Linux schedule Cgoup

原创 伟林 Linux阅码场

作者简介
伟林，中年码农，从事过电信、手机、安全、芯片等行业，目前依旧从事Linux方向开发工作，个人爱好Linux相关知识分享，个人微博CSDN pwl999，欢迎大家关注！

Q 学员问：我最近在看k8s对cgroup的管理部分，对于cfs对cgroup的调度有些疑惑。想搞明白cgroup里面的 period、quota是如何影响cfs的调度的

A 伟林老师给出如下文章进行解答

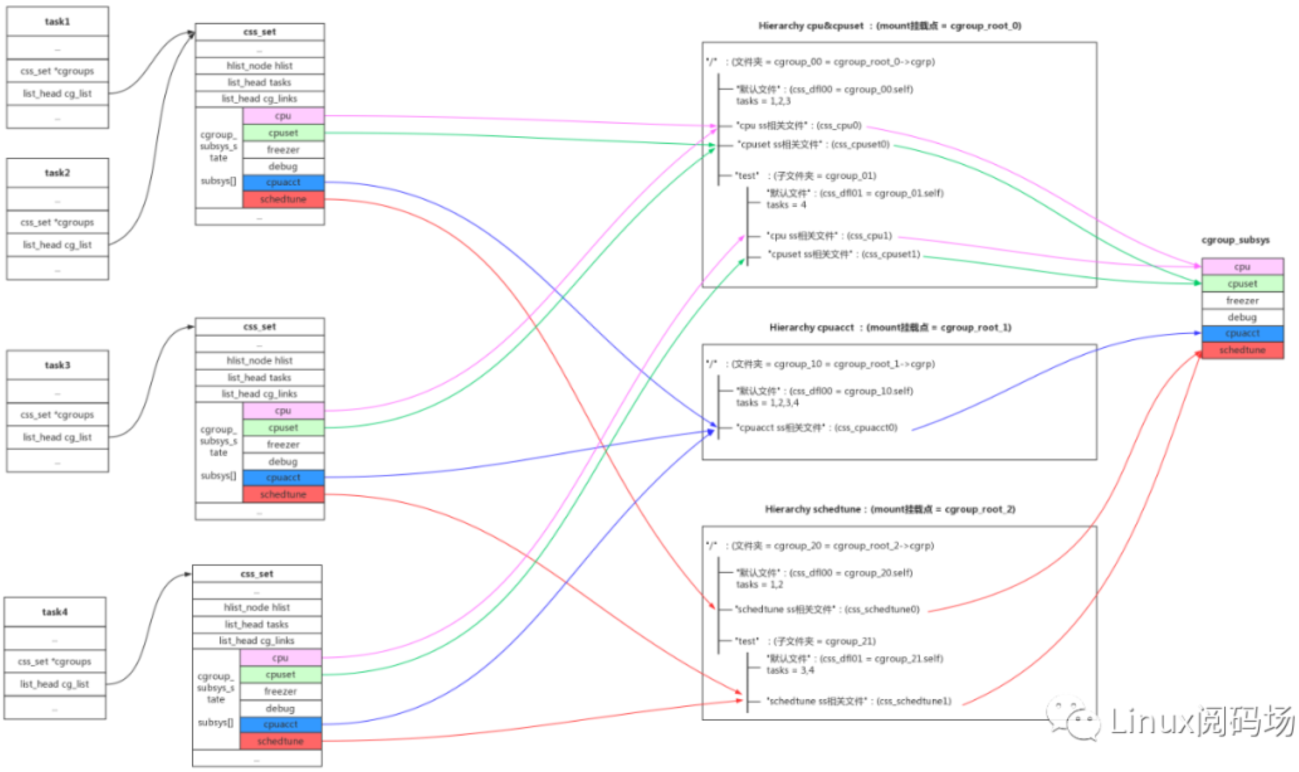
1.Cgoup

1.1、cgroup概念

cgroup最基本的操作时我们可以使用以下命令创建一个cgroup文件夹：

```
mount -t cgroup -o cpu,cpuset cpu&cpuset /dev/cpu_cpuset_test
```

那么/dev/cpu_cpuset_test文件夹下就有一系列的cpu、cpuset cgroup相关的控制节点，tasks文件中默认加入了所有进程到这个cgroup中。可以继续创建子文件夹，子文件夹继承了父文件夹的结构形式，我们可以给子文件夹配置不同的参数，把一部分进程加入到子文件夹中的tasks文件当中，久可以实现分开的cgroup控制了。

