

Configs - Userspace-driven Kernel Object Configuration

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What is configs?

configs is a ram-based filesystem that provides the converse of sysfs's functionality. Where sysfs is a filesystem-based view of kernel objects, configs is a filesystem-based manager of kernel objects, or config_items.

With sysfs, an object is created in kernel (for example, when a device is discovered) and it is registered with sysfs. Its attributes then appear in sysfs, allowing userspace to read the attributes via `readdir(3)/read(2)`. It may allow some attributes to be modified via `write(2)`. The important point is that the object is created and destroyed in kernel, the kernel controls the lifecycle of the sysfs representation, and sysfs is merely a window on all this.

A configs config_item is created via an explicit userspace operation: `mkdir(2)`. It is destroyed via `rmdir(2)`. The attributes appear at `mkdir(2)` time, and can be read or modified via `read(2)` and `write(2)`. As with sysfs, `readdir(3)` queries the list of items and/or attributes. `symlink(2)` can be used to group items together. Unlike sysfs, the lifetime of the representation is completely driven by userspace. The kernel modules backing the items must respond to this.

Both sysfs and configs can and should exist together on the same system. One is not a replacement for the other.

Using configs

configs can be compiled as a module or into the kernel. You can access it by doing:

```
mount -t configs none /config
```

The configs tree will be empty unless client modules are also loaded. These are modules that register their item types with configs as subsystems. Once a client subsystem is loaded, it will appear as a subdirectory (or more than one) under /config. Like sysfs, the configs tree is always there, whether mounted on /config or not.

An item is created via `mkdir(2)`. The item's attributes will also appear at this time. `readdir(3)` can determine what the attributes are, `read(2)` can query their default values, and `write(2)` can store new values. Don't mix more than one attribute in one attribute file.

There are two types of configs attributes:

- Normal attributes, which similar to sysfs attributes, are small ASCII text files, with a maximum size of one page (PAGE_SIZE, 4096 on i386). Preferably only one value per file should be used, and the same caveats from sysfs apply. Configs expects `write(2)` to store the entire buffer at once. When writing to normal configs attributes, userspace processes should first read the entire file, modify the portions they wish to change, and then write the entire buffer back.
- Binary attributes, which are somewhat similar to sysfs binary attributes, but with a few slight changes to semantics. The PAGE_SIZE limitation does not apply, but the whole binary item must fit in single kernel vmalloc'ed buffer. The `write(2)` calls from user space are buffered, and the attributes' `write_bin_attribute` method will be invoked on the final close, therefore it is imperative for user-space to check the return code of `close(2)` in order to verify that the operation finished successfully. To avoid a malicious user OOMing the kernel, there's a per-binary attribute maximum buffer value.

When an item needs to be destroyed, remove it with `rmdir(2)`. An item cannot be destroyed if any other item has a link to it (via `symlink(2)`). Links can be removed via `unlink(2)`.

Configuring FakeNBD: an Example

Imagine there's a Network Block Device (NBD) driver that allows you to access remote block devices. Call it FakeNBD. FakeNBD uses configs for its configuration. Obviously, there will be a nice program that sysadmins use to configure FakeNBD, but somehow that program has to tell the driver about it. Here's where configs comes in.

When the FakeNBD driver is loaded, it registers itself with configs. `readdir(3)` sees this just fine:

```
# ls /config
fakenbd
```

A fakenbd connection can be created with `mkdir(2)`. The name is arbitrary, but likely the tool will make some use of the name. Perhaps it is a uuid or a disk name:

```
# mkdir /config/fakenbd/disk1
# ls /config/fakenbd/disk1
target device rw
```

The target attribute contains the IP address of the server FakeNBD will connect to. The device attribute is the device on the server. Predictably, the rw attribute determines whether the connection is read-only or read-write:

```
# echo 10.0.0.1 > /config/fakenbd/disk1/target
# echo /dev/sda1 > /config/fakenbd/disk1/device
# echo 1 > /config/fakenbd/disk1/rw
```

That's it. That's all there is. Now the device is configured, via the shell no less.

Coding With configs

Every object in configs is a `config_item`. A `config_item` reflects an object in the subsystem. It has attributes that match values on that object. configs handles the filesystem representation of that object and its attributes, allowing the subsystem to ignore all but the basic show/store interaction.

