Objects in Linux

Trust us, we know what we are doing...

Greg Kroah-Hartman
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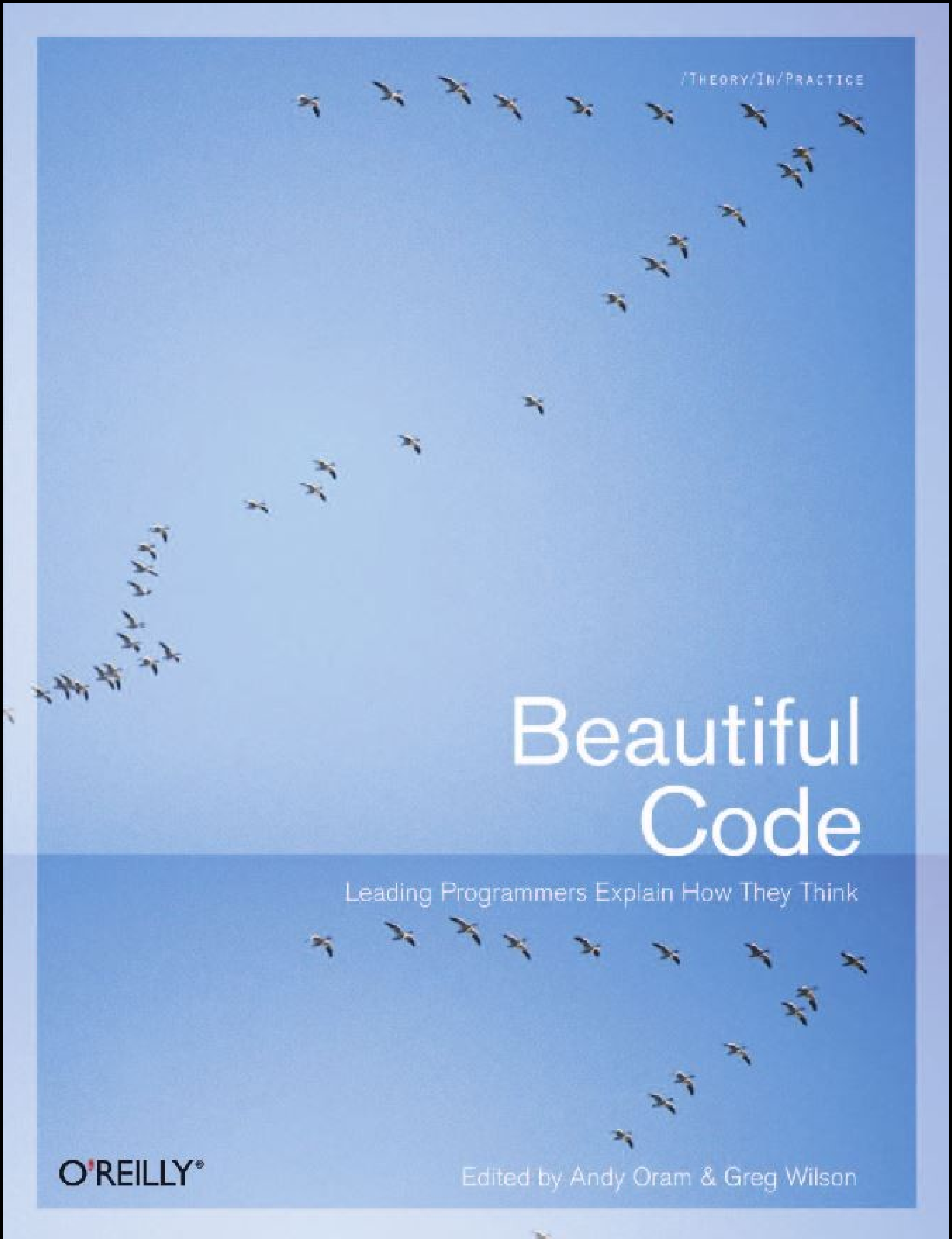


/Theory/In/Practice

Beautiful Code

Leading Programmers Explain How They Think

O'REILLY®

Edited by Andy Oram & Greg Wilson

“Unify all Linux devices”

Pat Mochel – OSDL
Greg Kroah-Hartman – IBM
2001-2003

```
struct device {
        struct list_head node;
        struct list_head children;
        struct device *parent;

        char name[DEVICE_NAME_SIZE];
        bus_id[BUS_ID_SIZE];

        spinlock_t lock;

        atomic_t refcount;

        struct driver_dir_entry *dir;
        struct device_driver *driver;

        void *driver_data;
        void *platform_data;
        u32 current_state;
        unsigned char *saved_state;
  };
```

“sysfs looks like a web woven by a spider on drugs”

– lwn.net

```
int device_register(struct device *dev);
void device_unregister(struct device *dev);



struct bus_type {
        …
        int (*probe)(struct device *dev);
        int (*remove)(struct device *dev);
        …
};
```

```
struct usb_interface {
        struct usb_interface_descriptor *altsetting;
        int act_altsetting;
        int num_altsetting;
        int max_altsetting;
        struct usb_driver *driver;
        struct device dev;
};
```

```
static int usb_probe(struct device *d)
{
        struct usb_interface *intf;

        intf = container_of(d, struct usb_interface, dev);
        …

}
```

```
#define container_of(ptr, type, member) ({              \
    const typeof( ((type *)0)->member ) *_ _mptr = (ptr); \
    (type *)( (char *)_ _mptr - offsetof(type,member) );})
```

