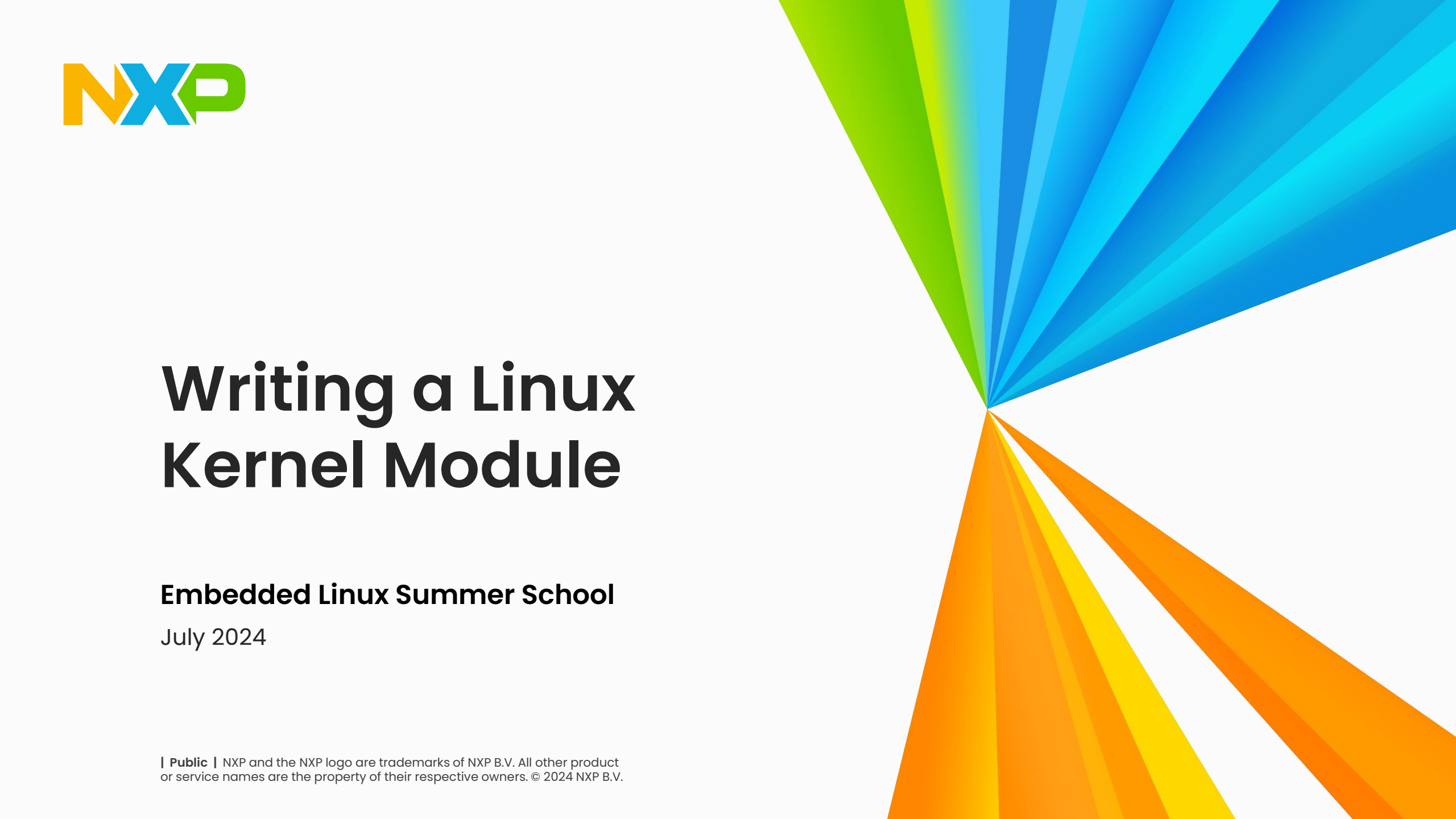

Writing a Linux Kernel Module

Embedded Linux Summer School