Items are created and destroyed inside a `config_group`. A group is a collection of items that share the same attributes and operations. Items are created by `mkdir(2)` and removed by `rmdir(2)`, but configs handles that. The group has a set of operations to perform these tasks

A subsystem is the top level of a client module. During initialization, the client module registers the subsystem with configs, the subsystem appears as a directory at the top of the configs filesystem. A subsystem is also a `config_group`, and can do everything a `config_group` can.

struct config_item

```
struct config_item {
    char                *ci_name;
    char                ci_namebuf[UOBJ_NAME_LEN];
    struct kref          ci_kref;
    struct list_head     ci_entry;
    struct config_item  *ci_parent;
    struct config_group  *ci_group;
    struct config_item_type *ci_type;
    struct dentry        *ci_dentry;
};

void config_item_init(struct config_item *);
void config_item_init_type_name(struct config_item *,
                                const char *name,
                                struct config_item_type *type);
struct config_item *config_item_get(struct config_item *);
void config_item_put(struct config_item *);
```

Generally, `struct config_item` is embedded in a container structure, a structure that actually represents what the subsystem is doing. The `config_item` portion of that structure is how the object interacts with configs.

Whether statically defined in a source file or created by a parent `config_group`, a `config_item` must have one of the `_init()` functions called on it. This initializes the reference count and sets up the appropriate fields.

All users of a `config_item` should have a reference on it via `config_item_get()`, and drop the reference when they are done via `config_item_put()`.

By itself, a `config_item` cannot do much more than appear in configs. Usually a subsystem wants the item to display and/or store attributes, among other things. For that, it needs a type.

struct config_item_type

```
struct configs_item_operations {
    void (*release)(struct config_item *);
    int (*allow_link)(struct config_item *src,
                     struct config_item *target);
    void (*drop_link)(struct config_item *src,
                     struct config_item *target);
};

struct config_item_type {
    struct module                *ct_owner;
    struct configs_item_operations *ct_item_ops;
    struct configs_group_operations *ct_group_ops;
    struct configs_attribute      **ct_attrs;
    struct configs_bin_attribute  **ct_bin_attrs;
};
```

The most basic function of a `config_item_type` is to define what operations can be performed on a `config_item`. All items that have been allocated dynamically will need to provide the `ct_item_ops->release()` method. This method is called when the `config_item`'s reference count reaches zero.

struct configs_attribute

```
struct configs_attribute {
    char                *ca_name;
    struct module       *ca_owner;
    umode_t             ca_mode;
    ssize_t (*show)(struct config_item *, char *);
    ssize_t (*store)(struct config_item *, const char *, size_t);
};
```

When a `config_item` wants an attribute to appear as a file in the item's configs directory, it must define a `configs_attribute` describing it. It then adds the attribute to the NULL-terminated array `config_item_type->ct_attrs`. When the item appears in configs, the attribute file will appear with the `configs_attribute->ca_name` filename. `configs_attribute->ca_mode` specifies the file permissions.

If an attribute is readable and provides a `->show` method, that method will be called whenever userspace asks for a `read(2)` on the attribute. If an attribute is writable and provides a `->store` method, that method will be called whenever userspace asks for a `write(2)` on the attribute.

struct configs_bin_attribute

```
struct configs_bin_attribute {
    struct configs_attribute cb_attr;
    void                    *cb_private;
    size_t                  cb_max_size;
};
```

The binary attribute is used when the one needs to use binary blob to appear as the contents of a file in the item's configs directory. To do so add the binary attribute to the NULL-terminated array `config_item_type->ct_bin_attrs`, and the item appears in configs, the attribute file will appear with the `configs_bin_attribute->cb_attr.ca_name` filename. `configs_bin_attribute->cb_attr.ca_mode` specifies the file permissions. The `cb_private` member is provided for use by the driver, while the `cb_max_size` member specifies the maximum amount of `vmalloc` buffer to be used.

If binary attribute is readable and the `config_item` provides a `ct_item_ops->read_bin_attribute()` method, that method will be called whenever userspace asks for a `read(2)` on the attribute. The converse will happen for `write(2)`. The reads/writes are buffered so only a single read/write will occur; the attributes' need not concern itself with it.

struct config_group

A `config_item` cannot live in a vacuum. The only way one can be created is via `mknod(2)` on a `config_group`. This will trigger creation of a child item.

```
struct config_group {
    struct config_item    cg_item;
    struct list_head      cg_children;
    struct configs_subsystem *cg_subsys;
    struct list_head      default_groups;
    struct list_head      group_entry;
};

void config_group_init(struct config_group *group);
void config_group_init_type_name(struct config_group *group,
                                const char *name,
                                struct config_item_type *type);
```

The `config_group` structure contains a `config_item`. Properly configuring that item means that a group can behave as an item in its own right. However, it can do more: it can create child items or groups. This is accomplished via the group operations specified on the group's `config_item_type`:

```
struct configs_group_operations {
    struct config_item *(*make_item)(struct config_group *group,
                                     const char *name);
    struct config_group *(*make_group)(struct config_group *group,
                                       const char *name);
    int (*commit_item)(struct config_item *item);
    void (*disconnect_notify)(struct config_group *group,
                              struct config_item *item);
    void (*drop_item)(struct config_group *group,
                      struct config_item *item);
};
```

A group creates child items by providing the `ct_group_ops->make_item()` method. If provided, this method is called from `mknod(2)` in the group's directory. The subsystem allocates a new `config_item` (or more likely, its container structure), initializes it, and returns it to configs. Configs will then populate the filesystem tree to reflect the new item.