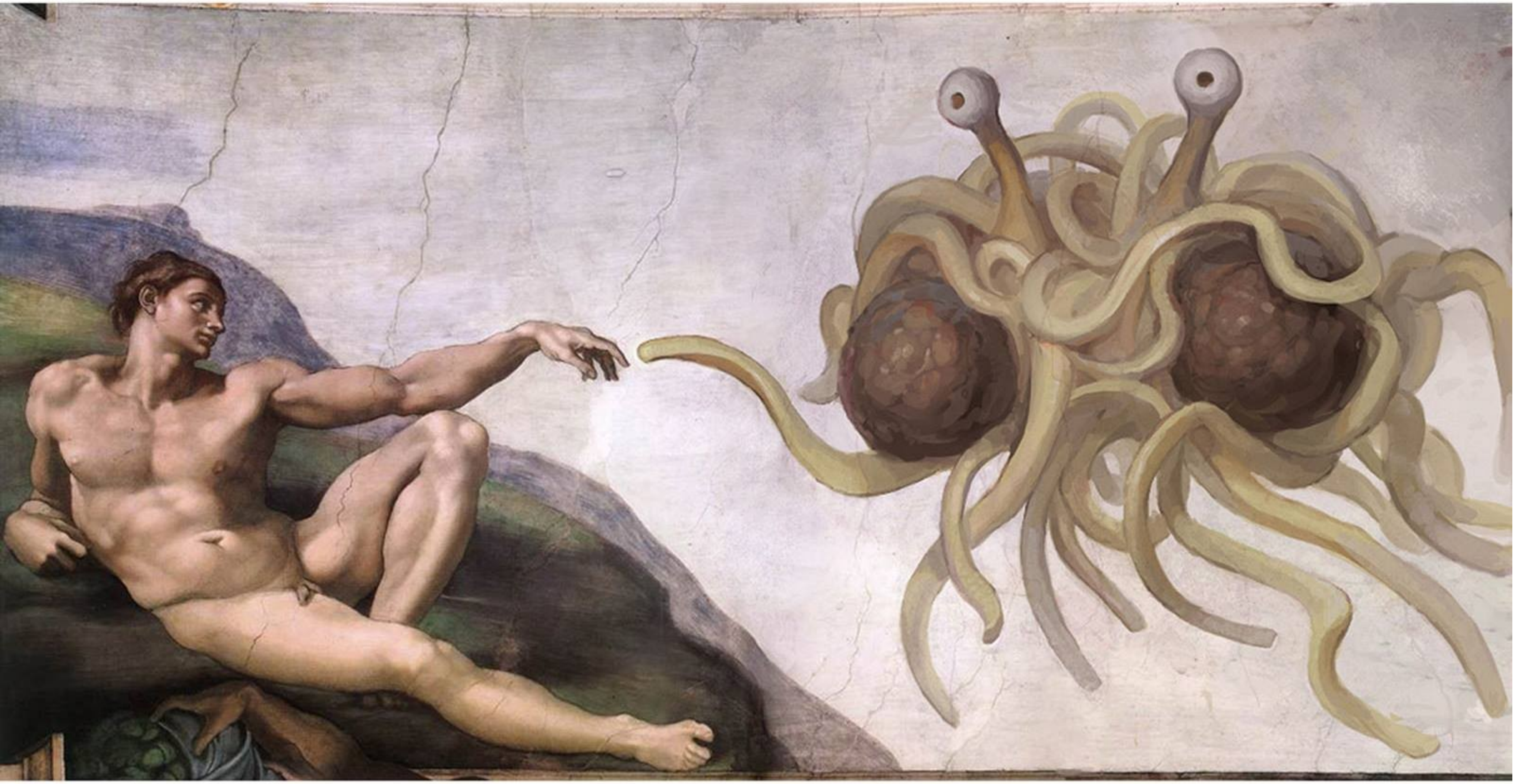
```
intf = container_of(d, struct usb_interface, dev);
intf = ({
    const struct device *__mptr = d;
    (struct usb_interface *)( (char *)__mptr -
      offsetof(struct usb_interface, dev));
});
```

```
intf = ({
    const struct device *__mptr = d;
    (struct usb_interface *)( (char *)__mptr - 20));
});
```

```
intf = *d - 20;
```

No type safety at all, you just “know” what type of object you have.

“Linux is evolution, not intelligent design.” – Linus Torvalds



```
struct device {
        struct list_head node;
        struct list_head children;
        struct device *parent;

        char name[DEVICE_NAME_SIZE];
        bus_id[BUS_ID_SIZE];

        spinlock_t lock;

        atomic_t refcount;

        struct driver_dir_entry *dir;
        struct device_driver *driver;

        void *driver_data;
        void *platform_data;
        u32 current_state;
        unsigned char *saved_state;
  };
```

```
static inline void get_device(struct device *dev)
{
        BUG_ON(!atomic_read(&dev->refcount));
        atomic_inc(&dev->refcount);
}
```

```
void put_device(struct device *dev)
{
    if (!atomic_dec_and_lock(&dev->refcount,&device_lock))
        return;

...

    /* Tell the driver to clean up after itself.
     * Note that we likely didn’t allocate the device,
     * so this is the driver’s chance to free that up...
     */
    if (dev->driver && dev->driver->remove)
        dev->driver->remove(dev, REMOVE_FREE_RESOURCES);
}
```

```
struct kobject {
        char name[KBOJ_NAME_LEN];
        atomic_t refcount;
        struct list_head entry;
        struct kobject *parent
        struct subsystem *subsys;
        struct dentry *dentry;
};
```

```
struct device {
        struct list_head g_list;
        struct list_head node;
        struct list_head bus_list;
        struct list_head driver_list;
        struct list_head children;
        struct list_head intf_list;
        struct device *parent;

        struct kobject kobj;

        char bus_id[BUS_ID_SIZE];

...

};

#define to_dev(obj) \
    container_of(obj, struct device, kobj)
```

```c
struct kref {
        atomic_t refcount;
};

static inline void kref_init(struct kref *kref)
{
        atomic_set(&kref->refcount, 1);
}

static inline void kref_get(struct kref *kref)
{
        /* If refcount was 0 before incrementing then
         * we have a race condition when this kref is
         * freeing by some other thread right now.
         */
        WARN_ON_ONCE(atomic_inc_return(&kref->refcount)
                     < 2);
}
```

```
int kref_put(struct kref *kref,
             void (*release)(struct kref *kref))
{
        WARN_ON(release == NULL);
        WARN_ON(release ==
                (void (*)(struct kref *))kfree);

        if (atomic_dec_and_test(&kref->refcount)) {
                release(kref);
                return 1;
        }
        return 0;
}
```

```
struct kobject {
        char name[KOBJ_NAME_LEN];
        struct kref kref;
        ...
};
```

```
void put_device(struct device *dev)
{
    if (!atomic_dec_and_lock(&dev->refcount,&device_lock))
        return;

...

    /* Tell the driver to clean up after itself.
     * Note that we likely didn’t allocate the device,
     * so this is the driver’s chance to free that up...
     */
    if (dev->driver && dev->driver->remove)
        dev->driver->remove(dev, REMOVE_FREE_RESOURCES);
}
```

```
void put_device(struct device *dev)
{
        /* might_sleep(); */
        if (dev)
                kobject_put(&dev->kobj);
}

void kobject_put(struct kobject *kobj)
{
        if (kobj) {
                if (!kobj->state_initialized)
                        WARN(1, …);
                kref_put(&kobj->kref, kobject_release);
        }
}
```

```
static inline int kref_put_mutex(struct kref *kref,
                       void (*release)(struct kref *kref),
                       struct mutex *lock)
{
        WARN_ON(release == NULL);

        if (!atomic_add_unless(&kref->refcount, -1, 1)) {
                mutex_lock(lock);
                if (!atomic_dec_and_test(&kref->refcount)) {
                        mutex_unlock(lock);
                        return 0;
                }
                release(kref);
                return 1;
        }
        return 0;
}
```