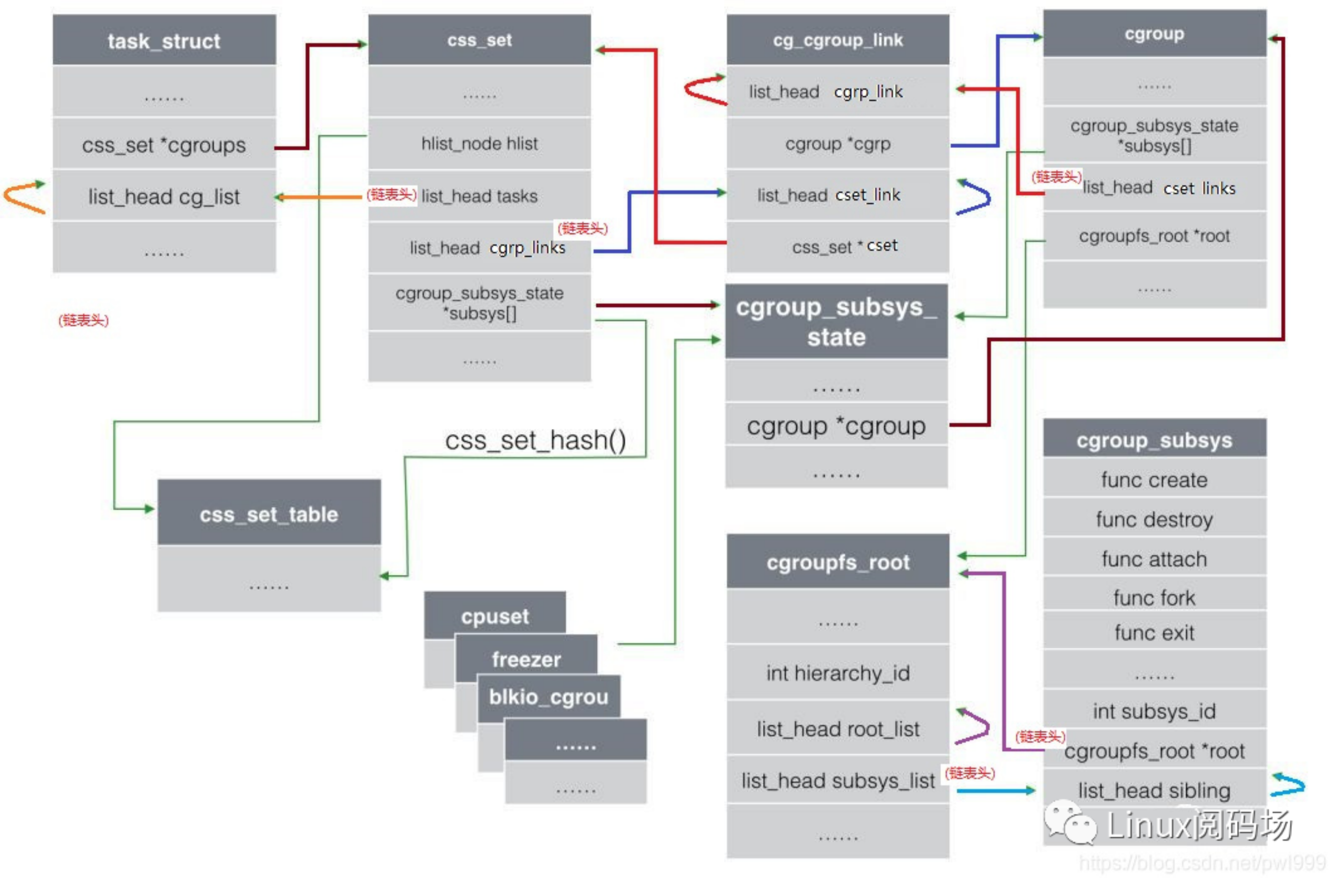

task1
task2
task3
task4
...
css_set *cgroups
list_head cg_list
css_set
hlist_node hlist
list_head tasks
list_head cg_links
cgroup_subsys_state subsys[]
cpu
cpuset
freezer
debug
cpuacct
schedtune
Hierarchy cpu&cpuset ：(mount挂载点 = cgroup_root_0)
"/" ：(文件夹 = cgroup_00 = cgroup_root_0->cgrp)
"默认文件"：(css_dfl00 = cgroup_00.self)
tasks = 1,2,3
"cpu ss相关文件"：(css_cpu0)
"cpuset ss相关文件"：(css_cpuset0)
"test" ：(子文件夹 = cgroup_01)
"默认文件"：(css_dfl01 = cgroup_01.self)
tasks = 4
"cpu ss相关文件"：(css_cpu1)
"cpuset ss相关文件"：(css_cpuset1)
Hierarchy cpuacct ：(mount挂载点 = cgroup_root_1)
"/" ：(文件夹 = cgroup_10 = cgroup_root_1->cgrp)
"默认文件"：(css_dfl00 = cgroup_10.self)
tasks = 1,2,3,4
"cpuacct ss相关文件"：(css_cpuacct0)
Hierarchy schedtune：(mount挂载点 = cgroup_root_2)
"/" ：(文件夹 = cgroup_20 = cgroup_root_2->cgrp)
"默认文件"：(css_dfl00 = cgroup_20.self)
tasks = 1,2
"schedtune ss相关文件"：(css_schedtune0)
"test" ：(子文件夹 = cgroup_21)
"默认文件"：(css_dfl01 = cgroup_21.self)
tasks = 3,4
"schedtune ss相关文件"：(css_schedtune1)
cgroup_subsys

关于cgroup的结构有以下规则和规律：

- 1、cgroup有很多subsys，我们平时接触到的cpu、cpuset、cpuacct、memory、blkio都是cgroup_subsys；
- 2、一个cgroup hierarchy，就是使用mount命令挂载的一个cgroup文件系统，hierarchy对应mount的根cgroup_root；
- 3、一个hierarchy可以制定一个subsys，也可以制定多个subsys。可以是一个subsys，也可以是一个subsys组合；
- 4、一个subsys只能被一个hierarchy引用一次，如果subsys已经被hierarchy引用，新hierarchy创建时不能引用这个subsys；唯一例外的是，我们可以创建和旧的hierarchy相同的subsys组合，这其实没有创建新的hierarchy，只是简单的符号链接；

- 5、hierarchy对应一个文件系统，cgroup对应这个文件系统中的文件夹；subsys是基类，而css(cgroup_subsys_state)是cgroup引用subsys的实例；比如父目录和子目录分别是两个cgroup，他们都要引用相同的subsys，但是他们需要不同的配置，所以会创建不同的css供cgroup->subsys[]来引用；
- 6、一个任务对系统中不同的subsys一定会有引用，但是会引用到不同的hierarchy不同的cgroup即不同css当中；所以系统使用css_set结构来管理任务对css的引。如果任务引用的css组合相同，那他们开源使用相同的css_set；
- 7、还有cgroup到task的反向引用，系统引入了cg_group_link结构。这部分可以参考Docker背后的内核知识——cgroups资源限制一文的描述，如下图的结构关系：

cgroup数据结构之间的关系



1、subsys是一组基类(cpu、blkio)，css(cgroup_subsys_state)是基类的实例化。

2、cgroup的一组css的集合。

3、hierarchy是多个cgoup的组合，它决定cgroup中能创建哪些subsys的css。hierarchy可以任意引用几种subsys，但是一个subsys只能被一个hierarchy引用。如果一个hierarchy已经引用某个subsys，那么其他hierarchy就不能再引用这个subsys了。hierarchy对应cgroupfs_root数据结构。

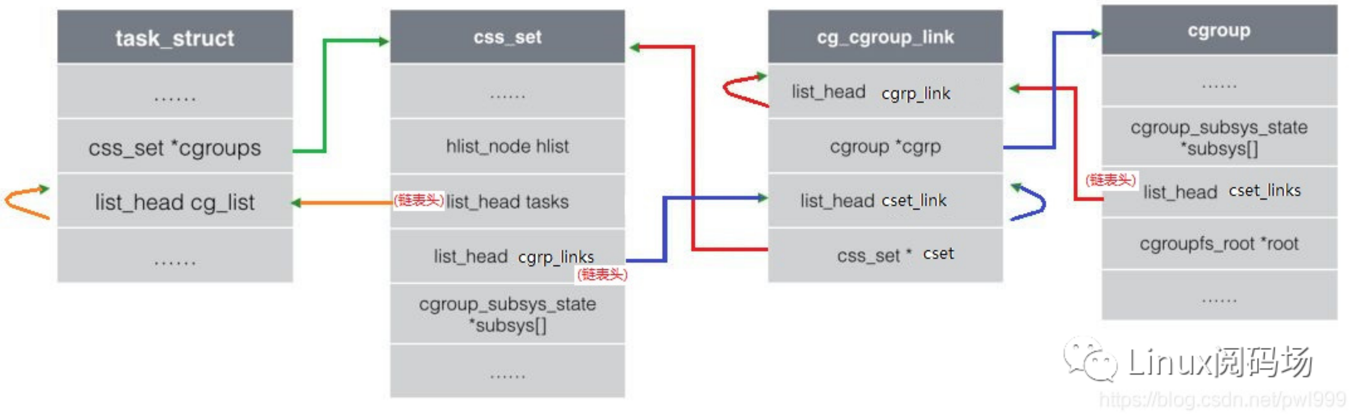
4、一旦hierarchy确定了subsys，那么它下面的cgroup只能创建对应的css实例。一个subsys只能存在于某个hierarchy中，hierarchy下的多个cgroup可以创建这个subsys对应的多个css。

5、hierarchy、cgroup、css三者还使用文件系统来表示层次关系：hierarchy是文件系统挂载点，cgroup是文件夹，css是文件夹中的文件。css的值，以及兄弟和父子关系，表示了subsys资源配额的关系。

6、cgoup是为了划分资源配额，配置的主体是进程task。每个task在每一类别的subsys上都有配额，所以每个task在每个类别的subsys上有一个唯一的css与之关联。

7、进程和css是一对多(1 x N)的关系。而系统中的多个进程和多个css，是多对多(M x N)的关系。为了收敛这种多对多的关系，系统把所有css属性都相同的一组进程放在一个css_set当中，把多个css放在一个cgroup当中，这样还是多对多但是已经收敛(M/a x N/b)。css_set根据属性组合，存入css_set_table当中。

8、css_set代表a个css属性相同的进程，cgroup代表引用的b个subsys。多对多的关系从task vs css的(M x N)，收敛到css_set vs cgroup的(M/a x N/b)。为了进一步简化css_set和cgroup之间多对多关系的双向查找，引入了cg_group_link数据结构：

