Subsystems with object lifetime issues (in the embedded case)

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29.06.2023, EOSS 2023

Basics

Reference counting

Wikipedia definition

In computer science, reference counting is a programming technique of storing the number of references, pointers, or handles to a resource, such as an object, a block of memory, disk space, and others. ...
The main advantage of the reference counting ... is that objects are reclaimed as soon as they can no longer be referenced...

Done in the Kernel via

- `struct kref`[1]

[1] described in Documentation/core-api/kref.rst

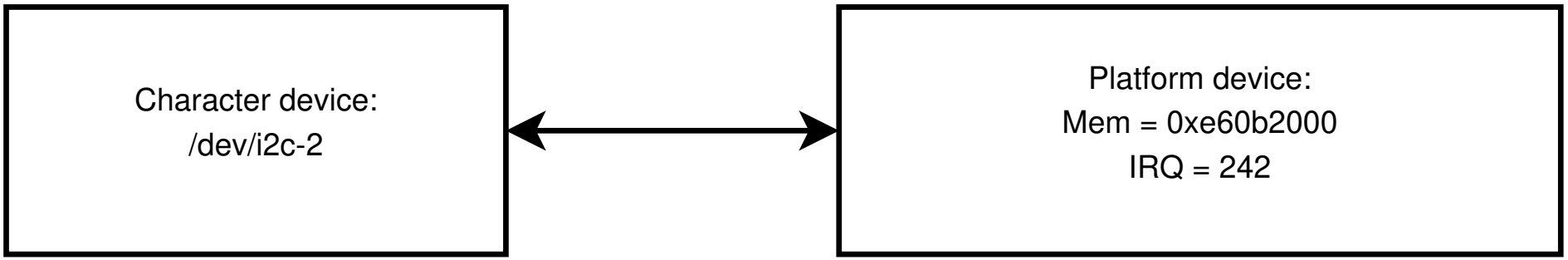
Now to the Linux driver model

`struct device` is the research element here!

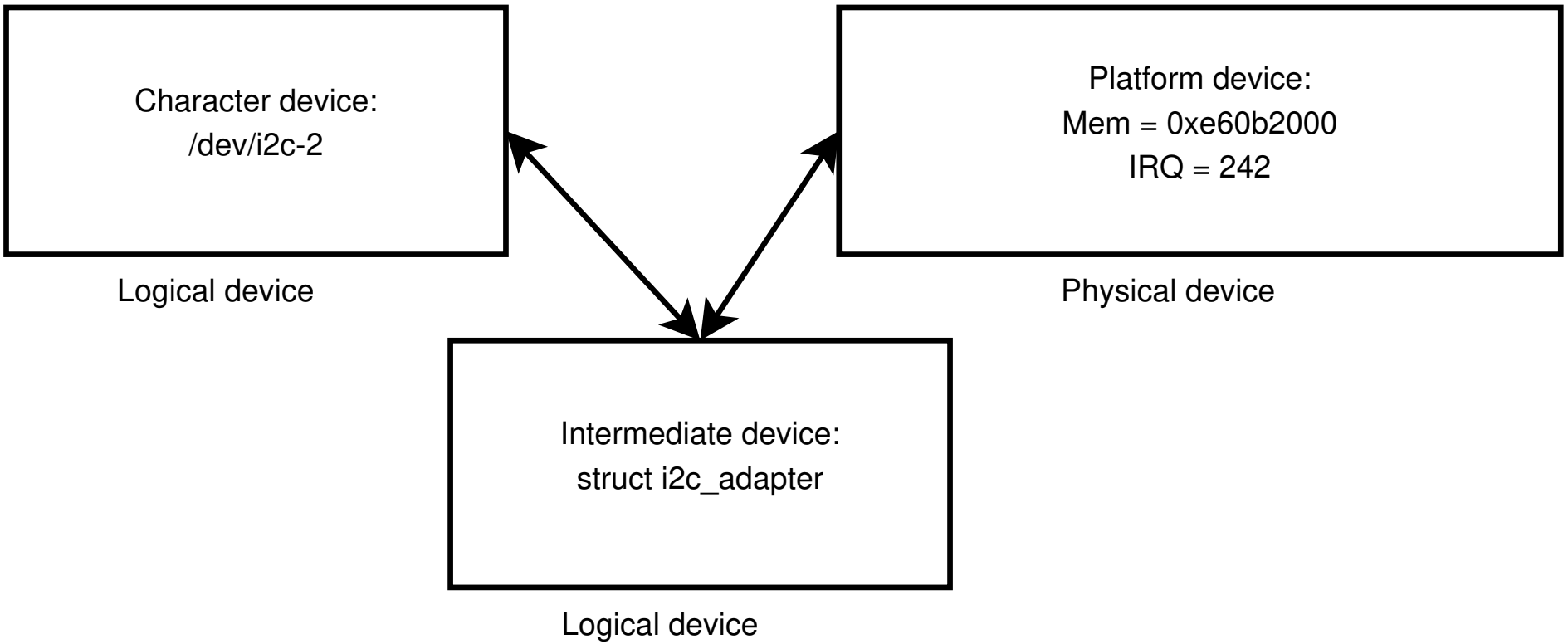
- embeds `struct kobject`[2] which embeds `struct kref`
- refcount is modified with `get_device` and `put_device`
- a `release` callback is used when refcount is 0