github.com/gregkh/presentation-kref

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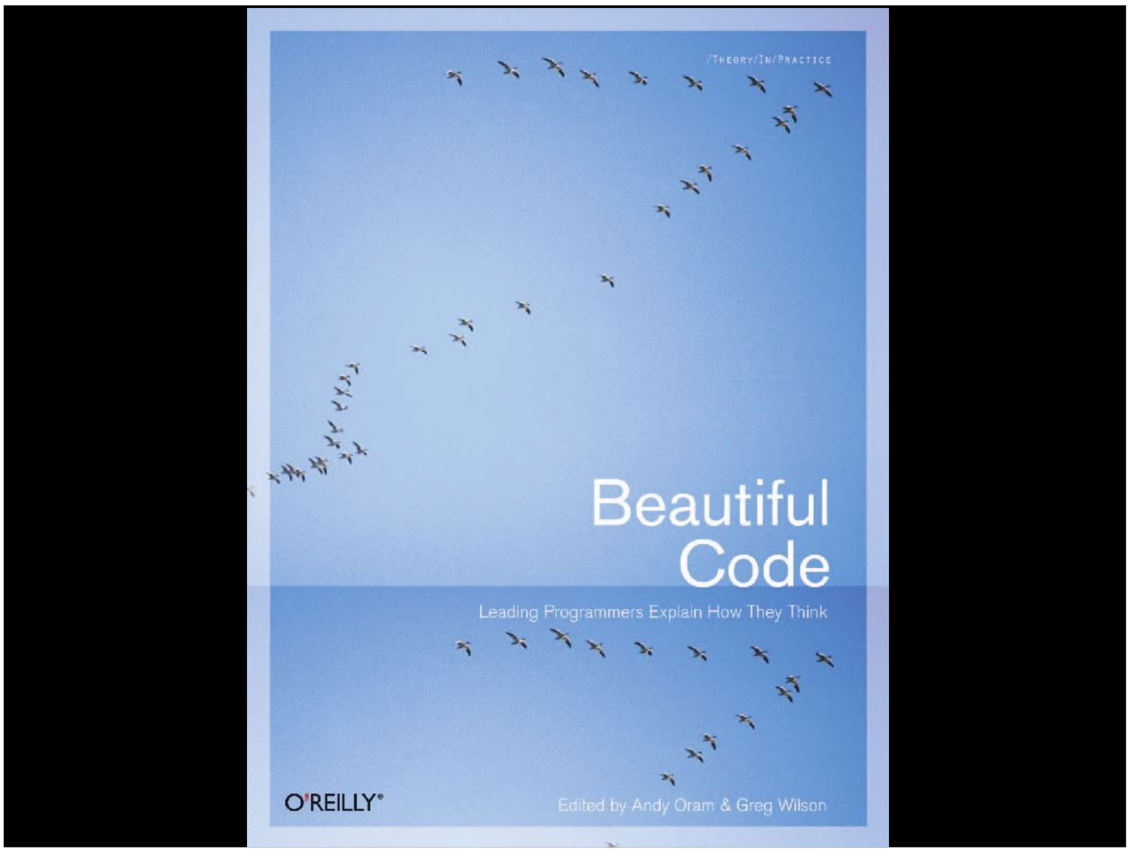
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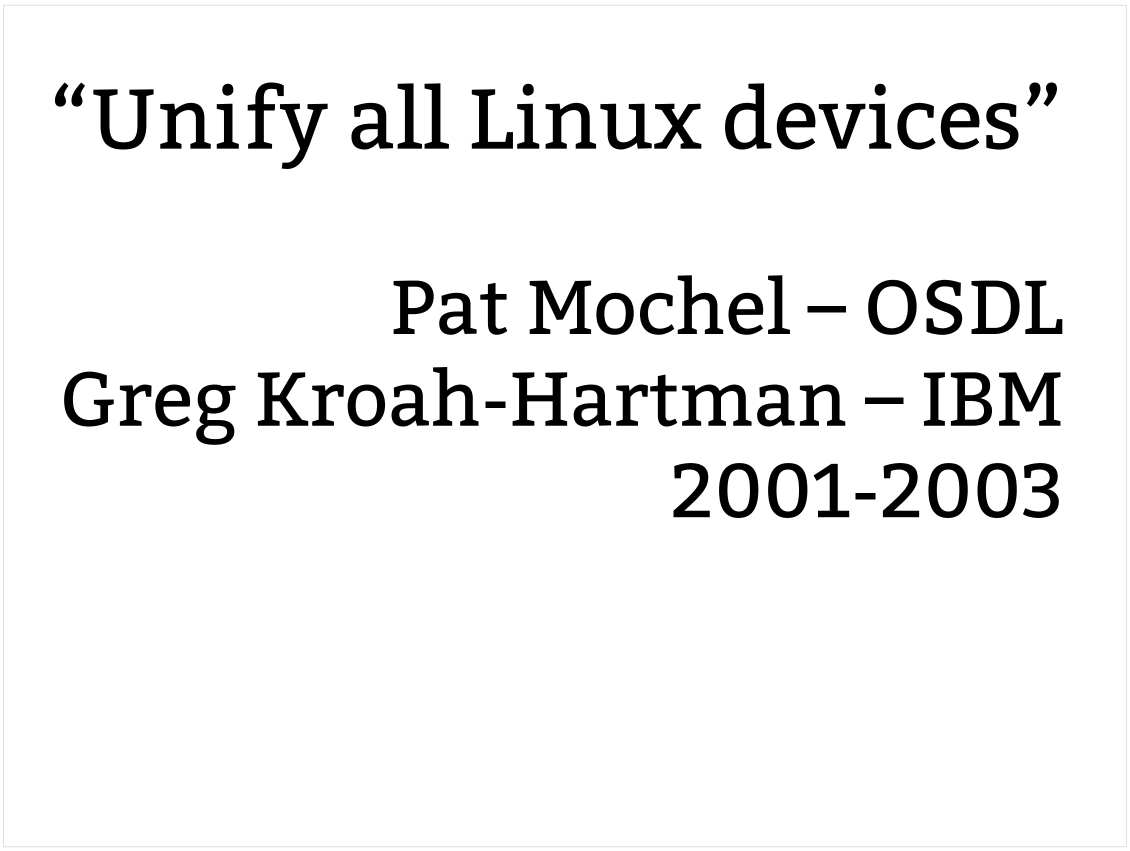
Leading Programmers Explain How They Think
O'REILLY
Edited by Andy Oram & Greg Wilson