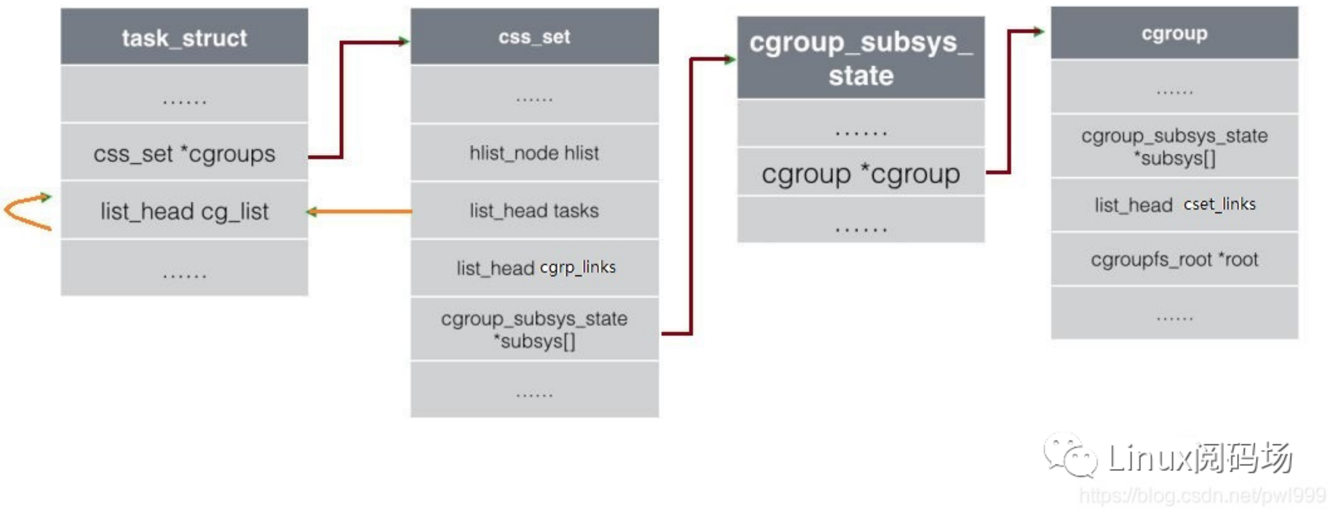


task_struct通过->cgroup成员找到css_set结构，css_set利用->tasks链表把所有css属性相同的进程链接到一起。

dir	descript
css_set → cgroup	css_set的->cgrp_links链表上挂载了这组css相关cgroup对应的cg_cgroup_link，通过cg_cgro

	up_link->cgrp找到cgroup，再通过cgroup->subsys[]找到css。
cgroup → css_set	cgroup的->cset_links链表上挂载了所有指向本cgoup的task对应的cg_cgroup_link，通过cg_cgroup_link->cset找到css_set，再通过css_set->tasks找到所有的task_struct。

9、还有一条task_struct → cgroup 的通路：



路径： task_struct->cgroup → css_set->subsys[] → cgroup_subsys_state->cgroup → cgroup

1.2、代码分析

1、"/proc/cgroups"

subsys的链表：for_each_subsys(ss, i)
一个susbsys对应一个hierarchy：ss->root
一个hierarchy有多少个cgroup：ss->root->nr_cgrps

```
# ount -t cgroup -o freezer,debug bbb freezer_test/

# cat /proc/cgroups
#subsys_name    hierarchy       num_cgroups     enabled
cpuset  4       6       1
cpu     3       2       1
```

```
cpuacct 1       147     1
schedtune       2       3       1
freezer 6       1       1
debug   6       1       1

```

```
static int proc_cgroupstats_show(struct seq_file *m, void *v)
{
  struct cgroup_subsys *ss;
  int i;

  seq_puts(m, "#subsys_name\thierarchy\tnum_cgroups\tenabled\n");
  /*
   * ideally we don't want subsystems moving around while we do this.
   * cgroup_mutex is also necessary to guarantee an atomic snapshot of
   * subsys/hierarchy state.
   */
  mutex_lock(&cgroup_mutex);

  for_each_subsys(ss, i)
    seq_printf(m, "%s\t%d\t%d\t%d\n",
           ss->legacy_name, ss->root->hierarchy_id,
           atomic_read(&ss->root->nr_cgrps),
           cgroup_ssid_enabled(i));

  mutex_unlock(&cgroup_mutex);
  return 0;
}
```

2、"/proc/pid/cgroup"

每种subsys组合组成一个新的hierarchy，每个hierarchy在for_each_root(root)中创建一个root树；
每个hierarchy顶层目录和子目录都是一个cgroup，一个hierarchy可以有多个cgroup，对应的subsys组合一样，但是参数不一样
cgroup_root自带一个cgroup即root->cgrp，作为hierarchy的顶级目录

一个cgroup对应多个subsys，使用cgroup_subsys_state类型(css)的cgroup->subsys[CGROUP_SUBSYS_COUNT]数组去和多个subsys链接;

一个cgroup自带一个cgroup_subsys_state即cgrp->self，这个css的作用是css->parent指针，建立起cgroup之间的父子关系；

css一个公用结构，每个subsys使用自己的函数ss->css_alloc()分配自己的css结构，这个结构包含公用css + subsys私有数据；

每个subsys只能存在于一个组合(hierarchy)当中，如果一个subsys已经被一个组合引用，其他组合不能再引用这个subsys。唯一例外的是，我们可以重复mount相同的组合，但是这样并没有创建新组合，只是创建了一个链接指向旧组合；

进程对应每一种hierarchy，一定有一个cgroup对应。

```
# cat /proc/832/cgroup
6:freezer,debug:/
4:cpuset:/
3:cpu:/
2:schedtune:/
1:cpuacct:/
```

```
int proc_cgroup_show(struct seq_file *m, struct pid_namespace *ns,
         struct pid *pid, struct task_struct *tsk)
{
  char *buf, *path;
  int retval;
  struct cgroup_root *root;

  retval = -ENOMEM;
  buf = kmalloc(PATH_MAX, GFP_KERNEL);
  if (!buf)
    goto out;

  mutex_lock(&cgroup_mutex);
  spin_lock_bh(&css_set_lock);

  for_each_root(root) {
    struct cgroup_subsys *ss;
    struct cgroup *cgrp;
    int ssid, count = 0;

    if (root == &cgrp_dfl_root && !cgrp_dfl_root_visible)
      continue;

    seq_printf(m, "%d:", root->hierarchy_id);
    if (root != &cgrp_dfl_root)
      for_each_subsys(ss, ssid)
        if (root->subsys_mask & (1 << ssid))
          seq_printf(m, "%s%s", count++ ? "," : "",
               ss->legacy_name);
    if (strlen(root->name))
      seq_printf(m, "%sname=%s", count ? "," : "",
           root->name);
    seq_putc(m, ':');

    cgrp = task_cgroup_from_root(tsk, root);

    /*
     * On traditional hierarchies, all zombie tasks show up as
     * belonging to the root cgroup.  On the default hierarchy,
     * while a zombie doesn't show up in "cgroup.procs" and
     * thus can't be migrated, its /proc/PID/cgroup keeps
     * reporting the cgroup it belonged to before exiting.  If
     * the cgroup is removed before the zombie is reaped,
     * " (deleted)" is appended to the cgroup path.
     */
    if (cgroup_on_dfl(cgrp) || !(tsk->flags & PF_EXITING)) {
      path = cgroup_path(cgrp, buf, PATH_MAX);
      if (!path) {
        retval = -ENAMETOOLONG;
        goto out_unlock;
      }
    } else {
      path = "/";
    }

    seq_puts(m, path);

    if (cgroup_on_dfl(cgrp) && cgroup_is_dead(cgrp))
      seq_puts(m, " (deleted)\n");
    else
      seq_putc(m, '\n');
  }

  retval = 0;
out_unlock:
  spin_unlock_bh(&css_set_lock);
  mutex_unlock(&cgroup_mutex);
  kfree(buf);
out:
  return retval;
}
```