[2] described in Documentation/core-api/kobject.rst

Physical vs. logical device - simplified

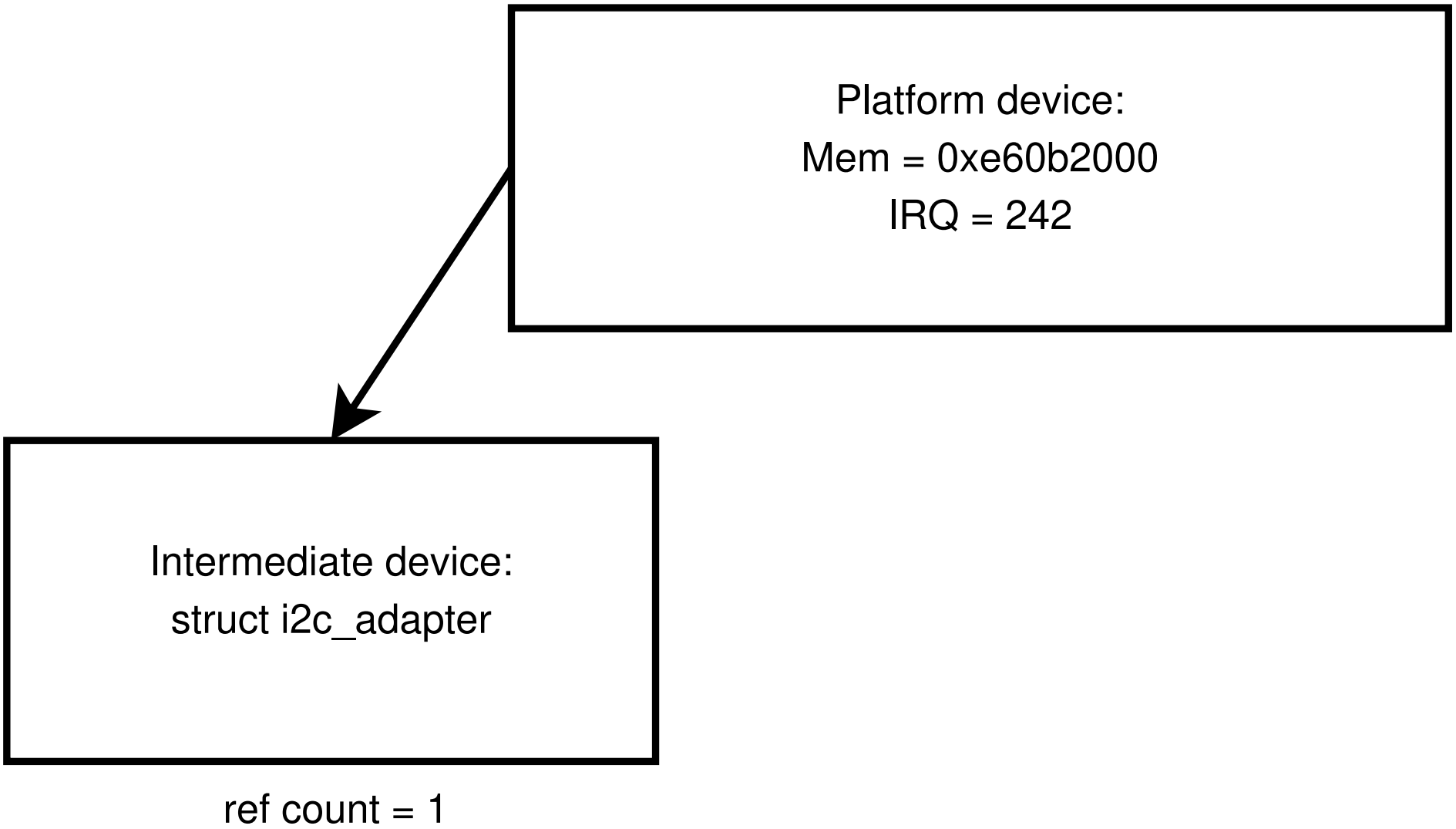