July 2024

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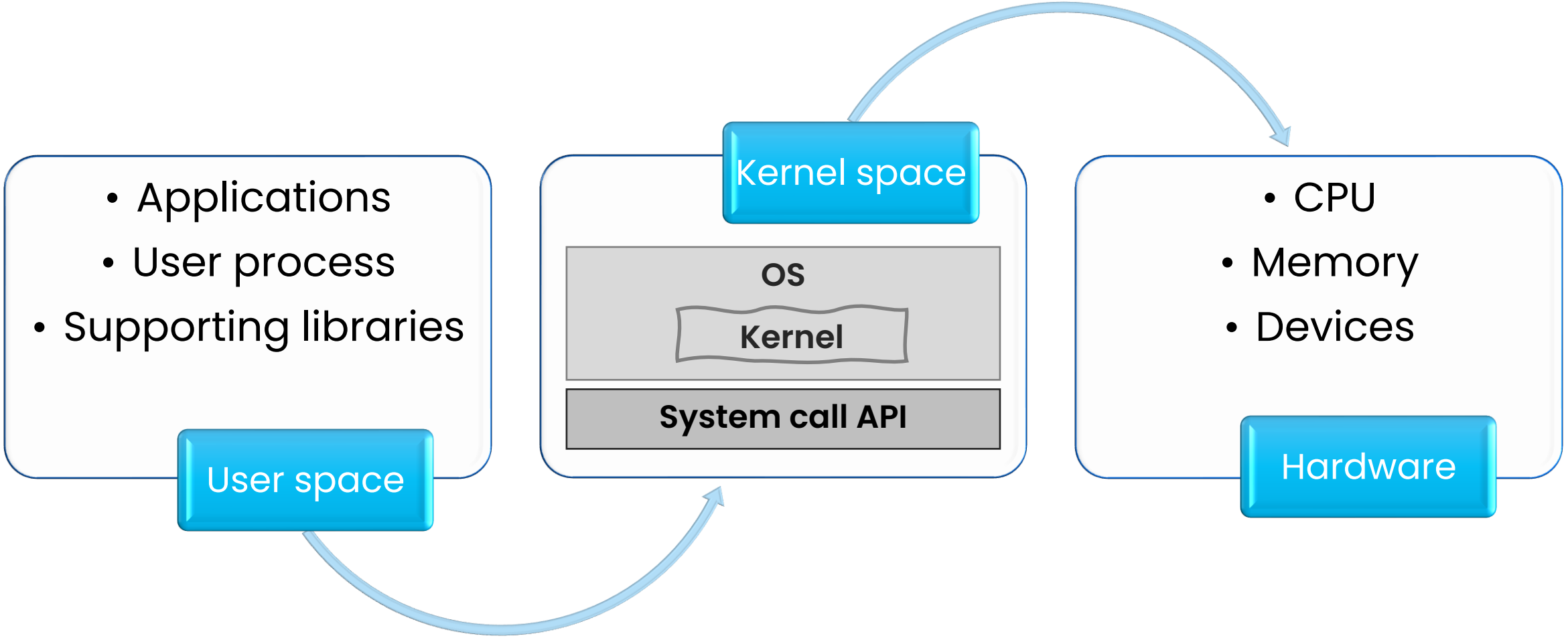