3、初始化

```
int __init cgroup_init_early(void)
{
  static struct cgroup_sb_opts __initdata opts;
  struct cgroup_subsys *ss;
  int i;

    /* (1) 初始化默认root cgrp_dfl_root，选项opts为空，初始了
        root->cgrp          // cgrp->root = root;
        root->cgrp.self     // cgrp->self.cgroup = cgrp; cgrp->self.flags |=
     */
  init_cgroup_root(&cgrp_dfl_root, &opts);
  cgrp_dfl_root.cgrp.self.flags |= CSS_NO_REF;

  RCU_INIT_POINTER(init_task.cgroups, &init_css_set);

    /* (2) 轮询subsys进行初始化 */
  for_each_subsys(ss, i) {
    WARN(!ss->css_alloc || !ss->css_free || ss->name || ss->id,
         "invalid cgroup_subsys %d:%s css_alloc=%p css_free=%p name:id=%d:%s
         i, cgroup_subsys_name[i], ss->css_alloc, ss->css_free,
         ss->id, ss->name);
    WARN(strlen(cgroup_subsys_name[i]) > MAX_CGROUP_TYPE_NAMELEN,
         "cgroup_subsys_name %s too long\n", cgroup_subsys_name[i]);

        /* (3) 初始化ss->id、ss->name */
    ss->id = i;
    ss->name = cgroup_subsys_name[i];
    if (!ss->legacy_name)
      ss->legacy_name = cgroup_subsys_name[i];

        /* (4) ss链接到默认root(cgrp_dfl_root)
            默认css_set(init_css_set)指向ss
         */
    if (ss->early_init)
      cgroup_init_subsys(ss, true);
  }
  return 0;
}

|→

static void __init cgroup_init_subsys(struct cgroup_subsys *ss, bool early)
{
  struct cgroup_subsys_state *css;

  printk(KERN_INFO "Initializing cgroup subsys %s\n", ss->name);

  mutex_lock(&cgroup_mutex);

  idr_init(&ss->css_idr);
  INIT_LIST_HEAD(&ss->cfts);

  /* Create the root cgroup state for this subsystem */
  ss->root = &cgrp_dfl_root;

  /* (4.1) subsys分配一个新的相关的cgroup_subsys_state */
  css = ss->css_alloc(cgroup_css(&cgrp_dfl_root.cgrp, ss));
  /* We don't handle early failures gracefully */
  BUG_ON(IS_ERR(css));

  /* (4.2) 初始化css的成员指向cgroup
      cgroup为默认值cgrp_dfl_root.cgrp:
      css->cgroup = cgrp;
```

```c
      css->ss = ss;
      INIT_LIST_HEAD(&css->sibling);
      INIT_LIST_HEAD(&css->children);
   */
  init_and_link_css(css, ss, &cgrp_dfl_root.cgrp);

  /*
   * Root csses are never destroyed and we can't initialize
   * percpu_ref during early init.  Disable refcnting.
   */
  css->flags |= CSS_NO_REF;

  if (early) {
    /* allocation can't be done safely during early init */
    css->id = 1;
  } else {
    css->id = cgroup_idr_alloc(&ss->css_idr, css, 1, 2, GFP_KERNEL);
    BUG_ON(css->id < 0);
  }

  /* Update the init_css_set to contain a subsys
   * pointer to this state - since the subsystem is
   * newly registered, all tasks and hence the
   * init_css_set is in the subsystem's root cgroup. */
  /* (4.3) css_set指向新的css */
  init_css_set.subsys[ss->id] = css;

  have_fork_callback |= (bool)ss->fork << ss->id;
  have_exit_callback |= (bool)ss->exit << ss->id;
  have_free_callback |= (bool)ss->free << ss->id;
  have_canfork_callback |= (bool)ss->can_fork << ss->id;

  /* At system boot, before all subsystems have been
   * registered, no tasks have been forked, so we don't
   * need to invoke fork callbacks here. */
  BUG_ON(!list_empty(&init_task.tasks));

    /* (4.4) cgroup测指向css:
        执行ss->css_online(css);
        css->cgroup->subsys[ss->id] = css;
```

```
     */
  BUG_ON(online_css(css));

  mutex_unlock(&cgroup_mutex);
}


int __init cgroup_init(void)
{
  struct cgroup_subsys *ss;
  int ssid;

  BUG_ON(percpu_init_rwsem(&cgroup_threadgroup_rwsem));
  BUG_ON(cgroup_init_cftypes(NULL, cgroup_dfl_base_files));
  BUG_ON(cgroup_init_cftypes(NULL, cgroup_legacy_base_files));

  /*
   * The latency of the synchronize_sched() is too high for cgroups,
   * avoid it at the cost of forcing all readers into the slow path.
   */
  rcu_sync_enter_start(&cgroup_threadgroup_rwsem.rss);

  mutex_lock(&cgroup_mutex);

  /*
   * Add init_css_set to the hash table so that dfl_root can link to
   * it during init.
   */
  hash_add(css_set_table, &init_css_set.hlist,
     css_set_hash(init_css_set.subsys));

  BUG_ON(cgroup_setup_root(&cgrp_dfl_root, 0));

  mutex_unlock(&cgroup_mutex);

  for_each_subsys(ss, ssid) {
    if (ss->early_init) {
      struct cgroup_subsys_state *css =
        init_css_set.subsys[ss->id];

      css->id = cgroup_idr_alloc(&ss->css_idr, css, 1, 2,
               GFP_KERNEL);
      BUG_ON(css->id < 0);
    } else {
      cgroup_init_subsys(ss, false);
    }

    list_add_tail(&init_css_set.e_cset_node[ssid],
            &cgrp_dfl_root.cgrp.e_csets[ssid]);

    /*
     * Setting dfl_root subsys_mask needs to consider the
     * disabled flag and cftype registration needs kmalloc,
     * both of which aren't available during early_init.
     */
    if (cgroup_disable_mask & (1 << ssid)) {
      static_branch_disable(cgroup_subsys_enabled_key[ssid]);
      printk(KERN_INFO "Disabling %s control group subsystem\n",
             ss->name);
      continue;
    }

        /* (1) 默认root(cgrp_dfl_root)，支持所有ss */
    cgrp_dfl_root.subsys_mask |= 1 << ss->id;

    if (!ss->dfl_cftypes)
      cgrp_dfl_root_inhibit_ss_mask |= 1 << ss->id;

        /* (2) 将cftypes(ss->legacy_cftypes/ss->legacy_cftypes)加入到ss->cfts
    if (ss->dfl_cftypes == ss->legacy_cftypes) {
      WARN_ON(cgroup_add_cftypes(ss, ss->dfl_cftypes));
    } else {
      WARN_ON(cgroup_add_dfl_cftypes(ss, ss->dfl_cftypes));
      WARN_ON(cgroup_add_legacy_cftypes(ss, ss->legacy_cftypes));
    }

    if (ss->bind)
      ss->bind(init_css_set.subsys[ssid]);
  }