Physical vs. logical device - more realistic

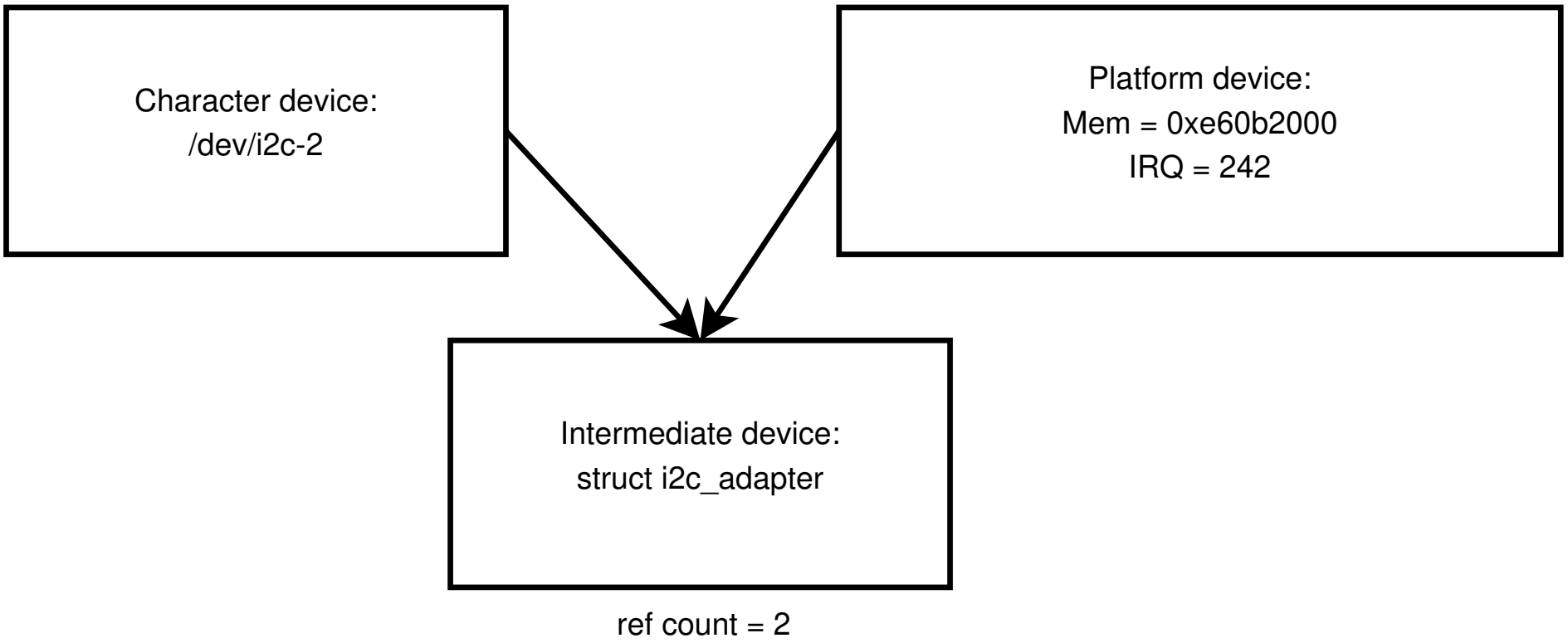


The actual problem

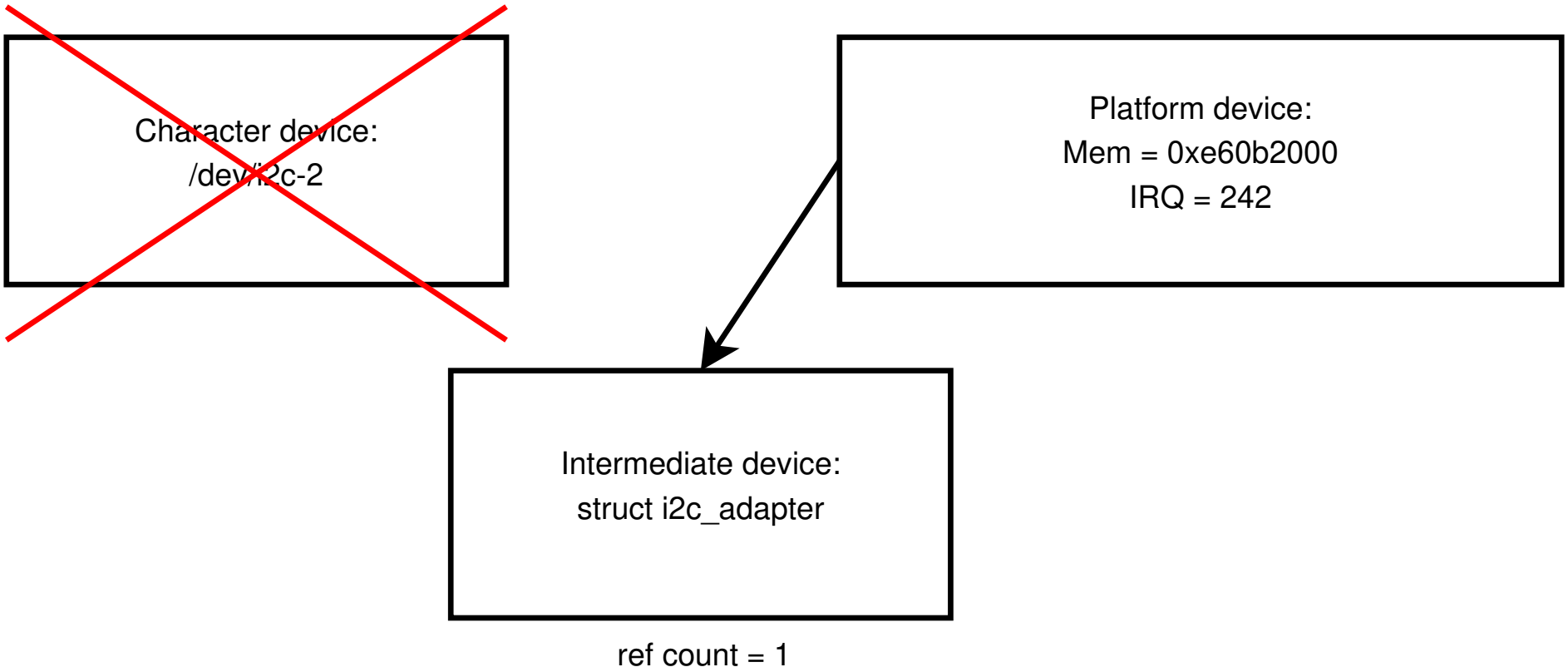
Good case - initialization during boot