If the subsystem wants the child to be a group itself, the subsystem provides `ct_group_ops->make_group()`. Everything else behaves

the same, using the group `_init()` functions on the group.

Finally, when userspace calls `rmdir(2)` on the item or group, `ct_group_ops->drop_item()` is called. As a `config_group` is also a `config_item`, it is not necessary for a separate `drop_group()` method. The subsystem must `config_item_put()` the reference that was initialized upon item allocation. If a subsystem has no work to do, it may omit the `ct_group_ops->drop_item()` method, and `configfs` will call `config_item_put()` on the item on behalf of the subsystem.

Important:

`drop_item()` is void, and as such cannot fail. When `rmdir(2)` is called, `configfs` WILL remove the item from the filesystem tree (assuming that it has no children to keep it busy). The subsystem is responsible for responding to this. If the subsystem has references to the item in other threads, the memory is safe. It may take some time for the item to actually disappear from the subsystem's usage. But it is gone from `configfs`.

When `drop_item()` is called, the item's linkage has already been torn down. It no longer has a reference on its parent and has no place in the item hierarchy. If a client needs to do some cleanup before this teardown happens, the subsystem can implement the `ct_group_ops->disconnect_notify()` method. The method is called after `configfs` has removed the item from the filesystem view but before the item is removed from its parent group. Like `drop_item()`, `disconnect_notify()` is void and cannot fail. Client subsystems should not drop any references here, as they still must do it in `drop_item()`.

A `config_group` cannot be removed while it still has child items. This is implemented in the `configfs rmdir(2)` code. `->drop_item()` will not be called, as the item has not been dropped. `rmdir(2)` will fail, as the directory is not empty.

struct configfs_subsystem

A subsystem must register itself, usually at module `_init` time. This tells `configfs` to make the subsystem appear in the file tree:

```
struct configfs_subsystem {
    struct Config_group    su_group;
    struct mutex           su_mutex;
};

int configfs_register_subsystem(struct configfs_subsystem *subsys);
void configfs_unregister_subsystem(struct configfs_subsystem *subsys);
```

A subsystem consists of a toplevel `config_group` and a mutex. The group is where child `config_items` are created. For a subsystem, this group is usually defined statically. Before calling `configfs_register_subsystem()`, the subsystem must have initialized the group via the usual group `_init()` functions, and it must also have initialized the mutex.

When the register call returns, the subsystem is live, and it will be visible via `configfs`. At that point, `mkdir(2)` can be called and the subsystem must be ready for it.

An Example

The best example of these basic concepts is the `simple_children` subsystem/group and the `simple_child` item in `samples/configfs/configfs_sample.c`. It shows a trivial object displaying and storing an attribute, and a simple group creating and destroying these children.

Hierarchy Navigation and the Subsystem Mutex

There is an extra bonus that `configfs` provides. The `config_groups` and `config_items` are arranged in a hierarchy due to the fact that they appear in a filesystem. A subsystem is NEVER to touch the filesystem parts, but the subsystem might be interested in this hierarchy. For this reason, the hierarchy is mirrored via the `config_group->cg_children` and `config_item->ci_parent` structure members.

A subsystem can navigate the `cg_children` list and the `ci_parent` pointer to see the tree created by the subsystem. This can race with `configfs`' management of the hierarchy, so `configfs` uses the subsystem mutex to protect modifications. Whenever a subsystem wants to navigate the hierarchy, it must do so under the protection of the subsystem mutex.

A subsystem will be prevented from acquiring the mutex while a newly allocated item has not been linked into this hierarchy. Similarly, it will not be able to acquire the mutex while a dropping item has not yet been unlinked. This means that an item's `ci_parent` pointer will never be NULL while the item is in `configfs`, and that an item will only be in its parent's `cg_children` list for the same duration. This allows a subsystem to trust `ci_parent` and `cg_children` while they hold the mutex.

Item Aggregation Via symlink(2)

`configfs` provides a simple group via the `group->item` parent/child relationship. Often, however, a larger environment requires aggregation outside of the parent/child connection. This is implemented via `symlink(2)`.

A `config_item` may provide the `ct_item_ops->allow_link()` and `ct_item_ops->drop_link()` methods. If the `->allow_link()` method exists, `symlink(2)` may be called with the `config_item` as the source of the link. These links are only allowed between `configfs` `config_items`. Any `symlink(2)` attempt outside the `configfs` filesystem will be denied.