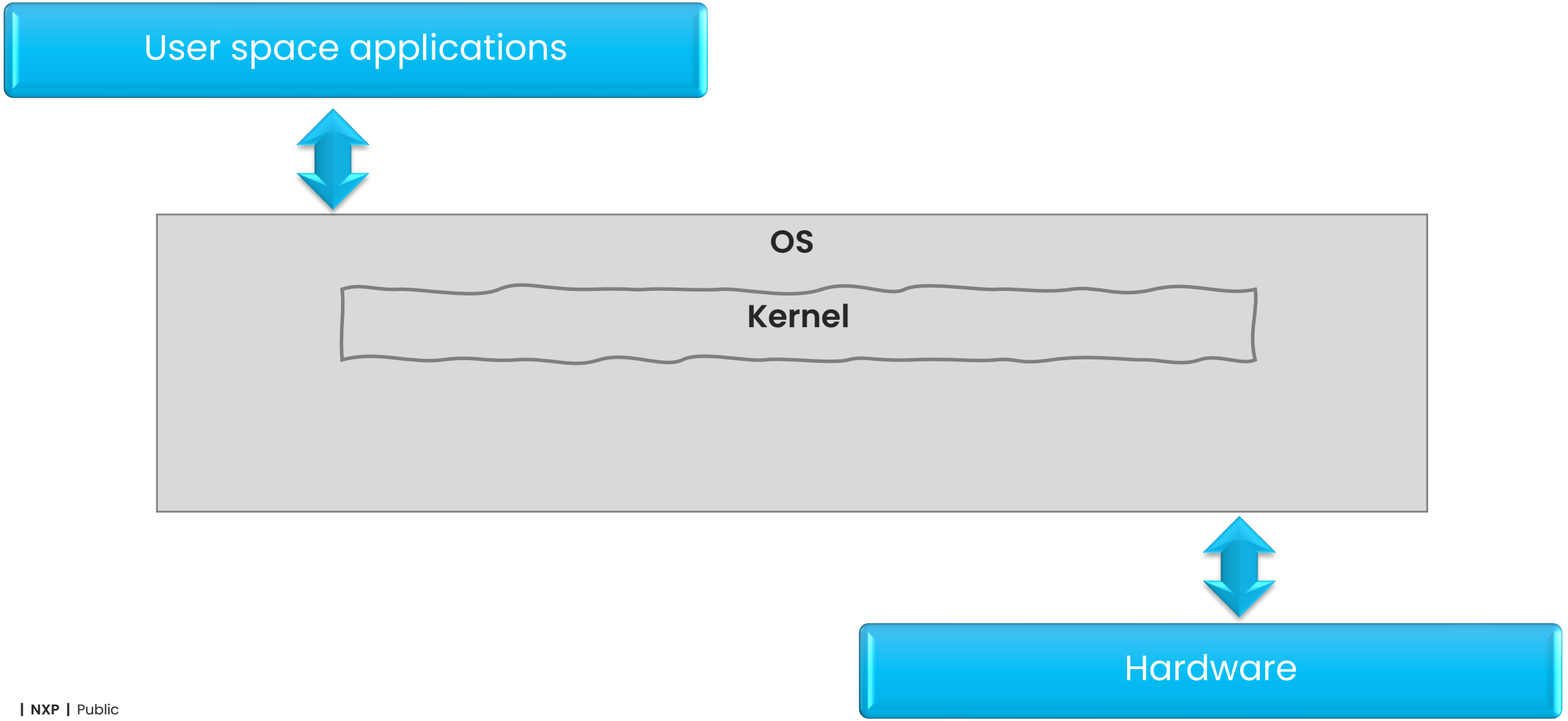
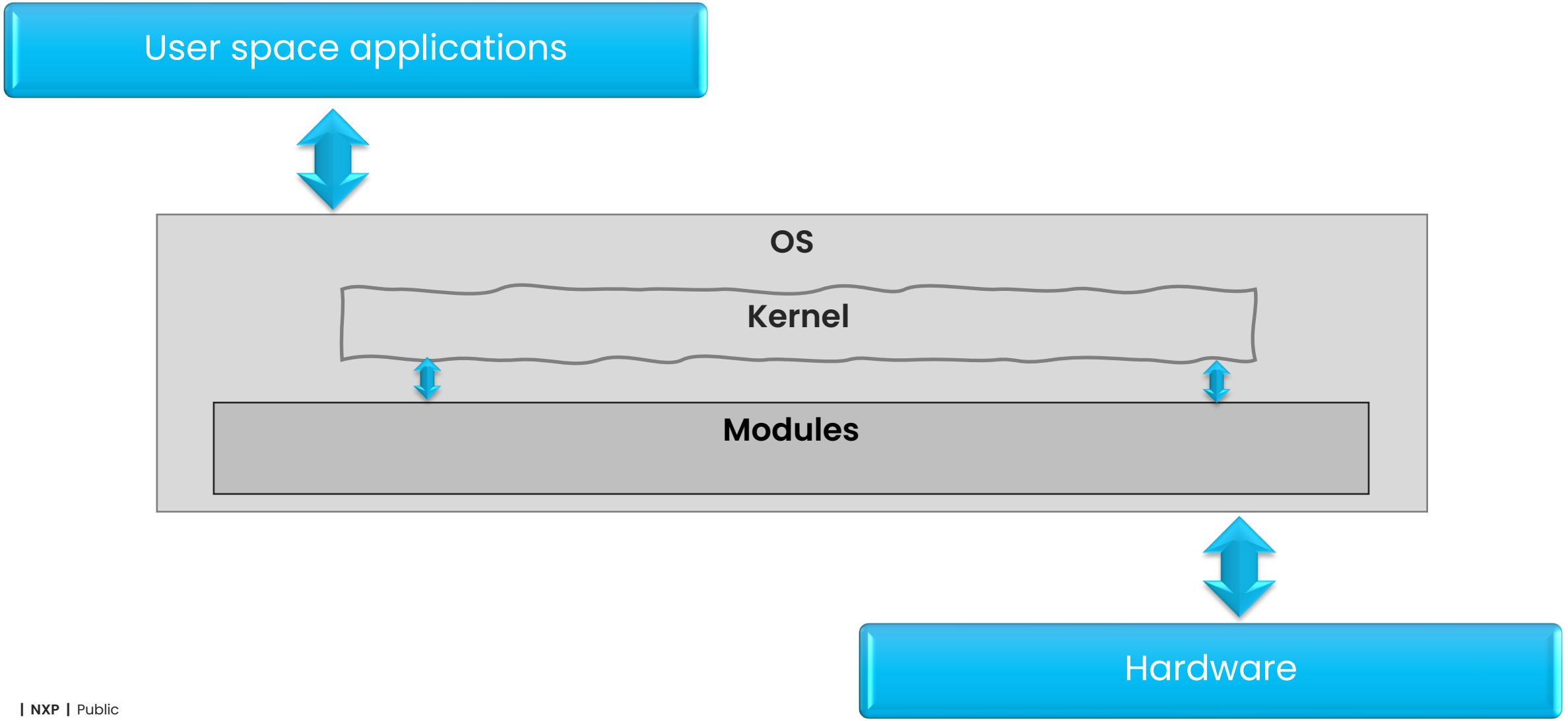
Kernel space vs User space