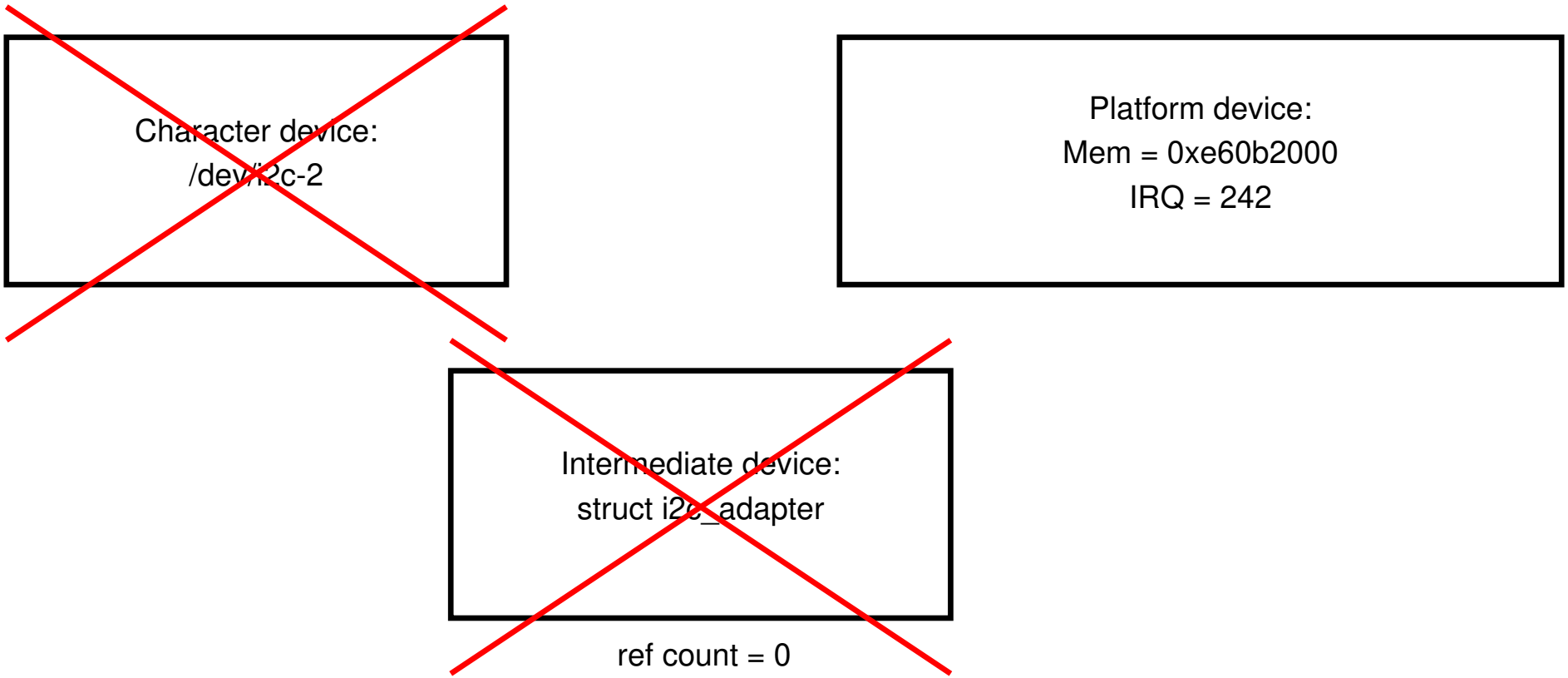
Good case - userspace open()



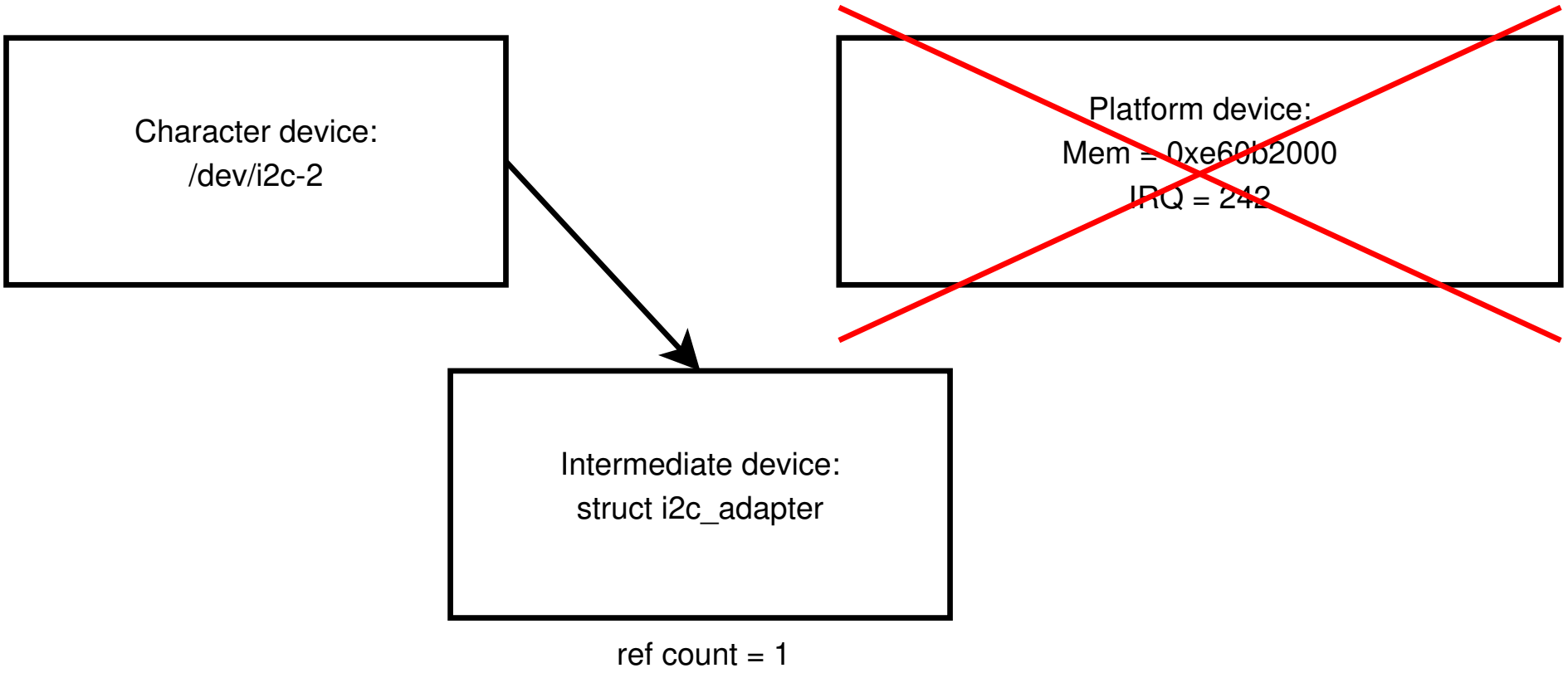
Good case - userspace close()