```

```
  /* init_css_set.subsys[] has been updated, re-hash */
  hash_del(&init_css_set.hlist);
  hash_add(css_set_table, &init_css_set.hlist,
     css_set_hash(init_css_set.subsys));

  WARN_ON(sysfs_create_mount_point(fs_kobj, "cgroup"));
  WARN_ON(register_filesystem(&cgroup_fs_type));
  WARN_ON(!proc_create("cgroups", 0, NULL, &proc_cgroupstats_operations));

  return 0;
}
```

4、mount操作

创建新的root，因为ss默认都和默认root(cgrp_dfl_root)建立了关系，所以ss需要先解除旧的root链接，再和新root建立起链接。

```
static struct dentry *cgroup_mount(struct file_system_type *fs_type,
       int flags, const char *unused_dev_name,
       void *data)
{
  struct super_block *pinned_sb = NULL;
  struct cgroup_subsys *ss;
  struct cgroup_root *root;
  struct cgroup_sb_opts opts;
  struct dentry *dentry;
  int ret;
  int i;
  bool new_sb;

  /*
   * The first time anyone tries to mount a cgroup, enable the list
   * linking each css_set to its tasks and fix up all existing tasks.
   */
  if (!use_task_css_set_links)
    cgroup_enable_task_cg_lists();

  mutex_lock(&cgroup_mutex);

  /* First find the desired set of subsystems */
  /* (1) 解析mount选项到opts */
  ret = parse_cgroupfs_options(data, &opts);
  if (ret)
    goto out_unlock;

  /* look for a matching existing root */
  if (opts.flags & CGRP_ROOT_SANE_BEHAVIOR) {
    cgrp_dfl_root_visible = true;
    root = &cgrp_dfl_root;
    cgroup_get(&root->cgrp);
    ret = 0;
    goto out_unlock;
  }

  /*
   * Destruction of cgroup root is asynchronous, so subsystems may
   * still be dying after the previous unmount.  Let's drain the
   * dying subsystems.  We just need to ensure that the ones
   * unmounted previously finish dying and don't care about new ones
   * starting.  Testing ref liveliness is good enough.
   */
  /* (2) */
  for_each_subsys(ss, i) {
    if (!(opts.subsys_mask & (1 << i)) ||
        ss->root == &cgrp_dfl_root)
      continue;

    if (!percpu_ref_tryget_live(&ss->root->cgrp.self.refcnt)) {
      mutex_unlock(&cgroup_mutex);
      msleep(10);
      ret = restart_syscall();
      goto out_free;
    }
    cgroup_put(&ss->root->cgrp);
  }

    /* (3) */
```

```
for_each_root(root) {
  bool name_match = false;

  if (root == &cgrp_dfl_root)
    continue;

  /*
   * If we asked for a name then it must match.  Also, if
   * name matches but sybsys_mask doesn't, we should fail.
   * Remember whether name matched.
   */
  if (opts.name) {
    if (strcmp(opts.name, root->name))
      continue;
    name_match = true;
  }

  /*
   * If we asked for subsystems (or explicitly for no
   * subsystems) then they must match.
   */
  if ((opts.subsys_mask || opts.none) &&
      (opts.subsys_mask != root->subsys_mask)) {
    if (!name_match)
      continue;
    ret = -EBUSY;
    goto out_unlock;
  }

  if (root->flags ^ opts.flags)
    pr_warn("new mount options do not match the existing superblock, will

  /*
   * We want to reuse @root whose lifetime is governed by its
   * ->cgrp.  Let's check whether @root is alive and keep it
   * that way.  As cgroup_kill_sb() can happen anytime, we
   * want to block it by pinning the sb so that @root doesn't
   * get killed before mount is complete.
   *
   * With the sb pinned, tryget_live can reliably indicate
```

```
    * whether @root can be reused.  If it's being killed,
    * drain it.  We can use wait_queue for the wait but this
    * path is super cold.  Let's just sleep a bit and retry.
    */
   pinned_sb = kernfs_pin_sb(root->kf_root, NULL);
   if (IS_ERR(pinned_sb) ||
     !percpu_ref_tryget_live(&root->cgrp.self.refcnt)) {
    mutex_unlock(&cgroup_mutex);
    if (!IS_ERR_OR_NULL(pinned_sb))
     deactivate_super(pinned_sb);
    msleep(10);
    ret = restart_syscall();
    goto out_free;
   }

   ret = 0;
   goto out_unlock;
  }

  /*
   * No such thing, create a new one.  name= matching without subsys
   * specification is allowed for already existing hierarchies but we
   * can't create new one without subsys specification.
   */
  if (!opts.subsys_mask && !opts.none) {
   ret = -EINVAL;
   goto out_unlock;
  }

   /* (4) 分配新的root */
  root = kzalloc(sizeof(*root), GFP_KERNEL);
  if (!root) {
   ret = -ENOMEM;
   goto out_unlock;
  }

    /* (5) 初始化新的root，初始了
     root->cgrp          // cgrp->root = root;
     root->cgrp.self     // cgrp->self.cgroup = cgrp; cgrp->self.flags |=
     root->name = opts->name
     */
  init_cgroup_root(root, &opts);

    /* (6) 将新的root和opts.subsys_mask指向的多个ss进行链接 */
  ret = cgroup_setup_root(root, opts.subsys_mask);
  if (ret)
    cgroup_free_root(root);

out_unlock:
  mutex_unlock(&cgroup_mutex);
out_free:
  kfree(opts.release_agent);
  kfree(opts.name);

  if (ret)
    return ERR_PTR(ret);

    /* (7) mount新root对应的根目录 */
  dentry = kernfs_mount(fs_type, flags, root->kf_root,
        CGROUP_SUPER_MAGIC, &new_sb);
  if (IS_ERR(dentry) || !new_sb)
    cgroup_put(&root->cgrp);

  /*
   * If @pinned_sb, we're reusing an existing root and holding an
   * extra ref on its sb.  Mount is complete.  Put the extra ref.
   */
  if (pinned_sb) {
    WARN_ON(new_sb);
    deactivate_super(pinned_sb);
  }

  return dentry;
}

|→

static int cgroup_setup_root(struct cgroup_root *root, unsigned long ss_mask
{
  LIST_HEAD(tmp_links);
```

```
struct cgroup *root_cgrp = &root->cgrp;
struct css_set *cset;
int i, ret;

lockdep_assert_held(&cgroup_mutex);

ret = cgroup_idr_alloc(&root->cgroup_idr, root_cgrp, 1, 2, GFP_KERNEL);
if (ret < 0)
  goto out;
root_cgrp->id = ret;

ret = percpu_ref_init(&root_cgrp->self.refcnt, css_release, 0,
          GFP_KERNEL);
if (ret)
  goto out;

/*
 * We're accessing css_set_count without locking css_set_lock here,
 * but that's OK - it can only be increased by someone holding
 * cgroup_lock, and that's us. The worst that can happen is that we
 * have some link structures left over
 */
ret = allocate_cgrp_cset_links(css_set_count, &tmp_links);
if (ret)
  goto cancel_ref;

ret = cgroup_init_root_id(root);
if (ret)
  goto cancel_ref;

  /* (6.1) 创建root对应的顶层root文件夹 */
root->kf_root = kernfs_create_root(&cgroup_kf_syscall_ops,
           KERNFS_ROOT_CREATE_DEACTIVATED,
           root_cgrp);
if (IS_ERR(root->kf_root)) {
  ret = PTR_ERR(root->kf_root);
  goto exit_root_id;
}
root_cgrp->kn = root->kf_root->kn;

