

This is an initial design for a transactional task attachment framework for cgroups. There are probably some potential simplifications that I've missed, particularly in the area of locking. Comments appreciated.

## The Problem

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Currently cgroups task movements are done in three phases

- 1) all subsystems in the destination cgroup get the chance to veto the movement (via their `can_attach()` callback)
- 2) `task->cgroups` is updated (while holding `task->alloc_lock`)
- 3) all subsystems get an `attach()` callback to let them perform any housekeeping updates

The problems with this include:

- There's no way to ensure that the result of `can_attach()` remains valid up until the `attach()` callback, unless any invalidating operations call `cgroup_lock()` to synchronize with the change. This is fine for something like cpuset, where invalidating operations are rare slow events like the user removing all cpus from a cpuset, or cpu hotplug triggering removal of a cpuset's last cpu. It's not so good for the virtual address space controller where the `can_attach()` check might be that the `res_counter` has enough space, and an invalidating operation might be another task in the cgroup allocating another page of virtual address space.
- It doesn't handle the case of the proposed "cgroup.procs" file which can move multiple threads into a cgroup in one operation; the `can_attach()` and `attach()` calls should be able to atomically allow all or none of the threads to move.
- it can create races around the time of the movement regarding to which cgroup a resource charge/uncharge should be assigned (e.g. between steps 2 and 3 new resource usage will be charged to the destination cgroup, but step 3 might involve migrating a charge equal to the task's resource usage from the old cgroup to the new, resulting in over/under-charges.

## Conceptual solution

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In ideal terms, a solution for this problem would meet the following requirements:

- support movement of an arbitrary set of threads between an arbitrary set of cgroups
- allow arbitrarily complex locking from the subsystems involved so that they can synchronize against concurrent changes, etc
- allow rollback at any point in the process

But in practice that would probably be way more complex than we'd want in the kernel. We don't want to encourage excessively-complex locking from subsystems, and we don't need to support arbitrary task movements.

(Hopefully!) Practical solution

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So here's a more practical solution, which hopefully catches the important parts of the requirements without being quite so complex.

The restrictions are:

- only supporting movement to one destination cgroup (in the same hierarchy, of course); if an entire process is being moved, then potentially its threads could be coming from different source cgroups
- a subsystem may optionally fail such an attach if it can't handle the synchronization this would entail.
- supporting moving either one thread, one entire thread group or (for the future) "all threads". This supports the existing "tasks" file, the proposed "procs" file and also allows scope for things like adding a subsystem to an existing hierarchy.
- locking/checking performed in two phases - one to support sleeping locks, and one to support spinlocks. This is to support both subsystems that use mutexes to protect their data, and subsystems that use spinlocks
- no locks allowed to be shared between multiple subsystems during the transaction, with the single exception of the `mmap_sem` of the thread/process being moved. This is because multiple subsystems use the `mmap_sem` for synchronization, and are quite likely to be mounted in the same hierarchy. The alternative would be to introduce a `down_read_unfair()` operation that would skip ahead of waiting writers, to safely allow a single thread to recursively lock `mm->mmap_sem`.

First we define the state for the transaction:

```
struct cgroup_attach_state {

    // The thread or process being moved, NULL if moving (potentially) all threads
    struct task_struct *task;
    enum {
        CGROUP_ATTACH_THREAD,
        CGROUP_ATTACH_PROCESS,
        CGROUP_ATTACH_ALL
    } mode;

    // The destination cgroup
    struct cgroup *dest;

    // The source cgroup for "task" (child threads *may* have different
    groups; subsystem must handle this if it needs to)
    struct cgroup *src;

    // Private state for the attach operation per-subsys. Subsystems are
    completely responsible for managing this
    void *subsys_state[CGROUP_SUBSYS_STATE];

    // "Recursive lock count" for task->mm->mmap_sem (needed if we don't
    introduce down_read_unfair())
    int mmap_sem_lock_count;
};
```

New cgroup subsystem callbacks (all optional):

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```
int prepare_attach_sleep(struct cgroup_attach_state *state);
```

Called during the first preparation phase for each subsystem. The subsystem may perform any sleeping behaviour, including waiting for mutexes and doing sleeping memory allocations, but may not disable interrupts or take any spinlocks. Return a -ve error on failure or 0 on success. If it returns failure, then no further callbacks will be made for this attach; if it returns success then exactly one of `abort_attach_sleep()` or `commit_attach()` is guaranteed to be called in the future

No two subsystems may take the same lock as part of their `prepare_attach_sleep()` callback. A special case is made for `mmap_sem`: if this callback needs to `down_read(&state->task->mmap_sem)` it should only do so if `state->mmap_sem_lock_count++ == 0`. (A helper function will be provided for this). The callback should not

write\_lock(&state->task->mmap\_sem).

Called with group\_mutex (which prevents any other task movement between cgroups) held plus any mutexes/semaphores taken by earlier subsystems's callbacks.

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```
int prepare_attach_nosleep(struct cgroup_attach_state *state);
```