Good case - unbind/poweroff



Problematic case 1 - not the main case here



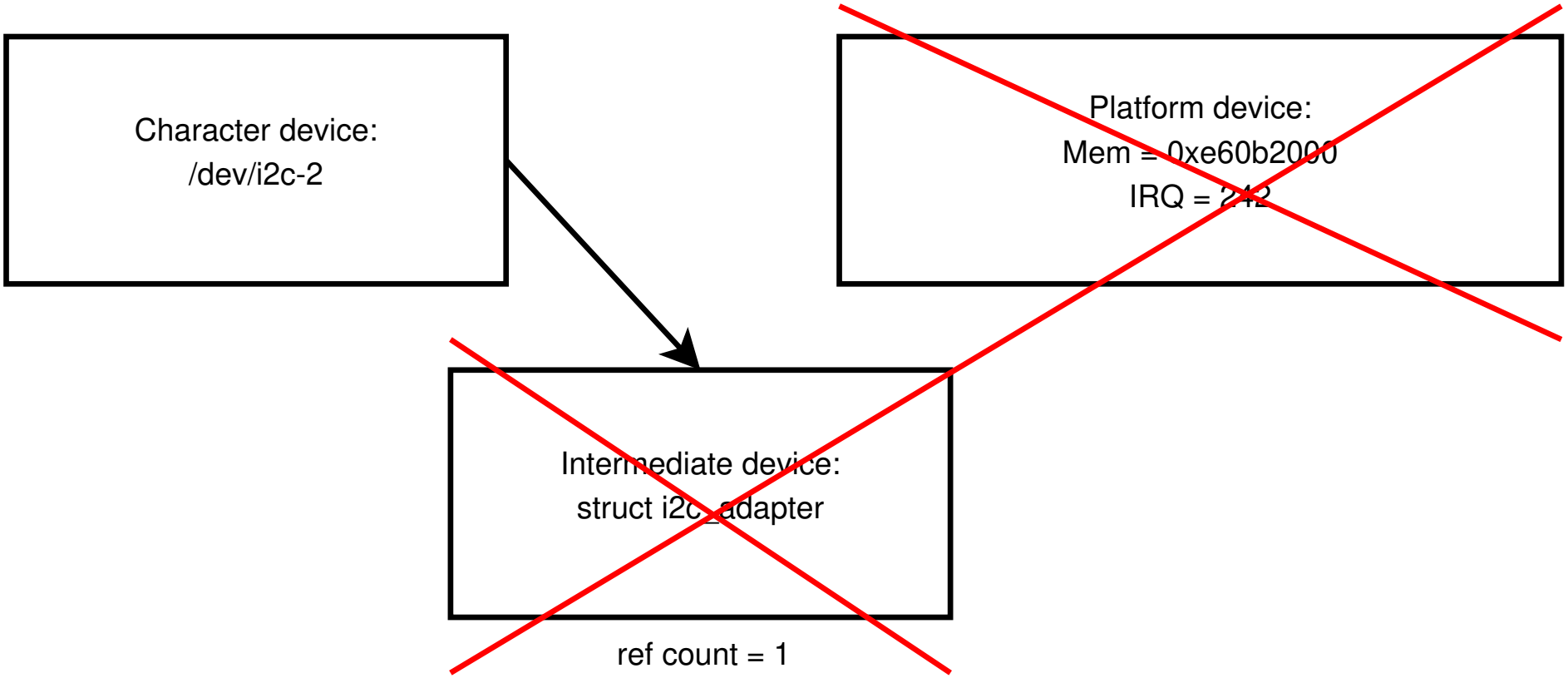
Dangerous construct! Mixes different lifetimes

```
struct rcar_i2c_priv {
        ...
        /* contains a struct device */
        struct i2c_adapter adap;
        ...
}


priv = devm_kzalloc(&pdev->dev, sizeof(*priv),
                    GFP_KERNEL);
...

ret = i2c_add_adapter(&priv->adap);
```

Problematic case 2 - this is the main case



Needs protection from the subsystem!

especially with `devm_kzalloc` (but this makes problems detectable)

My research questions

Which subsystems use structs with embedded kobjects[3] and allow allocation with `devm_kzalloc`?