Talk based on a chapter I wrote for "Beautiful Code – Leading Programmers Explain How They Think"

Edited by Andy Oram and Greg Wilson
O'Reilly
2007



“Unify all Linux devices”

Pat Mochel – OSDL
Greg Kroah-Hartman – IBM
2001-2003

Pat wanted this for power management and suspend/resume

I wanted this for persistant device naming.

All devices and subsystems were islands

Both tasks needed a way to see all devices in the system, suspend/resume wanted to know which device to suspend in which order.

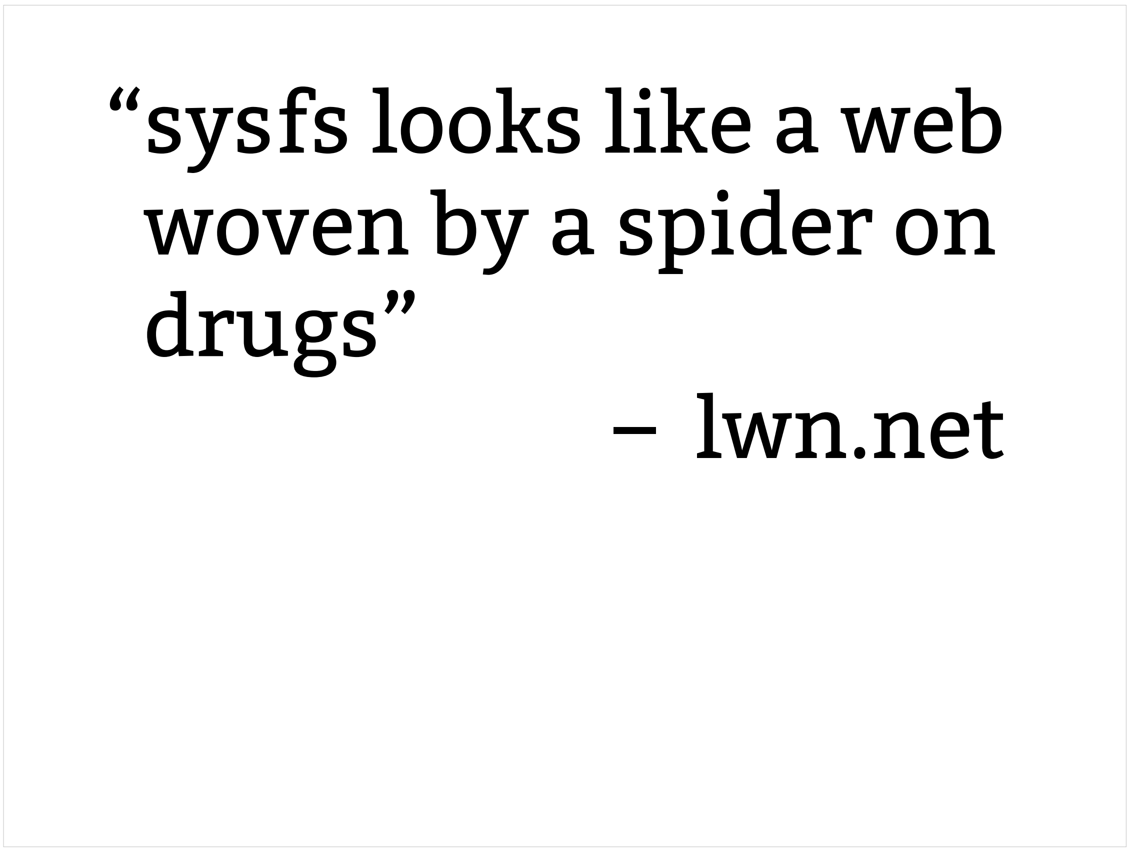
Naming needed a way to assign a character or block device to a specific hardware device

```
          struct device {
                  struct list_head node;
                  struct list_head children;
                  struct device *parent;

                  char name[DEVICE_NAME_SIZE];
                  bus_id[BUS_ID_SIZE];

                  spinlock_t lock;

                  atomic_t refcount;

                  struct driver_dir_entry *dir;
                  struct device_driver *driver;

                  void *driver_data;
                  void *platform_data;
                  u32 current_state;
                  unsigned char *saved_state;
            };
```

We came up with 'struct device'

All busses in the kernel were changed to create a structure based on this one. It was passed to the new driver core, and the driver core created a hierarchy of everything in the kernel.