Called during the second preparation phase (assuming no subsystem failed in the first phase). The subsystem may not sleep in any way, but may disable interrupts or take spinlocks. Return a -ve error on failure or 0 on success. If it returns failure, then abort\_attach\_sleep() will be called; if it returns success then either abort\_attach\_nosleep() followed by abort\_attach\_sleep() will be called, or commit\_attach() will be called

Called with cgroup\_mutex and alloc\_lock for task held (plus any mutexes/semaphores taken by subsystems in the prepare\_attach\_nosleep() phase, and any spinlocks taken by earlier subsystems in this phase . If state->mode == CGROUP\_ATTACH\_PROCESS then alloc\_lock for all threads in task's thread\_group are held. (Is this a really bad idea? Maybe we should call this without any task->alloc\_lock held?)

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```
void abort_attach_sleep(struct cgroup_attach_state *state);
```

Called following a successful return from prepare\_attach\_sleep(). Indicates that the attach operation was aborted and the subsystem should unwind any state changes made and locks taken by prepare\_attach\_sleep().

Called with same locks as prepare\_attach\_sleep()

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```
void abort_attach_nosleep(struct cgroup_attach_state *state);
```

Called following a successful return from prepare\_attach\_nosleep(). Indicates that the attach operation was aborted and the subsystem should unwind any state changes made and locks taken by prepare\_attach\_nosleep().

Called with the same locks as prepare\_attach\_nosleep();

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```
void commit_attach(struct cgroup_attach_state *state);
```

Called following a successful return from `prepare_attach_sleep()` for a subsystem that has no `prepare_attach_nosleep()`, or following a successful return from `prepare_attach_nosleep()`. Indicates that the attach operation is going ahead, and any partially-committed state should be finalized, and any taken locks should be released. No further callbacks will be made for this attach.

This is called immediately after updating `task->cgroups` (and threads if necessary) to point to the new cgroup set.

Called with the same locks held as `prepare_attach_nosleep()`

## Examples

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Here are a few examples of how you might use this. They're not intended to be syntactically correct or compilable - they're just an idea of what the routines might look like.

### 1) cpusets

cpusets (currently) uses `cgroup_mutex` for most of its changes that can invalidate a task attach. thus it can assume that any checks performed by `prepare_attach_*`() will remain valid without needing any additional locking. The existing `callback_mutex` used to synchronize cpuset changes can't be taken in `commit_attach()` since spinlocks are held at that point. However, I think that all the current uses of `callback_mutex` could actually be replaced with an `rwlock`, which would be permitted to be taken during `commit_attach()`. The cpuset subsystem wouldn't need to maintain any special state for the transaction. So:

- `prepare_attach_nosleep()`: same as existing `cpuset_can_attach()`
- `commit_attach()`: update tasks' allowed cpus; schedule memory migration in a workqueue if necessary (since we can't take locks at this point).

### 2) memrlimit

memrlimit needs to be able to ensure that:

- changes to an mm's virtual address space size can't occur

concurrently with the mm's owner moving between cgroups (including via a change of mm ownership).

- moving the mm's owner doesn't over-commit the destination cgroup

- once the destination cgroup has been checked, additional charges can't be made that result in the original move becoming invalid

Currently all normal charges and uncharges are done under the protection of `down_write(&mm->mmap_sem)`; uncharging following a change that was charged but failed for other reasons isn't done under `mmap_sem`, but isn't a critical path so could probably be changed to do so (it wouldn't have to be all one big critical section).

Additionally, `mm->owner` changes are also done under `down_write(&mmap_sem)`. Thus holding `down_read(&mmap_sem)` across the transaction is sufficient. So (roughly):

```
prepare_attach_sleep() {
    // prevent mm->owner and mm->total_vm changes
    down_read(&mm->mmap_sem);
    // Nothing to do if we're not moving the owner
    if (mm->owner != state->task) return 0;
    if ((ret = res_counter_charge(state->dest, mm->total_vm)) {
        // If we failed to allocate in the destination, clean up
        up_read(&mm->mmap_sem);
    }
    return ret;
}
```