- coccinelle to the rescue!
- only scanned for `struct device` instead of all kobjects to limit the search space
- found ~630 structs embedding a `struct device`, either directly or indirectly
- each struct was then scanned for allocation with `devm_kzalloc`

And how does it protect against a too early release of the embedded kobject?

- needs manual inspection

[3] like I2C uses `i2c_adapter` embedding a `struct device`

Results

I have good news and bad news

Good news

- less subsystems than I guessed are affected

I have good news and bad news

Good news

- less subsystems than I guessed are affected

Bad news

- every subsystem that was found I have issues with

Live Demo: Good case: UART

Live Demo: MTD

Results: MTD

- `struct spi_nor` embeds `struct mtd_info` which embeds `struct device`
- crashes when unbinding while `mtdXro` is opened
- no protection mechanism found
- but this comment in mtdcore.c from March 2009

```
/* REVISIT once MTD uses the driver model better, whoever allocates
 * the mtd_info will probably want to use the release() hook...
 */
```

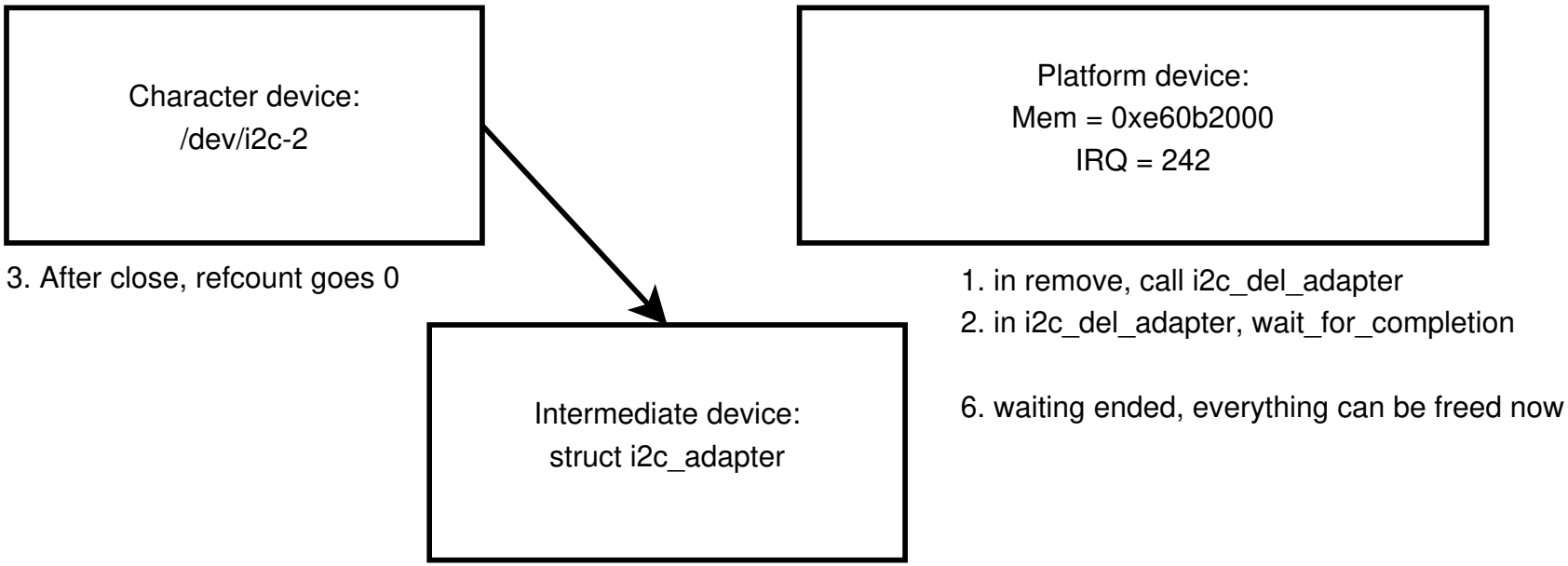
Live Demo: I2C

Results: I2C

- `struct i2c_adapter` embeds `struct device`
- blocks uninterruptible when unbinding while `i2c-X` is opened
- `i2c_del_adapter` waits until all references are gone using a `struct completion` with the release function of the logical device
- also has a comment from January 2015

```
/* wait until all references to the device are gone
 *
 * FIXME: This is old code and should ideally be replaced by an
 * alternative which results in decoupling the lifetime of the struct
 * device from the i2c_adapter, like spi or netdev do. Any solution
 * should be thoroughly tested with DEBUG_KOBJECT_RELEASE enabled!
 */
```

How does this completion work?



Results: I3C

- `struct i3c_master_controller` embeds `struct device`
- can't test because no HW
- there may be some protection, not fully understood yet
- but for backwards compatibility, it also embeds `struct i2c_adapter`
- and uses `i2c_del_adapter` to remove it
- so it also uses a completion when unbinding

  Sorry!