This can be seen in sysfs (which used to be called driverfs)



"sysfs looks like a web woven by a spider on drugs"

– lwn.net

Sysfs is crazy, links to everything, from everywhere, showing how the hardware is linked to userspace in all possible ways.

```
int device_register(struct device *dev);
void device_unregister(struct device *dev);



struct bus_type {
        …
        int (*probe)(struct device *dev);
        int (*remove)(struct device *dev);
        …
};
```

The driver core wants a 'struct device' and passes you back a struct device when it wants to pass probe onto a driver.

With that pointer, how can a bus get to what it really wants, its bus-specific structure?

```
struct usb_interface {
        struct usb_interface_descriptor *altsetting;
        int act_altsetting;
        int num_altsetting;
        int max_altsetting;
        struct usb_driver *driver;
        struct device dev;
};
```

Let's look at how USB handles this.

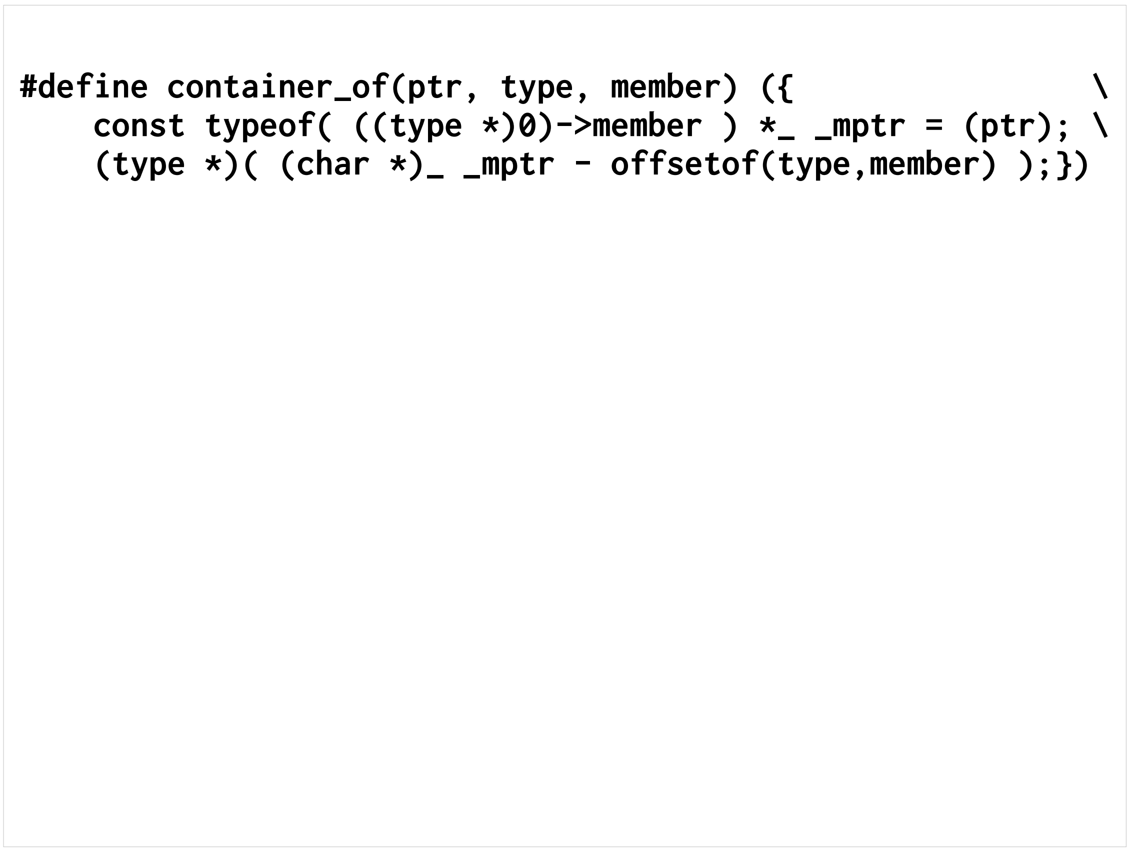
This is a usb interface, what a usb driver binds to and controls.

Here we imbed into the usb_interface structure, struct device. usb_interface “inherits” the properties of struct device, like name, locks, private storage, driver bindings, sysfs files, etc.

```
static int usb_probe(struct device *d)
{
        struct usb_interface *intf;

        intf = container_of(d, struct usb_interface, dev);
        …

}
```

When the usb core is called by the driver core, it passes in a struct device.

The usb core then automagically converts that struct device into the struct usb_interface structure that it “knows” was passed to it.



```
#define container_of(ptr, type, member) ({                \
    const typeof( ((type *)0)->member ) *_ _mptr = (ptr); \
    (type *)( (char *)_ _mptr - offsetof(type,member) );})
```