```

```
    /* (6.2) 创建cgroup自己对应的一些file，cgroup自己的file由cgroup自己的css(cgr
        后面cgroup会依次创建每个subsys的file，subsys的file由每个ss对应的css(cgrp
     */
  ret = css_populate_dir(&root_cgrp->self, NULL);
  if (ret)
    goto destroy_root;

    /* (6.3) 将新root需要的subsys和原默认root(cgrp_dfl_root)解除关系，
        并且把这些ss重新和新root建立关系
     */
  ret = rebind_subsystems(root, ss_mask);
  if (ret)
    goto destroy_root;

  /*
   * There must be no failure case after here, since rebinding takes
   * care of subsystems' refcounts, which are explicitly dropped in
   * the failure exit path.
   */
  list_add(&root->root_list, &cgroup_roots);
  cgroup_root_count++;

  /*
   * Link the root cgroup in this hierarchy into all the css_set
   * objects.
   */
  spin_lock_bh(&css_set_lock);
  hash_for_each(css_set_table, i, cset, hlist) {
    link_css_set(&tmp_links, cset, root_cgrp);
    if (css_set_populated(cset))
      cgroup_update_populated(root_cgrp, true);
  }
  spin_unlock_bh(&css_set_lock);

  BUG_ON(!list_empty(&root_cgrp->self.children));
  BUG_ON(atomic_read(&root->nr_cgrps) != 1);

  kernfs_activate(root_cgrp->kn);
  ret = 0;
  goto out;
```

```

destroy_root:
  kernfs_destroy_root(root->kf_root);
  root->kf_root = NULL;
exit_root_id:
  cgroup_exit_root_id(root);
cancel_ref:
  percpu_ref_exit(&root_cgrp->self.refcnt);
out:
  free_cgrp_cset_links(&tmp_links);
  return ret;
}

||→

static int rebind_subsystems(struct cgroup_root *dst_root,
           unsigned long ss_mask)
{
  struct cgroup *dcgrp = &dst_root->cgrp;
  struct cgroup_subsys *ss;
  unsigned long tmp_ss_mask;
  int ssid, i, ret;

  lockdep_assert_held(&cgroup_mutex);

  for_each_subsys_which(ss, ssid, &ss_mask) {
    /* if @ss has non-root csses attached to it, can't move */
    if (css_next_child(NULL, cgroup_css(&ss->root->cgrp, ss)))
      return -EBUSY;

    /* can't move between two non-dummy roots either */
    if (ss->root != &cgrp_dfl_root && dst_root != &cgrp_dfl_root)
      return -EBUSY;
  }

  /* skip creating root files on dfl_root for inhibited subsystems */
  tmp_ss_mask = ss_mask;
  if (dst_root == &cgrp_dfl_root)
    tmp_ss_mask &= ~cgrp_dfl_root_inhibit_ss_mask;

  for_each_subsys_which(ss, ssid, &tmp_ss_mask) {
    struct cgroup *scgrp = &ss->root->cgrp;
    int tssid;

        /* (6.3.1) 在新root的根cgroup(dst_root->cgrp)下，
            根据subsys的file链表(css->ss->cfts)创建subsys对应的file
        */
    ret = css_populate_dir(cgroup_css(scgrp, ss), dcgrp);
    if (!ret)
      continue;

    /*
     * Rebinding back to the default root is not allowed to
     * fail.  Using both default and non-default roots should
     * be rare.  Moving subsystems back and forth even more so.
     * Just warn about it and continue.
     */
    if (dst_root == &cgrp_dfl_root) {
      if (cgrp_dfl_root_visible) {
        pr_warn("failed to create files (%d) while rebinding 0x%lx to defaul
          ret, ss_mask);
        pr_warn("you may retry by moving them to a different hierarchy and
      }
      continue;
    }

    for_each_subsys_which(ss, tssid, &tmp_ss_mask) {
      if (tssid == ssid)
        break;
      css_clear_dir(cgroup_css(scgrp, ss), dcgrp);
    }
    return ret;
  }

  /*
   * Nothing can fail from this point on.  Remove files for the
   * removed subsystems and rebind each subsystem.
   */
  for_each_subsys_which(ss, ssid, &ss_mask) {
    struct cgroup_root *src_root = ss->root;
    struct cgroup *scgrp = &src_root->cgrp;
    struct cgroup_subsys_state *css = cgroup_css(scgrp, ss);
    struct css_set *cset;

    WARN_ON(!css || cgroup_css(dcgrp, ss));

    css_clear_dir(css, NULL);

        /* (6.3.2) 取消原root cgroup对subsys的css的引用 */
    RCU_INIT_POINTER(scgrp->subsys[ssid], NULL);

    /* (6.3.3) 链接新root cgroup和subsys的css的引用 */
    rcu_assign_pointer(dcgrp->subsys[ssid], css);
    ss->root = dst_root;
    css->cgroup = dcgrp;

    spin_lock_bh(&css_set_lock);
    hash_for_each(css_set_table, i, cset, hlist)
      list_move_tail(&cset->e_cset_node[ss->id],
               &dcgrp->e_csets[ss->id]);
    spin_unlock_bh(&css_set_lock);

    src_root->subsys_mask &= ~(1 << ssid);
    scgrp->subtree_control &= ~(1 << ssid);
    cgroup_refresh_child_subsys_mask(scgrp);

    /* default hierarchy doesn't enable controllers by default */
    dst_root->subsys_mask |= 1 << ssid;
    if (dst_root == &cgrp_dfl_root) {
      static_branch_enable(cgroup_subsys_on_dfl_key[ssid]);
    } else {
      dcgrp->subtree_control |= 1 << ssid;
      cgroup_refresh_child_subsys_mask(dcgrp);
      static_branch_disable(cgroup_subsys_on_dfl_key[ssid]);
    }

    if (ss->bind)
      ss->bind(css);
  }

  kernfs_activate(dcgrp->kn);
  return 0;
}
```