Kernel space vs User space

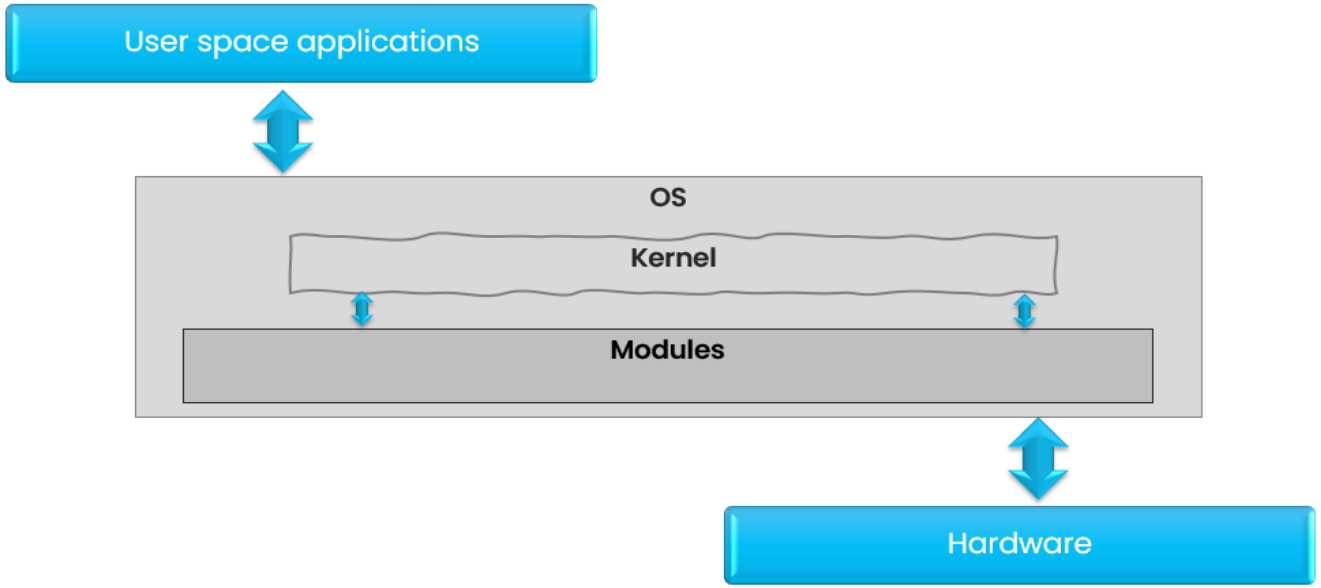


Kernel space vs User space



What is a Linux Kernel Module?