It does this through the “magic” of container_of

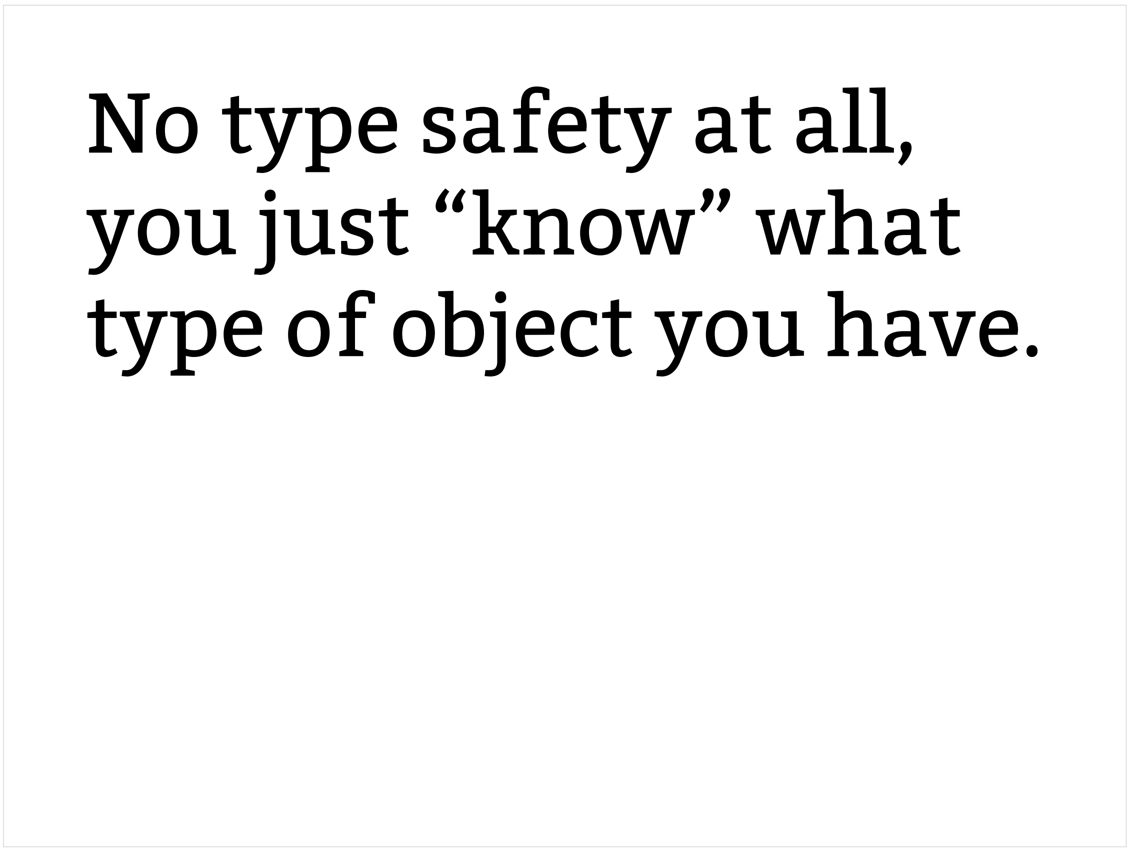
This is how the kernel does object inheritance. It is how the kernel does lots of magic things, let's break it down and see how it works specifically.

```
intf = container_of(d, struct usb_interface, dev);
intf = ({
    const struct device *__mptr = d;
    (struct usb_interface *)( (char *)__mptr -
      offsetof(struct usb_interface, dev));
});
```

```
intf = ({
    const struct device *__mptr = d;
    (struct usb_interface *)( (char *)__mptr - 20));
});
```

```
intf = *d - 20;
```

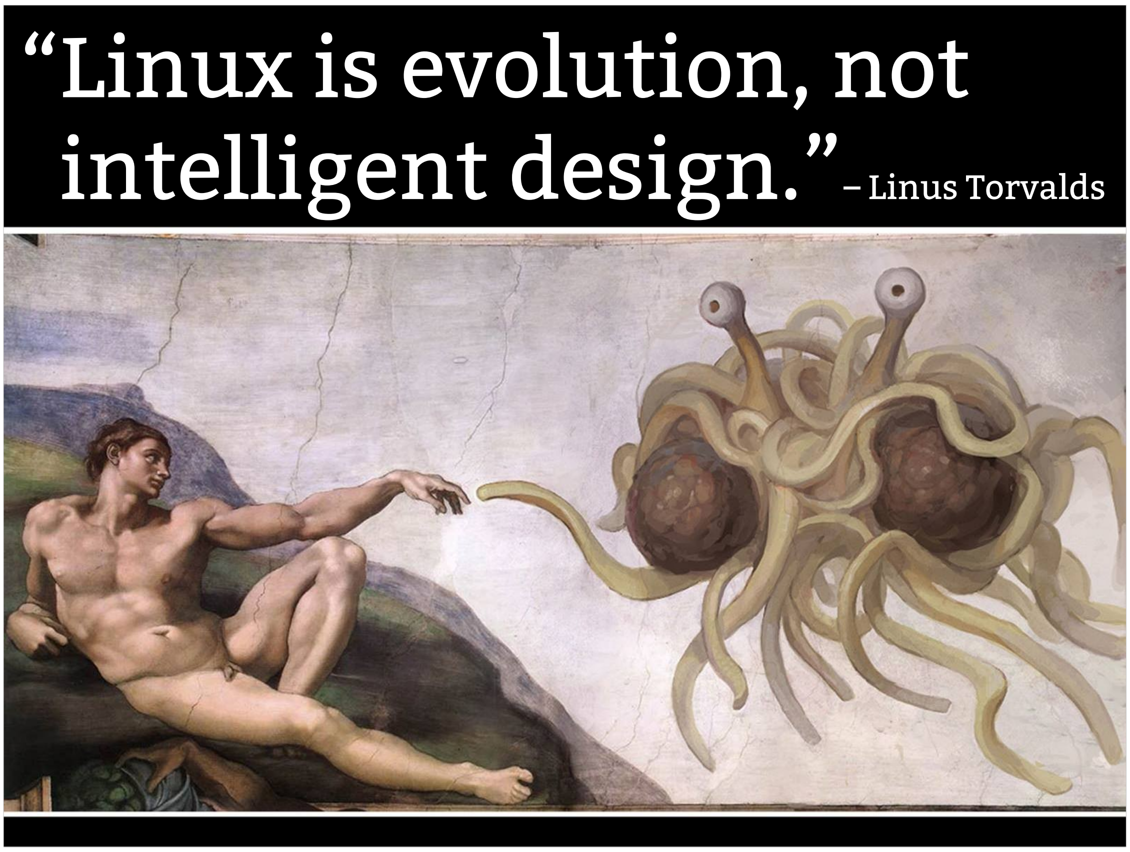
Pointer math is fast.



No type safety at all, you just “know” what type of object you have.

Trust us…

This is unlike almost all c object systems. It requires a very concious decision by the authors as to how to handle objects and pass them around. We trust the receiver of the object to know what it is, based on the call that was made by the driver core itself.


"Linux is evolution, not intelligent design." – Linus Torvalds

This is how the driver model started.

But as we were doing this work, other developers were watching it, and realized that it would pertain to much more than just drivers and devices, they wanted it to control all structures within the kernel that a user could access.

