后计算具体的count值，只需要将baseCount的值和counterCells里面的值求和就行；

```
private final void addCount(long x, int check) {
        CounterCell[] as; long b, s;  //as中记录的是每个桶的结点数量

        //尝试把数量加到baseCount上，如果失败了再加到分段的CounterCell上
        if ((as = counterCells) != null ||
            !U.compareAndSwapLong(this, BASECOUNT, b = baseCount, s = b + x)) {
            CounterCell a; long v; int m;
            boolean uncontended = true;
            //如果当前as为空，或者长度为0，或者当前线程所在的段为null，或者当前线程的段上加数
量失败
            if (as == null || (m = as.length - 1) < 0 ||
                (a = as[ThreadLocalRandom.getProbe() & m]) == null ||
                !(uncontended =
                  U.compareAndSwapLong(a, CELLVALUE, v = a.value, v + x))) {
                //强制增加数量，不同线程对应的不同段都更新失败说明冲突已经发生，对
counterCells进行扩容，减少多线程hash到同一段的概率；
                fullAddCount(x, uncontended);
                return;
            }
            //check大于1，为添加元素，小于等于1则不是
            if (check <= 1)
                return;
            //计算数组元素个数
            s = sumCount();
        }
        if (check >= 0) {
            Node<K,V>[] tab, nt; int n, sc;
            while (s >= (long)(sc = sizeCtl) && (tab = table) != null &&
                   (n = tab.length) < MAXIMUM_CAPACITY) {

                //resizeStamp会将n向移动15为得到值给rs
                int rs = resizeStamp(n);
                if (sc < 0) {//小于0说明有其他线程正在执行扩容操作，线程会协助扩容
                    if ((sc >>> RESIZE_STAMP_SHIFT) != rs || sc == rs + 1 ||
                        sc == rs + MAX_RESIZERS || (nt = nextTable) == null ||
                        transferIndex <= 0)
                        break;
                    if (U.compareAndSwapInt(this, SIZECTL, sc, sc + 1))
```

```
                        transfer(tab, nt);//协助扩容
                    }
                    //这里rs向左移动16位，加上之前移动的15位那么就是移动了31位，最高位将会变成
1,;
                    //所以这里是尝试将sizeCtl修改为负值，当sizeCtl为负值；；
                    else if (U.compareAndSwapInt(this, SIZECTL, sc,
                                                 (rs << RESIZE_STAMP_SHIFT) + 2))
                        //如果修改成功，则执行扩容过程
                        transfer(tab, null);//进行扩容
                    s = sumCount();
                }
            }
        }
```