Results: NTB

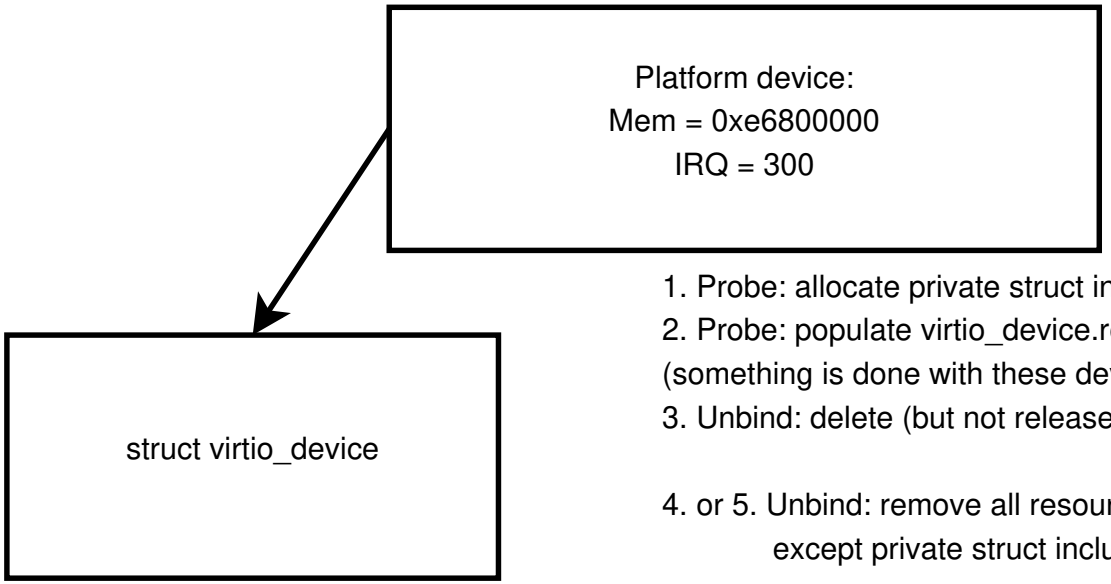
- `struct ntb_dev` embeds `struct device`
- can't test because no HW
- review reveals it also uses a completion when unbinding

Live Demo: VIRTIO

Results: VIRTIO

- `virtio_device` embeds `struct device`
- forces all drivers to use the release callback
- one driver gets it wrong with devres
- fails when enabling CONFIG_DEBUG_KOBJECT_RELEASE

How does this release callback work?

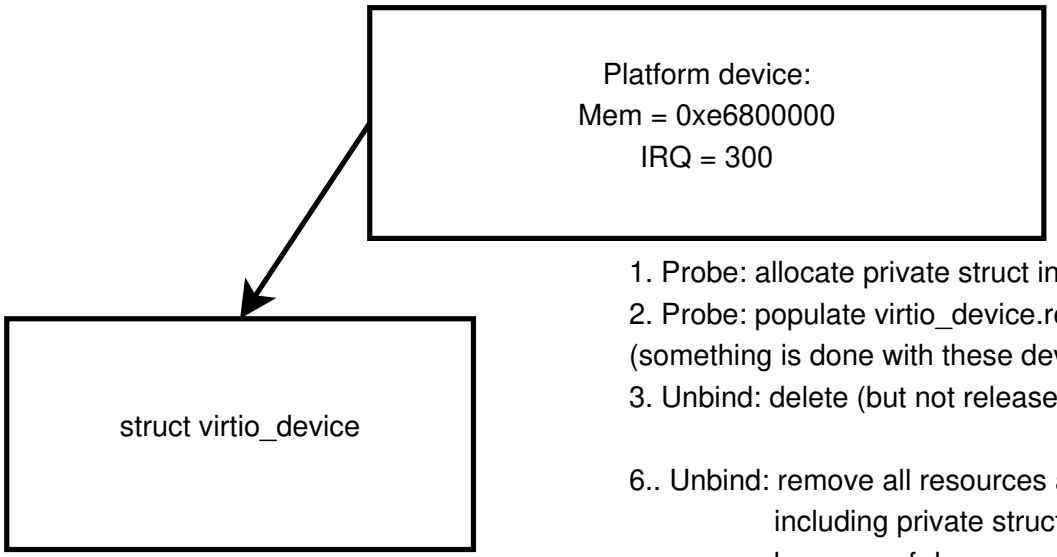


4. or 5. call release, private struct

1. Probe: allocate private struct including a virtio_device with kzalloc
2. Probe: populate virtio_device.release with a callback calling kfree
(something is done with these devices)
3. Unbind: delete (but not release) virtio_device, refcount goes 0

4. or 5. Unbind: remove all resources attached to the platform_device
except private struct including the virtio_device

Why did this one driver fail?



1. Probe: allocate private struct including a virtio_device with devm_kzalloc
2. Probe: populate virtio_device.release with a callback calling devm_kfree
(something is done with these devices)
3. Unbind: delete (but not release) virtio_device, refcount goes 0

6.. Unbind: remove all resources attached to the platform_device
including private struct including the virtio_device
because of devres

4. refcount is 0, release will be called
5. actually calling release will be delayed by
CONFIG_DEBUG_KOBJECT_RELEASE

7. try to call release but the device and its
release function are gone
8. OOPS

I don't like this approach

It was tried multiple times to get it right:

```
edfd52e63672 ("virtio: Add platform bus driver for memory mapped virtio device")
cecdbdc3771e ("virtio_mmio: Set dev.release() to avoid warning")
7eb781b1bbb7 ("virtio_mmio: add cleanup for virtio_mmio_probe")
c2e90800aef2 ("virtio_mmio: fix devm cleanup")
```

And it was still not correct until a few ~~hours~~ minutes ago[4].