5、文件操作

创建一个新文件夹，相当于创建一个新的cgroup。我们重点来看看新建文件夹的操作：

```
static struct kernfs_syscall_ops cgroup_kf_syscall_ops = {
  .remount_fs    = cgroup_remount,
  .show_options    = cgroup_show_options,
  .mkdir      = cgroup_mkdir,
  .rmdir      = cgroup_rmdir,
  .rename      = cgroup_rename,
};

static int cgroup_mkdir(struct kernfs_node *parent_kn, const char *name,
      umode_t mode)
{
  struct cgroup *parent, *cgrp;
  struct cgroup_root *root;
  struct cgroup_subsys *ss;
  struct kernfs_node *kn;
  int ssid, ret;

  /* Do not accept '\n' to prevent making /proc/<pid>/cgroup unparsable.
   */
  if (strchr(name, '\n'))
    return -EINVAL;

  parent = cgroup_kn_lock_live(parent_kn);
  if (!parent)
    return -ENODEV;
  root = parent->root;

  /* allocate the cgroup and its ID, 0 is reserved for the root */
  /* (1) 分配新的cgroup */
```

```
cgrp = kzalloc(sizeof(*cgrp), GFP_KERNEL);
if (!cgrp) {
  ret = -ENOMEM;
  goto out_unlock;
}

ret = percpu_ref_init(&cgrp->self.refcnt, css_release, 0, GFP_KERNEL);
if (ret)
  goto out_free_cgrp;

/*
 * Temporarily set the pointer to NULL, so idr_find() won't return
 * a half-baked cgroup.
 */
cgrp->id = cgroup_idr_alloc(&root->cgroup_idr, NULL, 2, 0, GFP_KERNEL);
if (cgrp->id < 0) {
  ret = -ENOMEM;
  goto out_cancel_ref;
}

  /* (2) 初始化cgroup */
init_cgroup_housekeeping(cgrp);

  /* (3) 和父cgroup之间建立起关系 */
cgrp->self.parent = &parent->self;
cgrp->root = root;

if (notify_on_release(parent))
  set_bit(CGRP_NOTIFY_ON_RELEASE, &cgrp->flags);

if (test_bit(CGRP_CPUSET_CLONE_CHILDREN, &parent->flags))
  set_bit(CGRP_CPUSET_CLONE_CHILDREN, &cgrp->flags);

/* create the directory */
/* (3) 创建新的cgroup对应的文件夹 */
kn = kernfs_create_dir(parent->kn, name, mode, cgrp);
if (IS_ERR(kn)) {
  ret = PTR_ERR(kn);
  goto out_free_id;
}
```

```
cgrp->kn = kn;

/*
 * This extra ref will be put in cgroup_free_fn() and guarantees
 * that @cgrp->kn is always accessible.
 */
kernfs_get(kn);

cgrp->self.serial_nr = css_serial_nr_next++;

/* allocation complete, commit to creation */
list_add_tail_rcu(&cgrp->self.sibling, &cgroup_parent(cgrp)->self.children
atomic_inc(&root->nr_cgrps);
cgroup_get(parent);

/*
 * @cgrp is now fully operational.  If something fails after this
 * point, it'll be released via the normal destruction path.
 */
cgroup_idr_replace(&root->cgroup_idr, cgrp, cgrp->id);

ret = cgroup_kn_set_ugid(kn);
if (ret)
  goto out_destroy;

  /* (4) 新cgroup文件夹下创建cgroup自己css对应的默认file */
ret = css_populate_dir(&cgrp->self, NULL);
if (ret)
  goto out_destroy;

/* let's create and online css's */
/* (5) 针对root对应的各个susbsys， 每个subsys创建新的css
    并且在cgroup文件夹下创建css对应的file
*/
for_each_subsys(ss, ssid) {
  if (parent->child_subsys_mask & (1 << ssid)) {
    ret = create_css(cgrp, ss,
         parent->subtree_control & (1 << ssid));
    if (ret)
      goto out_destroy;
    }
  }

  /*
   * On the default hierarchy, a child doesn't automatically inherit
   * subtree_control from the parent.  Each is configured manually.
   */
  if (!cgroup_on_dfl(cgrp)) {
    cgrp->subtree_control = parent->subtree_control;
    cgroup_refresh_child_subsys_mask(cgrp);
  }

  kernfs_activate(kn);

  ret = 0;
  goto out_unlock;

out_free_id:
  cgroup_idr_remove(&root->cgroup_idr, cgrp->id);
out_cancel_ref:
  percpu_ref_exit(&cgrp->self.refcnt);
out_free_cgrp:
  kfree(cgrp);
out_unlock:
  cgroup_kn_unlock(parent_kn);
  return ret;

out_destroy:
  cgroup_destroy_locked(cgrp);
  goto out_unlock;
}
```

cgroup默认文件，有一些重要的文件比如“tasks”，我们来看看具体的操作。

```
static struct cftype cgroup_legacy_base_files[] = {
  {
    .name = "cgroup.procs",
    .seq_start = cgroup_pidlist_start,
    .seq_next = cgroup_pidlist_next,
    .seq_stop = cgroup_pidlist_stop,
    .seq_show = cgroup_pidlist_show,
    .private = CGROUP_FILE_PROCS,
    .write = cgroup_procs_write,
  },
  {
    .name = "cgroup.clone_children",
    .read_u64 = cgroup_clone_children_read,
    .write_u64 = cgroup_clone_children_write,
  },
  {
    .name = "cgroup.sane_behavior",
    .flags = CFTYPE_ONLY_ON_ROOT,
    .seq_show = cgroup_sane_behavior_show,
  },
  {
    .name = "tasks",
    .seq_start = cgroup_pidlist_start,
    .seq_next = cgroup_pidlist_next,
    .seq_stop = cgroup_pidlist_stop,
    .seq_show = cgroup_pidlist_show,
    .private = CGROUP_FILE_TASKS,
    .write = cgroup_tasks_write,
  },
  {
    .name = "notify_on_release",
    .read_u64 = cgroup_read_notify_on_release,
    .write_u64 = cgroup_write_notify_on_release,
  },
  {
    .name = "release_agent",
    .flags = CFTYPE_ONLY_ON_ROOT,
    .seq_show = cgroup_release_agent_show,
    .write = cgroup_release_agent_write,
    .max_write_len = PATH_MAX - 1,
  },
  { }  /* terminate */
}
```

```

static ssize_t cgroup_tasks_write(struct kernfs_open_file *of,
          char *buf, size_t nbytes, loff_t off)
{
  return __cgroup_procs_write(of, buf, nbytes, off, false);
}

|→

static ssize_t __cgroup_procs_write(struct kernfs_open_file *of, char *buf,
            size_t nbytes, loff_t off, bool threadgroup)
{
  struct task_struct *tsk;
  struct cgroup_subsys *ss;
  struct cgroup *cgrp;
  pid_t pid;
  int ssid, ret;

  if (kstrtoint(strstrip(buf), 0, &pid) || pid < 0)
    return -EINVAL;

  cgrp = cgroup_kn_lock_live(of->kn);
  if (!cgrp)
    return -ENODEV;

  percpu_down_write(&cgroup_threadgroup_rwsem);
  rcu_read_lock();
  if (pid) {
    tsk = find_task_by_vpid(pid);
    if (!tsk) {
      ret = -ESRCH;
      goto out_unlock_rcu;
    }
  } else {
    tsk = current;
  }

  if (threadgroup)
    tsk = tsk->group_leader;

  /*
   * Workqueue threads may acquire PF_NO_SETAFFINITY and become
   * trapped in a cpuset, or RT worker may be born in a cgroup
   * with no rt_runtime allocated.  Just say no.
   */
  if (tsk == kthreadd_task || (tsk->flags & PF_NO_SETAFFINITY)) {
    ret = -EINVAL;
    goto out_unlock_rcu;
  }

  get_task_struct(tsk);
  rcu_read_unlock();

  ret = cgroup_procs_write_permission(tsk, cgrp, of);
  if (!ret) {
      /* (1) attach task到cgroup */
    ret = cgroup_attach_task(cgrp, tsk, threadgroup);
#if defined(CONFIG_CPUSETS) && !defined(CONFIG_MTK_ACAO)
    if (cgrp->id != SS_TOP_GROUP_ID && cgrp->child_subsys_mask == CSS_CPUSET
    && excl_task_count > 0) {
      remove_set_exclusive_task(tsk->pid, 0);
    }
#endif
  }
  put_task_struct(tsk);
  goto out_unlock_threadgroup;

out_unlock_rcu:
  rcu_read_unlock();
out_unlock_threadgroup:
  percpu_up_write(&cgroup_threadgroup_rwsem);
  for_each_subsys(ss, ssid)
    if (ss->post_attach)
      ss->post_attach();
  cgroup_kn_unlock(of->kn);
  return ret ?: nbytes;
}

||→