7.2 fullAddCount函数（countercells为空，或者当线程无法对countercells加值时）

强制增加数量，不同线程对应的不同段都更新失败说明冲突已经发生，对counterCells进行扩容，减少多线程hash到同一段的概率；




```
private final void fullAddCount(long x, boolean wasUncontended) {
        int h;
        //计算数组角标h
        if ((h = ThreadLocalRandom.getProbe()) == 0) {
            ThreadLocalRandom.localInit();      // force initialization
            h = ThreadLocalRandom.getProbe();
            wasUncontended = true;
        }
        boolean collide = false;                // True if last slot nonempty
        for (;;) {
            CounterCell[] as; CounterCell a; int n; long v;
```

```
            //如果counterCells不为空，并且as的长度大于0
            if ((as = counterCells) != null && (n = as.length) > 0) {
                //如果当前线程对应的counterCell位置中槽位为空，在此位置添加一个
CounterCell元素；
                //再并发环境下，可能存在多线程同时尝试对counterCells槽中位置添加
counterCell所以cellBusy是一个标记位
                //如果cellsBusy为0，才可以添加counterCell；
                if ((a = as[(n - 1) & h]) == null) {
                    //如果当前CounterCell没有再扩容，使用Double Check；
                    if (cellsBusy == 0) {            // Try to attach new Cell
                        CounterCell r = new CounterCell(x); // Optimistic create
                        //
                        if (cellsBusy == 0 &&
                            U.compareAndSwapInt(this, CELLSBUSY, 0, 1)) {
                            boolean created = false;
                            //尝试在j位置添加counterCell；
                            try {               // Recheck under lock
                                CounterCell[] rs; int m, j;
                                if ((rs = counterCells) != null &&
                                    (m = rs.length) > 0 &&
                                    rs[j = (m - 1) & h] == null) {
                                    rs[j] = r;
                                    created = true;
                                }
                            } finally {
                                //添加成功后将cellsBusy置为0
                                cellsBusy = 0;
                            }
                            if (created)
                                break;
                            continue;           // Slot is now non-empty
                        }
                    }
                    collide = false;
                }
                //如果对应counterCells槽位置不为空
                else if (!wasUncontended)       // CAS already known to fail
                    wasUncontended = true;      // Continue after rehash
                //尝试CAS修改countercells对应槽中的value值；
                else if (U.compareAndSwapLong(a, CELLVALUE, v = a.value, v + x))
                    break;

                //如果数组的长度大于cpu个数，没必要进行扩容了
                else if (counterCells != as || n >= NCPU)
                    collide = false;            // At max size or stale
                //为扩容做准备
                else if (!collide)
                    collide = true;
                //如果这些线程尝试向counterCells中添加元素失败了，说明这个countercells太
小了，需要进行扩容操作。CAS + 自旋尝试对counterCells扩容，扩容为原来的两倍，并且将原来的
counterCells数组元素拷贝到新数组中；
                else if (cellsBusy == 0 &&
                         U.compareAndSwapInt(this, CELLSBUSY, 0, 1)) {
                    try {
                        if (counterCells == as) {// Expand table unless stale
                            CounterCell[] rs = new CounterCell[n << 1];
                            for (int i = 0; i < n; ++i)
                                rs[i] = as[i];
```

```java
                            counterCells = rs;
                        }
                    } finally {
                        cellsBusy = 0;
                    }
                    collide = false;
                    continue;                   // Retry with expanded table
                }
                h = ThreadLocalRandom.advanceProbe(h);
            }
            //如果CounterCells没有被初始化，没有其他线程对其进行初始化，那么当前线程尝试CAS
修改cellBusy为1
            //默认初始化为2
            else if (cellsBusy == 0 && counterCells == as &&
                     U.compareAndSwapInt(this, CELLSBUSY, 0, 1)) {
                boolean init = false;
                try {                           // Initialize table
                    if (counterCells == as) {
                        CounterCell[] rs = new CounterCell[2];
                        rs[h & 1] = new CounterCell(x);
                        counterCells = rs;
                        init = true;
                    }
                } finally {
                    cellsBusy = 0;
                }
                if (init)
                    break;
            }
            //如果数组正在被创建的过程中，那么当选线程优先往basecount里面加值；
            else if (U.compareAndSwapLong(this, BASECOUNT, v = baseCount, v +
x))
                break;                          // Fall back on using base
        }
    }
```

7.3 helpTransfer协助扩容

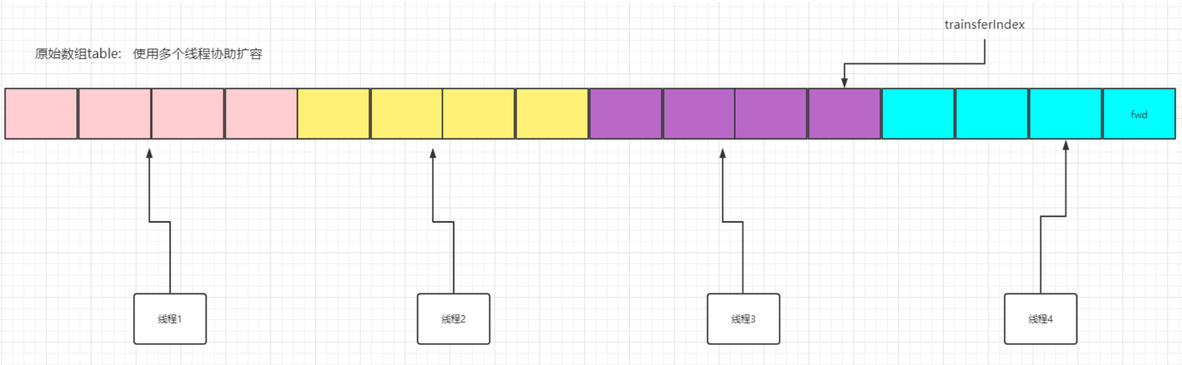
```java
final Node<K,V>[] helpTransfer(Node<K,V>[] tab, Node<K,V> f) {
    Node<K,V>[] nextTab; int sc;
    if (tab != null && (f instanceof ForwardingNode) &&
        (nextTab = ((ForwardingNode<K,V>)f).nextTable) != null) {
        int rs = resizeStamp(tab.length); //n左移动15位
        //如果有线程正在执行扩容
        while (nextTab == nextTable && table == tab &&
               (sc = sizeCtl) < 0) {
            //判断是否已经有足够的的线程进行扩容，也就是slot不够
            if ((sc >>> RESIZE_STAMP_SHIFT) != rs || sc == rs + 1 ||
                sc == rs + MAX_RESIZERS || transferIndex <= 0)
                break;
            //cas尝试协助扩容；
            if (U.compareAndSwapInt(this, SIZECTL, sc, sc + 1)) {
                transfer(tab, nextTab);
                break;
            }
```