- Code that executes as part of the Linux kernel
  - Pieces of code that can be loaded and unloaded into the kernel upon demand
- Extends the capabilities and sometimes might modify the behavior of the kernel
- Without modules, one would have to build monolithic kernels and add new functionality directly into the kernel image
- Besides having larger kernels, this has the disadvantage of requiring us to rebuild and reboot the kernel every time we want new functionality



Anatomy of a Kernel Module

- Several typical components:
  - MODULE_AUTHOR("Jane Doe")
  - MODULE_LICENSE("GPL")
    - The license **must** be an open-source license (GPL,BSD, etc.) or you will "taint" your kernel

- `int init_module(void)`
  - Called when the kernel loads the module
  - Initialize all stuff here
  - Return 0 if all went well, negative if something wrong

- `void cleanup_module(void)`
  - Called when the kernel unloads the module
  - Free all resources here

Compiling a Kernel Module

- Accompany the kernel module with a 1-line GNU Makefile:

  `obj-m += hello.o`

  - Assumes file name is “hello.c”
- Run the magic make command:

  `make -C <kernel-src> M=`pwd` modules`

  - Produces: hello.ko

  - Assumes current directory is the module source

Kernel Module utilities

- lsmod - Show all loaded modules
- insmod - Insert a Module (excludes dependencies)

  `$sudo insmod <module_name>`
- modprobe - Load the kernel module plus any module dependencies