Don't let drivers handle the lifetime of objects outside their scope!

Bartosz formulated the same opinion in this talk.

[4] The fix is here

Results: Auxiliary bus

- also expects drivers to populate the release callback
- at least extensively documented[5]
- still `pmic_glink.c` got it likely wrong (can't test no HW)
- but the other drivers do it right

Or? Let's check this driver.

[5] include/linux/auxiliary_bus.h

Sketch of a better API?

```
gp_aux_data->region_start = pci_resource_start(pdev, 0);
gp_aux_data->region_end = pci_resource_end(pdev, 0);

aux_dev = auxiliary_device_alloc(&pdev->dev, gp_aux_data);
aux_dev->name = aux_dev_otp_e2p_name;
aux_dev->id = ida_alloc(&gp_client_ida, GFP_KERNEL);

/* And if you still do something special */
aux_dev->release = my_release_func;

aux_dev_register(aux_bus, aux_dev);
```

Results: USB Gadget

- `struct usb_gadget` embeds `struct device`
- also expects drivers to populate the release callback
- on unbind, it blocks like a completion but because of `cancel_work_sync`
- combinations of `devm_kzalloc` and release callback exist
- I was not able to trigger a problem so far, though
- USB is usually good, but I will investigate more

Conclusion

Summary

- we do have different kinds of life cycle problems in the Kernel
- including really long lasting ones
- `devm_kzalloc` is not directly responsible for the ones researched here
- `devm_kzalloc` makes it here easier to fall into the trap

Further research activities for this type of problem

- repeat the above search but for `kzalloc` with accompanying `kfree` in `remove` of the physical device (instead of the `release` callback in the logical device)
- scan for embedded `struct kobject` not only `struct device`
- scan for empty release functions
- ...

Potential solutions

- There seems to be an agreement that pushing responsibility to drivers is not the way to go
- garbage collector??
  Nobody likes it
- `__cleanup__` + kref as suggested by Bartosz?
  Paradigm shift, probably looong way to go
- Layers using devices should keep responsibility for them.
  Convert faulty subsystems to `*_alloc` and `*_register`
  My favourite solution because it also creates consistency among subsystems.

In any case, this is a **lot** of work!

Reminder: more lifecycle issues exist

- character devices interaction with platform devices
- dependency hell between devices
  I heard V4L2 knows about this...
- existing protections work mostly but still have race conditions
  At least with character devices, but at least a prototype solution exists
- ...

Our safety process for lifecycle issues in drivers

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If an issue regarding lifecycles of objects in Linux device drivers is discovered, the process is:

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If an issue regarding lifecycles of objects in Linux device drivers is discovered, the process is:

- **add it to the list of already known lifecycle problems.**

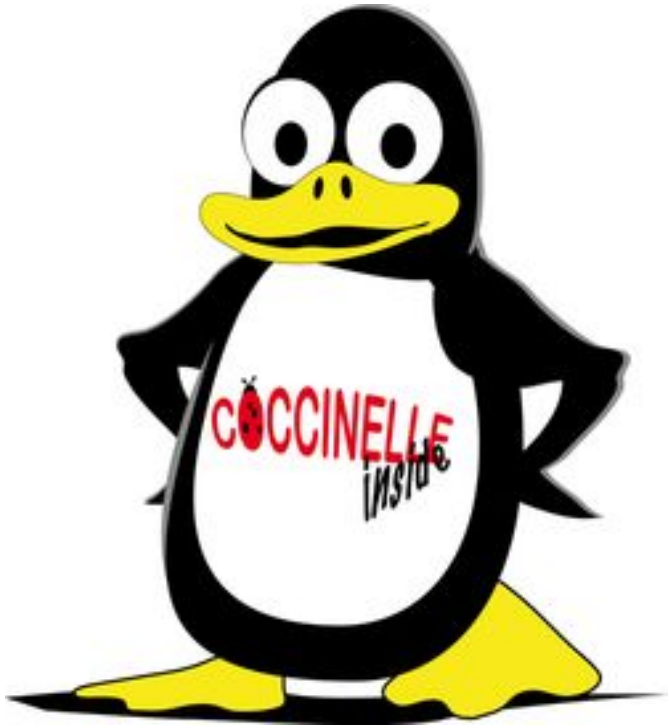
It is agreed that fixing these issues would be great. But nobody does it because there be dragons and it simply is a lot of annoying work.

The future

- Frankly? Not bright.
- I think these problems are not “raising spirits”, so I guess we see some of the FIXME comments above still in 10 years
- First step is to raise interest, so funding will be availabe to wok on lifecycle issues consistently. I’ll try.
- Until then, I will slowly start fixing the I2C subsystem, at least.
- At least, I fixed VIRTIO for this talk :)

Thank you for supporting this!

Thank you for coccinelle!



The End

Questions? Comments?

Questions?

- Right here, right now...
- At the conference
- wsa@kernel.org