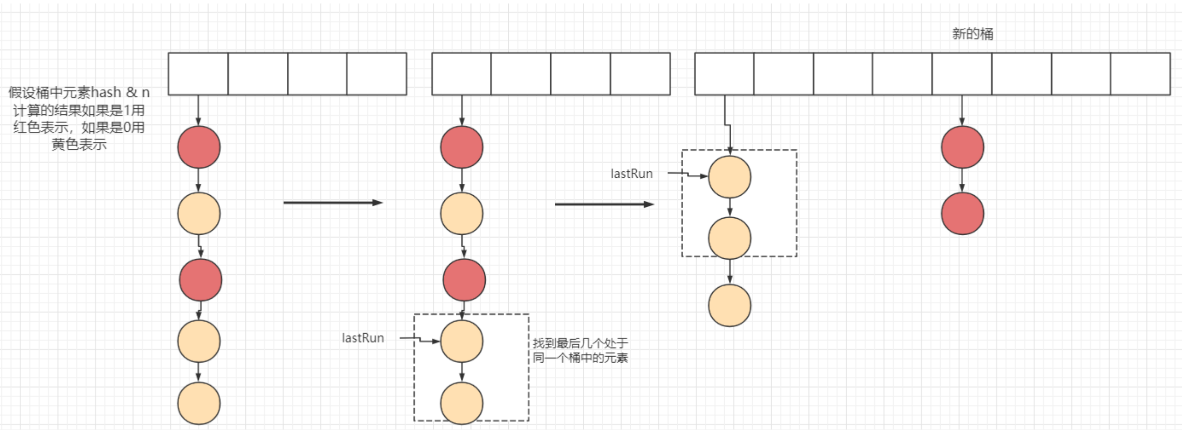
```
        }
        return nextTab;
    }
    return table;
}
```