  `$sudo modprobe <module_name>`
- modinfo - Show information about a module

  `$modinfo <module_name>`
- depmod - Build module dependency database

  `$/lib/modules/$(uname -r)/modules.dep`
- rmmod - Remove a module

  `$rmmod <module_name>`
- Show the log

  `$dmesg` or `$cat /var/log/syslog`

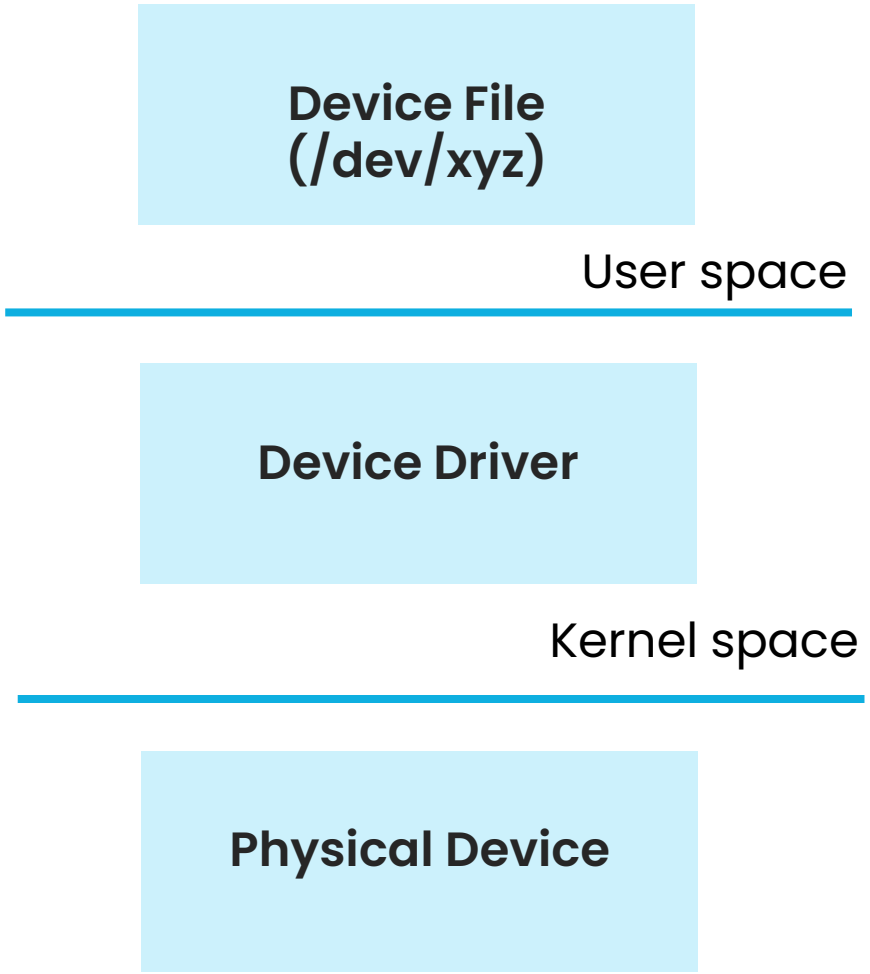
printk

- Log at kernel
- 8 priority levels (see: include/linux/kern_levels.h)
  - KERN_EMERG 0 system is unusable
  - KERN_ALERT 1 action must be taken immediately
  - KERN_CRIT 2 critical conditions
  - KERN_ERR 3 error conditions
  - KERN_WARNING 4 warning conditions
  - KERN_NOTICE 5 normal but significant condition
  - KERN_INFO 6 informational
  - KERN_DEBUG 7 debug-level messages
- `cat /proc/sys/kernel/printk`

Device drivers vs device files

- Everything is a file or a directory
- Every device is represented by a file in `/dev/`
- Device Driver: Kernel Module that controls a device
- Device File:
  - Interface for the Device Driver to
    - read from or write to a physical device
  - Also known as Device Nodes
  - Created with `mknod` system call

```
mknod [name] <c/b> <major> <minor>
```



Device files

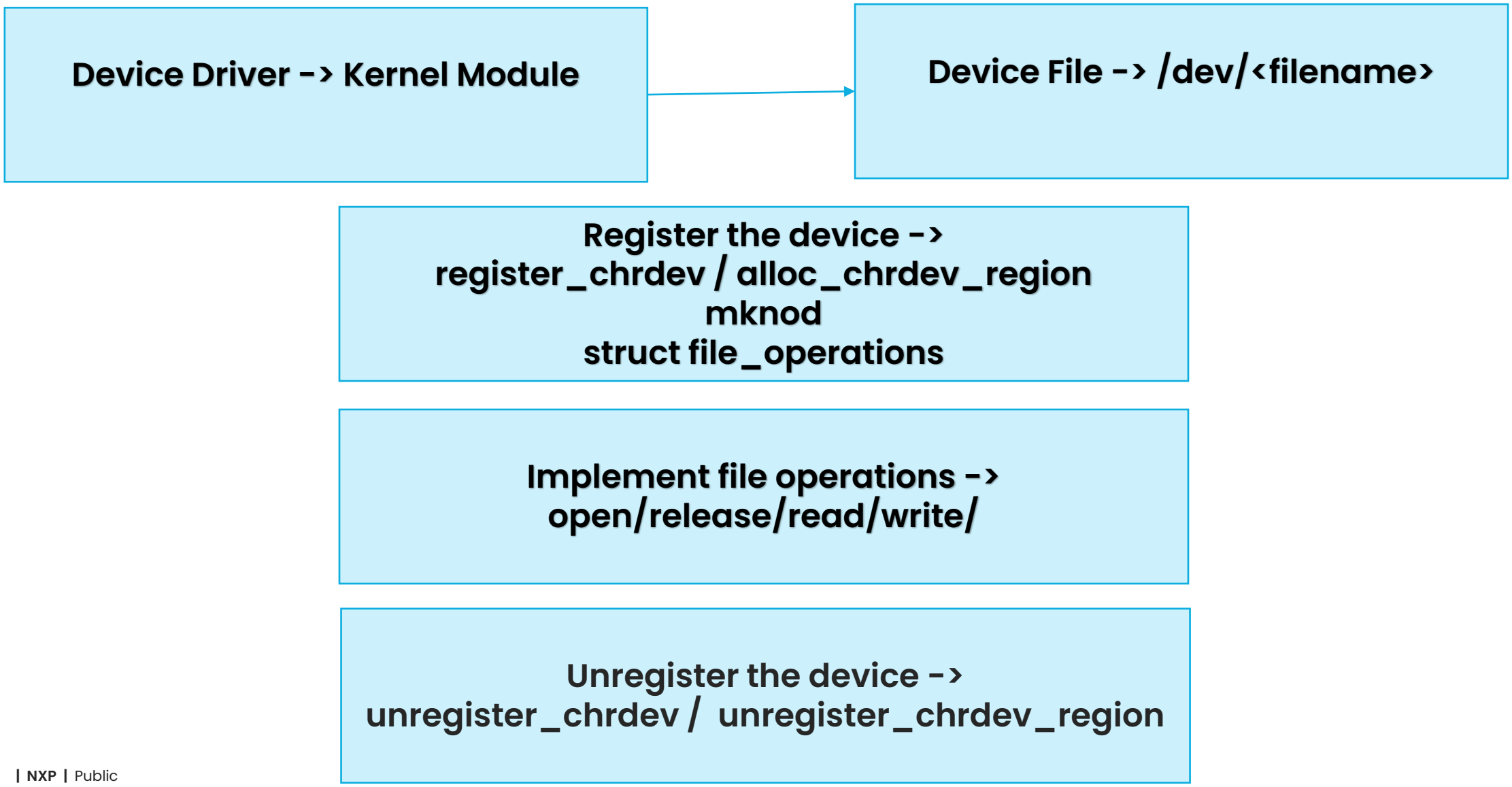
- Character device
  - Stream of data one character at a time
  - No restriction on number of bytes
- Block device
  - Random access to block of data
  - Can buffer and schedule the requests

```
$ ls -l /dev/
...
crw-------   1 root root     10,  60 Dec 15  2023 cpu_dma_latency
crw-------   1 root root     10, 203 Dec 15  2023 cuse
brw-rw----   1 root disk    253,   0 Dec 15  2023 dm-0
brw-rw----   1 root disk    253,   1 Dec 15  2023 dm-1
```