Al Viro saw this work, and started to modify the device structures, making them more generic and applicable to things like filesystems and other things:

```
struct device {
        struct list_head node;
        struct list_head children;
        struct device *parent;

        char name[DEVICE_NAME_SIZE];
        bus_id[BUS_ID_SIZE];

        spinlock_t lock;

        atomic_t refcount;

        struct driver_dir_entry *dir;
        struct device_driver *driver;

        void *driver_data;
        void *platform_data;
        u32 current_state;
        unsigned char *saved_state;
  };
```

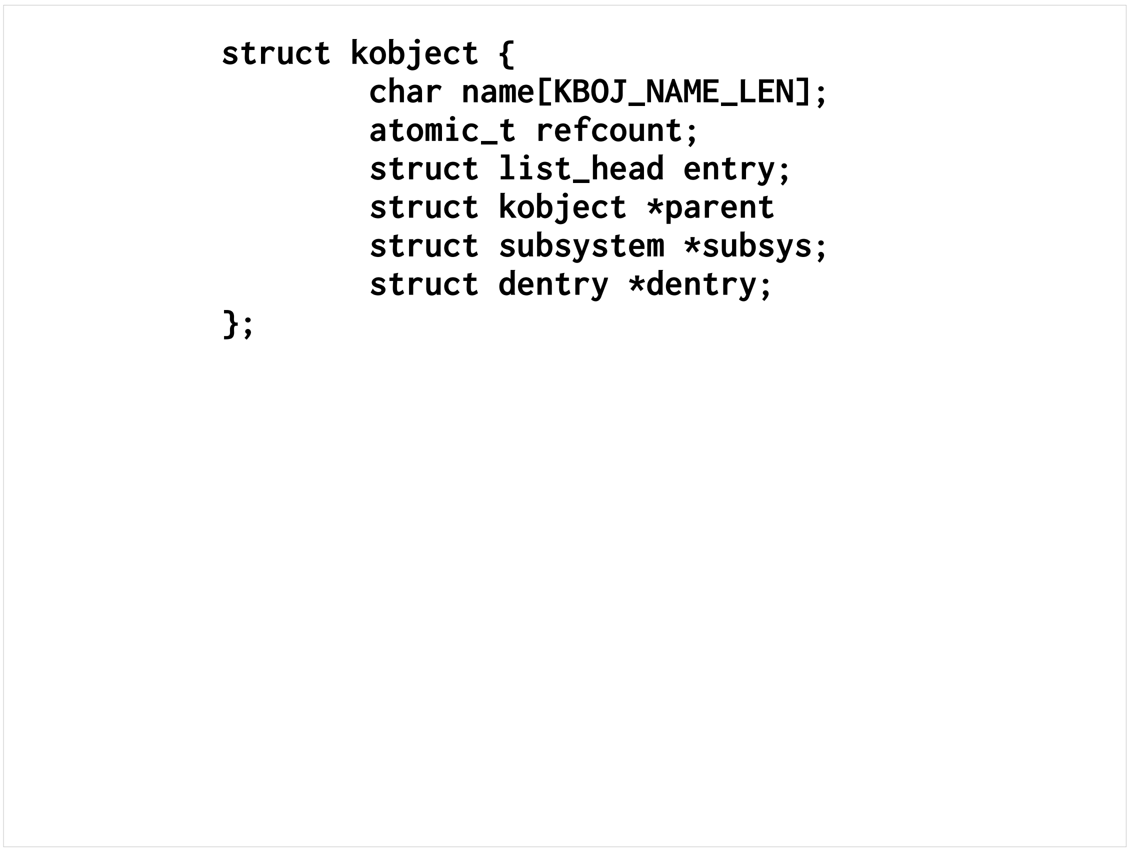
When the structure was initialized, this field was set to 1. Whenever any code wished to
use the structure, it had to first increment the reference count by calling the function get_
device , which checked that the reference count was valid and incremented the reference
count of the structure:

```
static inline void get_device(struct device *dev)
{
        BUG_ON(!atomic_read(&dev->refcount));
        atomic_inc(&dev->refcount);
}
```

When the structure was initialized, this field was set to 1. Whenever any code wished to
use the structure, it had to first increment the reference count by calling the function get_
device , which checked that the reference count was valid and incremented the reference
count of the structure:

```
void put_device(struct device *dev)
{
    if (!atomic_dec_and_lock(&dev->refcount,&device_lock))
        return;

...

    /* Tell the driver to clean up after itself.
     * Note that we likely didn't allocate the device,
     * so this is the driver's chance to free that up...
     */
    if (dev->driver && dev->driver->remove)
        dev->driver->remove(dev, REMOVE_FREE_RESOURCES);
}
```

This function decremented the reference count and then, if it was the last user of the
object, would tell the object to clean itself up and call a function that was previously set up
to free it from the system.



```
struct kobject {
        char name[KBOJ_NAME_LEN];
        atomic_t refcount;
        struct list_head entry;
        struct kobject *parent
        struct subsystem *subsys;
        struct dentry *dentry;
};
```

Pat created 'struct kobject' for Al, to use wherever a reference counted object was needed. This worked really well for filesystems, and to tie into scaling character and block devices up from only 256 minor numbers, to 32thousand in a way that did not require walking long lists of links.

```
struct device {
        struct list_head g_list;
        struct list_head node;
        struct list_head bus_list;
        struct list_head driver_list;
        struct list_head children;
        struct list_head intf_list;
        struct device *parent;

        struct kobject kobj;

        char bus_id[BUS_ID_SIZE];

...

};

#define to_dev(obj) \
    container_of(obj, struct device, kobj)
```

We put struct kobject into struct device, then struct device inherited all of the sysfs support, as well as reference counting.

```
struct kref {
        atomic_t refcount;
};

static inline void kref_init(struct kref *kref)
{
        atomic_set(&kref->refcount, 1);
}

static inline void kref_get(struct kref *kref)
{
        /* If refcount was 0 before incrementing then
         * we have a race condition when this kref is
         * freeing by some other thread right now.
         */
        WARN_ON_ONCE(atomic_inc_return(&kref->refcount)
                     < 2);
}
```