```
commit_attach() {
    if (mm->owner == state->task) {
        // Release the charge from the source
        res_counter_uncharge(state->src, mm->total_vm);
    }
    // Clean up locks
    up_read(&mm->mmap_sem);
}
```

```
abort_attach_sleep() {
    if (mm->owner == state->task) {
        // Remove the temporary charge from the destination
        res_counter_uncharge(state->dest_cgroup, mm->total_vm);
    }
    // Clean up locks
    up_read(&mm->mmap_sem);
}
```

As mentioned above, to handle the case where multiple subsystems need

to `down_read(&mm->mmap_sem)`, these down/up operations may actually end up being done via helper functions to avoid recursive locks.

### 3) memory

Currently the memory cgroup only uses the `mm->owner's` cgroup at charge time, and keeps a reference to the cgroup on the page. However, patches have been proposed that would move all non-shared (page count == 1) pages to the destination cgroup when the `mm->owner` moves to a new cgroup. Since it's not possible to prevent page count changes without locking all mms on the system, even this transaction approach can't really give guarantees. However, something like the following would probably be suitable. It's very similar to the `memrlimit` approach, except for the fact that we have to handle the fact that the number of pages we finally move might not be exactly the same as the number of pages we thought we'd be moving.

```
prepare_attach_sleep() {
    down_read(&mm->mmap_sem);
    if (mm->owner != state->task) return 0;
    count = count_unshared_pages(mm);
    // save the count charged to the new cgroup
    state->subsys[memcggroup_subsys_id] = (void *)count;
    if ((ret = res_counter_charge(state->dest, count)) {
        up_read(&mm->mmap_sem);
    }
    return ret;
}

commit_attach() {
    if (mm->owner == state->task) {
        final_count = move_unshared_pages(mm, state->dest);
        res_counter_uncharge(state->src, final_count);
        count = state->subsys[memcggroup_subsys_id];
        res_counter_force_charge(state->dest, final_count - count);
    }
    up_read(&mm->mmap_sem);
}

abort_attach_sleep() {
    if (mm->owner == state->task) {
        count = state->subsys[memcggroup_subsys_id];
        res_counter_uncharge(state->dest, count);
    }
    up_read(&mm->mmap_sem);
}
```

#### 4) numtasks:

Numtasks is different from the two memory-related controllers in that it may need to move charges from multiple source cgroups (for different threads); the memory cgroups only have to deal with the mm of a thread-group leader, and all threads in an attach operation are from the same thread\_group. So numtasks has to be able to handle uncharging multiple source cgroups in the commit\_attach() operation. In order to do this, it requires additional state:

```
struct numtasks_attach_state {
    int count;
    struct cgroup *cg;
    struct numtasks_attach_state *next;
}
```

It will build a list of numtasks\_attach\_state objects, one for each distinct source cgroup; in the general case either there will only be a single thread moving or else all the threads in the thread group will belong to the same cgroup, in which case this list will only be a single element; the list is very unlikely to get to more than a small number of elements.

The prepare\_attach\_sleep() function can rely on the fact that although tasks can fork/exit concurrently with the attach, since cgroup\_mutex is held, no tasks can change cgroups, and therefore a complete list of source cgroups can be constructed.

```
prepare_attach_sleep() {
    for each thread being moved:
        if the list doesn't yet have an entry for thread->cgroup:
            allocate new entry with cg = thread->cgroup, count = 0;
            add new entry to list
        store list in state->subsys[numtasks_subsys_id];
    return 0;
}
```

Then prepare\_attach\_nosleep() can move counts under protection of tasklist\_lock, to prevent any forks/exits

```
prepare_attach_nosleep() {
    read_lock(&tasklist_lock);
    for each thread being moved {
        find entry for thread->cgroup in list
        entry->count++;
        total_count++;
    }
    if ((ret = res_counter_charge(state->dest, total_count) != 0) {
```



```

    read_unlock(&tasklist_lock);
}
return ret;
}

commit_attach() {
    for each entry in list {
        res_counter_uncharge(entry->cg, entry->count);
    }
    read_unlock(&tasklist_lock);
    free list;
}

abort_attach_nosleep() {
    // just needs to clear up prepare_attach_nosleep()
    res_counter_uncharge(state->dest, total_count);
    read_unlock(&tasklist_lock);
}

abort_attach_sleep() {
    // just needs to clean up the list allocated in prepare_attach_sleep()
    free list;
}

```

So, thoughts? Is this just way to complex? Have I missed something that means this approach can't work?

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