When `symlink(2)` is called, the source `config_item`'s `->allow_link()` method is called with itself and a target item. If the source item allows linking to target item, it returns 0. A source item may wish to reject a link if it only wants links to a certain type of object (say, in its own subsystem).

When `unlink(2)` is called on the symbolic link, the source item is notified via the `->drop_link()` method. Like the `->drop_item()` method, this is a void function and cannot return failure. The subsystem is responsible for responding to the change.

A `config_item` cannot be removed while it links to any other item, nor can it be removed while an item links to it. Dangling symlinks are not allowed in configs.

Automatically Created Subgroups

A new `config_group` may want to have two types of child `config_items`. While this could be codified by magic names in `->make_item()`, it is much more explicit to have a method whereby userspace sees this divergence.

Rather than have a group where some items behave differently than others, `configs` provides a method whereby one or many subgroups are automatically created inside the parent at its creation. Thus, `mkdir("parent")` results in "parent", "parent/subgroup1", up through "parent/subgroupN". Items of type 1 can now be created in "parent/subgroup1", and items of type N can be created in "parent/subgroupN".

These automatic subgroups, or default groups, do not preclude other children of the parent group. If `ct_group_ops->make_group()` exists, other child groups can be created on the parent group directly.

A `configs` subsystem specifies default groups by adding them using the `configs_add_default_group()` function to the parent `config_group` structure. Each added group is populated in the `configs` tree at the same time as the parent group. Similarly, they are removed at the same time as the parent. No extra notification is provided. When a `->drop_item()` method call notifies the subsystem the parent group is going away, it also means every default group child associated with that parent group.

As a consequence of this, default groups cannot be removed directly via `rmdir(2)`. They also are not considered when `rmdir(2)` on the parent group is checking for children.

Dependent Subsystems

Sometimes other drivers depend on particular `configs` items. For example, `ocfs2` mounts depend on a heartbeat region item. If that region item is removed with `rmdir(2)`, the `ocfs2` mount must BUG or go readonly. Not happy.

`configs` provides two additional API calls: `configs_depend_item()` and `configs_undepend_item()`. A client driver can call `configs_depend_item()` on an existing item to tell `configs` that it is depended on. `configs` will then return `-EBUSY` from `rmdir(2)` for that item. When the item is no longer depended on, the client driver calls `configs_undepend_item()` on it.

These API cannot be called underneath any `configs` callbacks, as they will conflict. They can block and allocate. A client driver probably shouldn't call them of its own gumption. Rather it should be providing an API that external subsystems call.

How does this work? Imagine the `ocfs2` mount process. When it mounts, it asks for a heartbeat region item. This is done via a call into the heartbeat code. Inside the heartbeat code, the region item is looked up. Here, the heartbeat code calls `configs_depend_item()`. If it succeeds, then heartbeat knows the region is safe to give to `ocfs2`. If it fails, it was being torn down anyway, and heartbeat can gracefully pass up an error.

Committable Items

Note:

Committable items are currently unimplemented.

Some `config_items` cannot have a valid initial state. That is, no default values can be specified for the item's attributes such that the item can do its work. Userspace must configure one or more attributes, after which the subsystem can start whatever entity this item represents.

Consider the FakeNBD device from above. Without a target address *and* a target device, the subsystem has no idea what block device to import. The simple example assumes that the subsystem merely waits until all the appropriate attributes are configured, and then connects. This will, indeed, work, but now every attribute store must check if the attributes are initialized. Every attribute store must fire off the connection if that condition is met.

Far better would be an explicit action notifying the subsystem that the `config_item` is ready to go. More importantly, an explicit action allows the subsystem to provide feedback as to whether the attributes are initialized in a way that makes sense. `configs` provides this as committable items.

`configs` still uses only normal filesystem operations. An item is committed via `rename(2)`. The item is moved from a directory where it can be modified to a directory where it cannot.

Any group that provides the `ct_group_ops->commit_item()` method has committable items. When this group appears in `configs`, `mkdir(2)` will not work directly in the group. Instead, the group will have two subdirectories: "live" and "pending". The "live" directory does not support `mkdir(2)` or `rmdir(2)` either. It only allows `rename(2)`. The "pending" directory does allow `mkdir(2)` and `rmdir(2)`. An item is created in the "pending" directory. Its attributes can be modified at will. Userspace commits the item by renaming it into the

"live" directory. At this point, the subsystem receives the `->commit_item()` callback. If all required attributes are filled to satisfaction, the method returns zero and the item is moved to the "live" directory.

As `rmdir(2)` does not work in the "live" directory, an item must be shutdown, or "uncommitted". Again, this is done via `rename(2)`, this time from the "live" directory back to the "pending" one. The subsystem is notified by the `ct_group_ops->uncommit_object()` method.