7.4 transfer迁移元素

每个线程负责一部分的元素进行迁移，最小的任务单元的16；

如果table某个slot位置的元素已经被迁移完成，则将其位置设置为ForwardingNode结点；结点内部hash值为MOVED






```java
private final void transfer(Node<K,V>[] tab, Node<K,V>[] nextTab) {
        int n = tab.length, stride;
        //最小的任务单元是16个
        if ((stride = (NCPU > 1) ? (n >>> 3) / NCPU : n) < MIN_TRANSFER_STRIDE)
            stride = MIN_TRANSFER_STRIDE; // subdivide range
        //如果是正在扩容的线程而不是协助扩容的线程
        if (nextTab == null) {            // initiating
            try {
                @SuppressWarnings("unchecked")
                //新建一个数组，容量为原来数组的两倍
                Node<K,V>[] nt = (Node<K,V>[])new Node<?,?>[n << 1];
                nextTab = nt;
            } catch (Throwable ex) {      // try to cope with OOME
                sizeCtl = Integer.MAX_VALUE;
                return;
            }
            //nextTable记录新数组
            nextTable = nextTab;
            //记录旧数组的size
            transferIndex = n;
        }
```

```
        int nextn = nextTab.length;
        ForwardingNode<K,V> fwd = new ForwardingNode<K,V>(nextTab);
        boolean advance = true;
        boolean finishing = false; // to ensure sweep before committing nextTab
        for (int i = 0, bound = 0;;) {
            Node<K,V> f; int fh;

            //计算当前线程需要负责哪些部分
            while (advance) {
                int nextIndex, nextBound;
                if (--i >= bound || finishing)
                    advance = false;
                else if ((nextIndex = transferIndex) <= 0) {
                    i = -1;
                    advance = false;
                }
                //判断集合长度是否大于步长，大于nextBound = nextIndex - stride否则等于
0,每次都会修改transferindex
                else if (U.compareAndSwapInt
                         (this, TRANSFERINDEX, nextIndex,
                          nextBound = (nextIndex > stride ?
                                       nextIndex - stride : 0))) {
                    bound = nextBound;
                    i = nextIndex - 1;
                    advance = false;
                }
            }
            //判断是否扩容完成了
            if (i < 0 || i >= n || i + n >= nextn) {
                int sc;
                //如果扩容完成了，那么将新的Table赋值给原来的table;
                if (finishing) {
                    nextTable = null;
                    table = nextTab;
                    sizeCtl = (n << 1) - (n >>> 1); //sizeCtl = 0.75* n;  n<<1会
改变n的值，n>>>1不会改变n的值
                    return;
                }
                //如果扩容动作做完了，那么才会将finish标记为true
                if (U.compareAndSwapInt(this, SIZECTL, sc = sizeCtl, sc - 1)) {
                    if ((sc - 2) != resizeStamp(n) << RESIZE_STAMP_SHIFT)
                        return;
                    finishing = advance = true;
                    i = n; // recheck before commit
                }
            }
            //这一部分内容是具体的迁移过程
            else if ((f = tabAt(tab, i)) == null)//如果i的位置元素为空，那么不需要进行
迁移
                advance = casTabAt(tab, i, null, fwd); //直接往当前位置设置fwd;
            else if ((fh = f.hash) == MOVED)
                advance = true; // already processed
            else {
                synchronized (f) { //对迁移的位置加锁，这是为了防止多线程环境下一个线程正
在迁移元素，而其他线程对此位置进行元素添加或者删除操作

                    //首先判断还是之前那个slot吗，是的话继续迁移
                    if (tabAt(tab, i) == f) {
```

```
                        Node<K,V> ln, hn;
                        // 第一个元素的hash值大于等于0
                        // 说明该桶中元素是以链表形式存储的
                        // 这里与HashMap迁移算法基本类似
                        // 唯一不同的是多了一步寻找lastRun
                        // 这里的lastRun是提取出链表后面不用处理再特殊处理的子链表
                        // 比如所有元素的hash值与桶大小n与操作后的值分别为 0 0 4 4 0 0 0
                        // 则最后后面三个0对应的元素肯定还是在同一个桶中
                        // 这时lastRun对应的就是倒数第三个节点
                        // 至于为啥要这样处理，我也没太搞明白
                        if (fh >= 0) {//如果hash值大于0
                            //等于0的放到低位链表(low)中，不等于0的放到高位链表(high)中
                            int runBit = fh & n; //记录在新的桶中迁移是迁移到元素下标位
置还是原始下标位置加原始数组大小
                            Node<K,V> lastRun = f; //记录桶中最近一个迁移元素

                            //找到最后几个必定在同一个桶的元素
                            for (Node<K,V> p = f.next; p != null; p = p.next) {
                                int b = p.hash & n; //记录下一个元素的下标位置
                                if (b != runBit) { //如果下一个下标和前一个下标位置不
一致
                                    runBit = b; //当前迁移下标
                                    lastRun = p; //记录当前迁移元素
                                }
                            }
                            if (runBit == 0) { //runBit == 0说明在新数组中迁移到位置
不变
                                ln = lastRun;
                                hn = null;
                            }
                            else {//runBit == 1说明在新数组中迁移到位置改变了
                                hn = lastRun;
                                ln = null;
                            }

                            //遍历链表，把hash&n == 0的放在Low链表中、等于1的放入高链表
中；
                            for (Node<K,V> p = f; p != lastRun; p = p.next) {
                                int ph = p.hash; K pk = p.key; V pv = p.val;
                                if ((ph & n) == 0)
                                    ln = new Node<K,V>(ph, pk, pv, ln);
                                else
                                    hn = new Node<K,V>(ph, pk, pv, hn);
                            }
                            setTabAt(nextTab, i, ln);//将ln存放到低位
                            setTabAt(nextTab, i + n, hn); //将hn存放到高位
                            setTabAt(tab, i, fwd);//迁移完成的原来数组i位置设置为fwd;
                            advance = true;
                        }
                        //如果当前槽是树结构
                        // lo 记录低位头结点，loTail记录低位末尾节点， lc记录低位结点数
                        // hi 记录高位头结点， hiTail记录高位末尾节点，hc记录高位结点数
                        else if (f instanceof TreeBin) {
                            TreeBin<K,V> t = (TreeBin<K,V>)f;
                            TreeNode<K,V> lo = null, loTail = null;
                            TreeNode<K,V> hi = null, hiTail = null;
                            int lc = 0, hc = 0;
                            for (Node<K,V> e = t.first; e != null; e = e.next) {
```

```
                        int h = e.hash;
                        TreeNode<K,V> p = new TreeNode<K,V>
                            (h, e.key, e.val, null, null);
                        if ((h & n) == 0) {
                            if ((p.prev = loTail) == null)
                                lo = p;
                            else
                                loTail.next = p;
                            loTail = p;
                            ++lc;
                        }
                        else {
                            if ((p.prev = hiTail) == null)
                                hi = p;
                            else
                                hiTail.next = p;
                            hiTail = p;
                            ++hc;
                        }
                    }
                    //判断低位是否需要树退化，不需要退化就重新建立低位的红黑树结构
                    ln = (lc <= UNTREEIFY_THRESHOLD) ? untreeify(lo) :
                        (hc != 0) ? new TreeBin<K,V>(lo) : t;
                    //判断高位是否需要树退化，不需要退化就建立高位的红黑树结构
                    hn = (hc <= UNTREEIFY_THRESHOLD) ? untreeify(hi) :
                        (lc != 0) ? new TreeBin<K,V>(hi) : t;

                    setTabAt(nextTab, i, ln); //设置低位slot结点为root
                    setTabAt(nextTab, i + n, hn); //设置高位slot结点
                    setTabAt(tab, i, fwd); //设置原来数组位置为fwd;
                    advance = true;
                }
            }
        }
    }
  }
}
```