- Internally the kernel identifies each device by a triplet of information
  - Type - character or block
  - Major number - typically the category of devices
  - Minor number - typically the identifier of the device

```
crw-rw-rw- 1 root   root    1, 3   Feb 23 1999  null
crw------- 1 root   root   10, 1   Feb 23 1999  psaux
crw------- 1 rubini tty     4, 1   Aug 16 22:22 tty1
crw-rw-rw- 1 root   dialout 4, 64  Jun 30 11:19 ttyS0
crw-rw-rw- 1 root   dialout 4, 65  Aug 16 00:00 ttyS1
crw------- 1 root   sys     7, 1   Feb 23 1999  vcs1
crw------- 1 root   sys     7, 129 Feb 23 1999  vcsa1
crw-rw-rw- 1 root   root    1, 5   Feb 23 1999  zero
```

Character device driver implementation



Register device numbers

- `#include <linux/fs.h>`
- `int alloc_chrdev_region(dev_t *dev, unsigned baseminor, unsigned count, const char *name)`
  - Allocates a range of char device numbers. The major number will be chosen dynamically, and returned (along with the first minor number) in @dev
- Registered devices are visible in /proc/devices:

```
$ cat /dev/devices
```

```
Character devices:
  1 mem
  2 pty
  3 ttyp
  4 /dev/vc/0
  4 tty
 10 misc
...
```

```
Block devices:
  7 loop
  8 sd
 31 mtdblock
 65 sd
 66 sd
 67 sd
 68 sd
...
```

Character device registration

- `#include <linux/cdev.h>`
- `static struct cdev char_cdev;`

- `void cdev_init(struct cdev *cdev, struct file_operations *fops);`

- `int cdev_add(struct cdev *p, dev_t dev, unsigned count);`

- The kernel knows the association between the major/minor numbers and the file operations.
  - Device is ready to be used

Character device unregistration

- `#include <linux/cdev.h>`
- `void cdev_del(struct cdev *p);`

- `void unregister_chrdev_region(dev_t from, unsigned count);`

Reading / Writing from character device

`$ cat /dev/imx8mq_chardev`

- calls `read()` function

- `unsigned long copy_to_user (void __user * to, const void * from, unsigned long n);`

`$ echo "hello" > /dev/imx8mq_chardev`

- calls `write()` function

- `unsigned long copy_from_user (void * to, const void __user * from, unsigned long n);`

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