I realized that I was tired of auditing new driver submissions where people were hand rolling object reference counting, so I pulled the reference count out of struct kobject and put it into struct kref.

```
int kref_put(struct kref *kref,
             void (*release)(struct kref *kref))
{
        WARN_ON(release == NULL);
        WARN_ON(release ==
                (void (*)(struct kref *))kfree);

        if (atomic_dec_and_test(&kref->refcount)) {
                release(kref);
                return 1;
        }
        return 0;
}
```

Kernel programmers are lazy, protect them from themselves...

```
struct kobject {
        char name[KOBJ_NAME_LEN];
        struct kref kref;
        ...
};
```

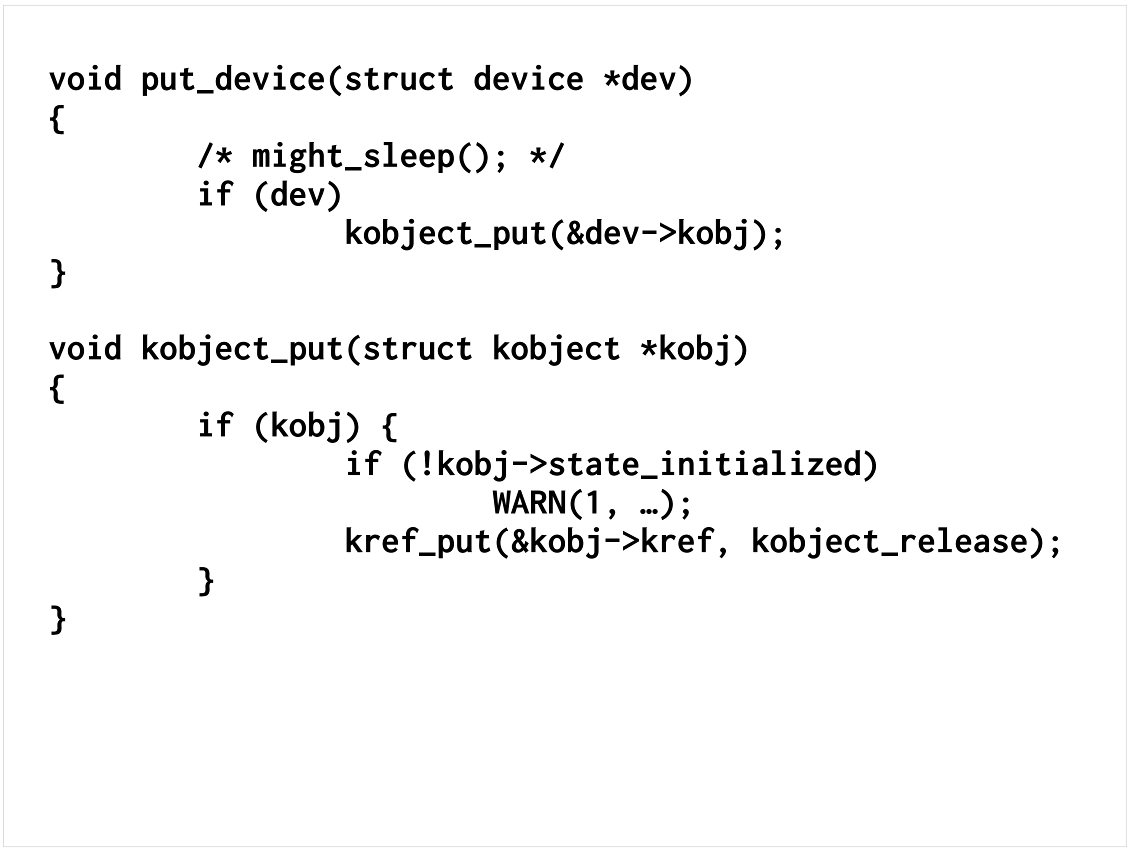
With the creation of struct kref , the struct kobject structure was changed to use it:

With all of these different structures embedded within other structures, the result is that the original struct usb_interface described earlier now contains a struct device , which contains a struct kobject , which contains a struct kref.

And who said it was hard to do object-oriented programming in the C language....

```
void put_device(struct device *dev)
{
    if (!atomic_dec_and_lock(&dev->refcount,&device_lock))
        return;

...

    /* Tell the driver to clean up after itself.
     * Note that we likely didn't allocate the device,
     * so this is the driver's chance to free that up...
     */
    if (dev->driver && dev->driver->remove)
        dev->driver->remove(dev, REMOVE_FREE_RESOURCES);
}
```

The original put_device()



```
void put_device(struct device *dev)
{
        /* might_sleep(); */
        if (dev)
                kobject_put(&dev->kobj);
}

void kobject_put(struct kobject *kobj)
{
        if (kobj) {
                if (!kobj->state_initialized)
                        WARN(1, …);
                kref_put(&kobj->kref, kobject_release);
        }
}
```

put_device() and kobject_put() today

What's wrong with this picture…

No lock!!!!

Bug has endured for over a decade. We got lucky, the device lock went away, but busses added/removed devices all sequentially.

Things get messy when you use kref() on your own.

Things are buggy if you use a kref on your own.

```
static inline int kref_put_mutex(struct kref *kref,
                       void (*release)(struct kref *kref),
                       struct mutex *lock)
{
        WARN_ON(release == NULL);

        if (!atomic_add_unless(&kref->refcount, -1, 1)) {
                mutex_lock(lock);
                if (!atomic_dec_and_test(&kref->refcount)) {
                        mutex_unlock(lock);
                        return 0;
                }
                release(kref);
                return 1;
        }
        return 0;
}
```

Behaves identical to kref_put with one exception. If the reference count drops to zero, the lock will be taken atomically wrt dropping the reference count.

Adds -1 to the reference count only if refcount was not already 1
If it succeeded (i.e. refcount was not 1) then the function returns 0

If it failed, then refcount was 1, it's now 0, so try to grab the lock.

After we grab the lock, we then try to decrement the reference count again to see if someone else incremented it before we got the lock. If we return 0, then someone else got here before we did, so unlock and return. If we don't return 0, then we were the last reference, so release the memory, and have the release function unlock the lock.

github.com/gregkh/presentation-kref

Obligatory Penguin Picture

[redacted]