```

```
static int cgroup_attach_task(struct cgroup *dst_cgrp,
            struct task_struct *leader, bool threadgroup)
{
  LIST_HEAD(preloaded_csets);
  struct task_struct *task;
  int ret;

  /* look up all src csets */
  spin_lock_bh(&css_set_lock);
  rcu_read_lock();
  task = leader;

  /* (1.1) 遍历task所在线程组，把需要迁移的进程的css_set加入到preloaded_csets链表
  do {
    cgroup_migrate_add_src(task_css_set(task), dst_cgrp,
               &preloaded_csets);
    if (!threadgroup)
      break;
  } while_each_thread(leader, task);
  rcu_read_unlock();
  spin_unlock_bh(&css_set_lock);

    /* (1.2) 去掉旧的css_set对css的应用,
        分配新的css_set承担新的css组合的应用，并且给进程使用
     */
  /* prepare dst csets and commit */
  ret = cgroup_migrate_prepare_dst(dst_cgrp, &preloaded_csets);
  if (!ret)
    ret = cgroup_migrate(leader, threadgroup, dst_cgrp);

  cgroup_migrate_finish(&preloaded_csets);
  return ret;
}
```

1.3、cgroup subsystem

我们关注cgroup子系统具体能提供的功能。

1.3.1、cpu

kernel/sched/core.c。会创建新的task_group，可以对cgroup对应的task_group进行cfs/rt类型的带宽控制。

```
static struct cftype cpu_files[] = {
#ifdef CONFIG_FAIR_GROUP_SCHED
  {
    .name = "shares",
    .read_u64 = cpu_shares_read_u64,
    .write_u64 = cpu_shares_write_u64,
  },
#endif
#ifdef CONFIG_CFS_BANDWIDTH     // cfs 带宽控制
  {
    .name = "cfs_quota_us",
    .read_s64 = cpu_cfs_quota_read_s64,
    .write_s64 = cpu_cfs_quota_write_s64,
  },
  {
    .name = "cfs_period_us",
    .read_u64 = cpu_cfs_period_read_u64,
    .write_u64 = cpu_cfs_period_write_u64,
  },
  {
    .name = "stat",
    .seq_show = cpu_stats_show,
  },
#endif
#ifdef CONFIG_RT_GROUP_SCHED    // rt 带宽控制
  {
    .name = "rt_runtime_us",
    .read_s64 = cpu_rt_runtime_read,
    .write_s64 = cpu_rt_runtime_write,
  },
  {
    .name = "rt_period_us",
    .read_u64 = cpu_rt_period_read_uint,
    .write_u64 = cpu_rt_period_write_uint,
  },
#endif
  { }  /* terminate */
};

struct cgroup_subsys cpu_cgrp_subsys = {
  .css_alloc  = cpu_cgroup_css_alloc,         // 分配新的task_group
  .css_released  = cpu_cgroup_css_released,
  .css_free  = cpu_cgroup_css_free,
  .fork    = cpu_cgroup_fork,
  .can_attach  = cpu_cgroup_can_attach,
  .attach    = cpu_cgroup_attach,
  .legacy_cftypes  = cpu_files,
  .early_init  = 1,
};
```

1.3.2、cpuset

kernel/cpusec.c。给cgroup分配不同的cpu和mem node节点，还可以配置一些flag。

```
static struct cftype files[] = {
  {
    .name = "cpus",
    .seq_show = cpuset_common_seq_show,
    .write = cpuset_write_resmask,
    .max_write_len = (100U + 6 * NR_CPUS),
    .private = FILE_CPULIST,
  },

  {
    .name = "mems",
    .seq_show = cpuset_common_seq_show,
    .write = cpuset_write_resmask,
    .max_write_len = (100U + 6 * MAX_NUMNODES),
    .private = FILE_MEMLIST,
  },

  {
    .name = "effective_cpus",
    .seq_show = cpuset_common_seq_show,
    .private = FILE_EFFECTIVE_CPULIST,
  },

  {
    .name = "effective_mems",
    .seq_show = cpuset_common_seq_show,
    .private = FILE_EFFECTIVE_MEMLIST,
  },

  {
    .name = "cpu_exclusive",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_CPU_EXCLUSIVE,
  },

  {
    .name = "mem_exclusive",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_MEM_EXCLUSIVE,
  },

  {
    .name = "mem_hardwall",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_MEM_HARDWALL,
  },

  {
    .name = "sched_load_balance",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_SCHED_LOAD_BALANCE,
  },

  {
    .name = "sched_relax_domain_level",
    .read_s64 = cpuset_read_s64,
    .write_s64 = cpuset_write_s64,
    .private = FILE_SCHED_RELAX_DOMAIN_LEVEL,
  },

  {
    .name = "memory_migrate",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_MEMORY_MIGRATE,
  },

  {
    .name = "memory_pressure",
    .read_u64 = cpuset_read_u64,
  },

  {
    .name = "memory_spread_page",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_SPREAD_PAGE,
  },

  {
    .name = "memory_spread_slab",
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_SPREAD_SLAB,
  },

  {
    .name = "memory_pressure_enabled",
    .flags = CFTYPE_ONLY_ON_ROOT,
    .read_u64 = cpuset_read_u64,
    .write_u64 = cpuset_write_u64,
    .private = FILE_MEMORY_PRESSURE_ENABLED,
  },

  { }  /* terminate */
}

struct cgroup_subsys cpuset_cgrp_subsys = {
  .css_alloc  = cpuset_css_alloc,
  .css_online  = cpuset_css_online,
  .css_offline  = cpuset_css_offline,
  .css_free  = cpuset_css_free,
  .can_attach  = cpuset_can_attach,
  .cancel_attach  = cpuset_cancel_attach,
  .attach    = cpuset_attach,
  .post_attach  = cpuset_post_attach,
  .bind    = cpuset_bind,
  .fork    = cpuset_fork,
  .legacy_cftypes  = files,
  .early_init  = 1,
};
```

1.3.3、schedtune

kernel/sched/tune.c，可以进行schedle boost操作。

```
static struct cftype files[] = {
  {
    .name = "boost",
    .read_u64 = boost_read,
    .write_u64 = boost_write,
  },
  {
    .name = "prefer_idle",
    .read_u64 = prefer_idle_read,
    .write_u64 = prefer_idle_write,
  },
  { }  /* terminate */
};
```

```

struct cgroup_subsys schedtune_cgrp_subsys = {
  .css_alloc  = schedtune_css_alloc,
  .css_free  = schedtune_css_free,
  .legacy_cftypes  = files,
  .early_init  = 1,
};
```

1.3.4、cpuacct

kernel/sched/cpuacct.c，可以按照cgroup的分组来统计cpu占用率。

```
static struct cftype files[] = {
  {
    .name = "usage",
    .read_u64 = cpuusage_read,
    .write_u64 = cpuusage_write,
  },
  {
    .name = "usage_percpu",
    .seq_show = cpuacct_percpu_seq_show,
  },
  {
    .name = "stat",
    .seq_show = cpuacct_stats_show,
  },
  { }  /* terminate */
};

struct cgroup_subsys cpuacct_cgrp_subsys = {
  .css_alloc  = cpuacct_css_alloc,
  .css_free  = cpuacct_css_free,
  .legacy_cftypes  = files,
  .early_init  = 1,
};
```

参考资料

1、linux 2.6 O(1)调度算法
2、linux cfs调度器_理论模型
3、linux cfs调度框图
4、linux cfs之特殊时刻vruntime的计算
5、entity级负载的计算
6、cpu级负载的计算update_cpu_load
7、系统级负载的计算:Linux Load Averages: Solving the Mystery
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9、Linux Scheduling Domains
10、[MTK文档：CPU Utilization-scheduler(V1.1)]
11、Docker背后的内核知识——cgroups资源限制
12、Linux资源管理之cgroups简介