Block device drivers

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Document sources, updates and translations:
http://free-electrons.com/docs/block-drivers
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Block devices

- After character devices and network devices, block devices are another important device type of any system
- Used for the storage of application code and data, and user data, they are often critical to the overall performance of the system
- A dedicated subsystem, the *block layer* is in charge of managing the block devices, together with hardware specific device drivers
- This subsystem has been completely rewritten during the 2.5 development cycle. The API covered in these slides is the one found in 2.6.x kernels.

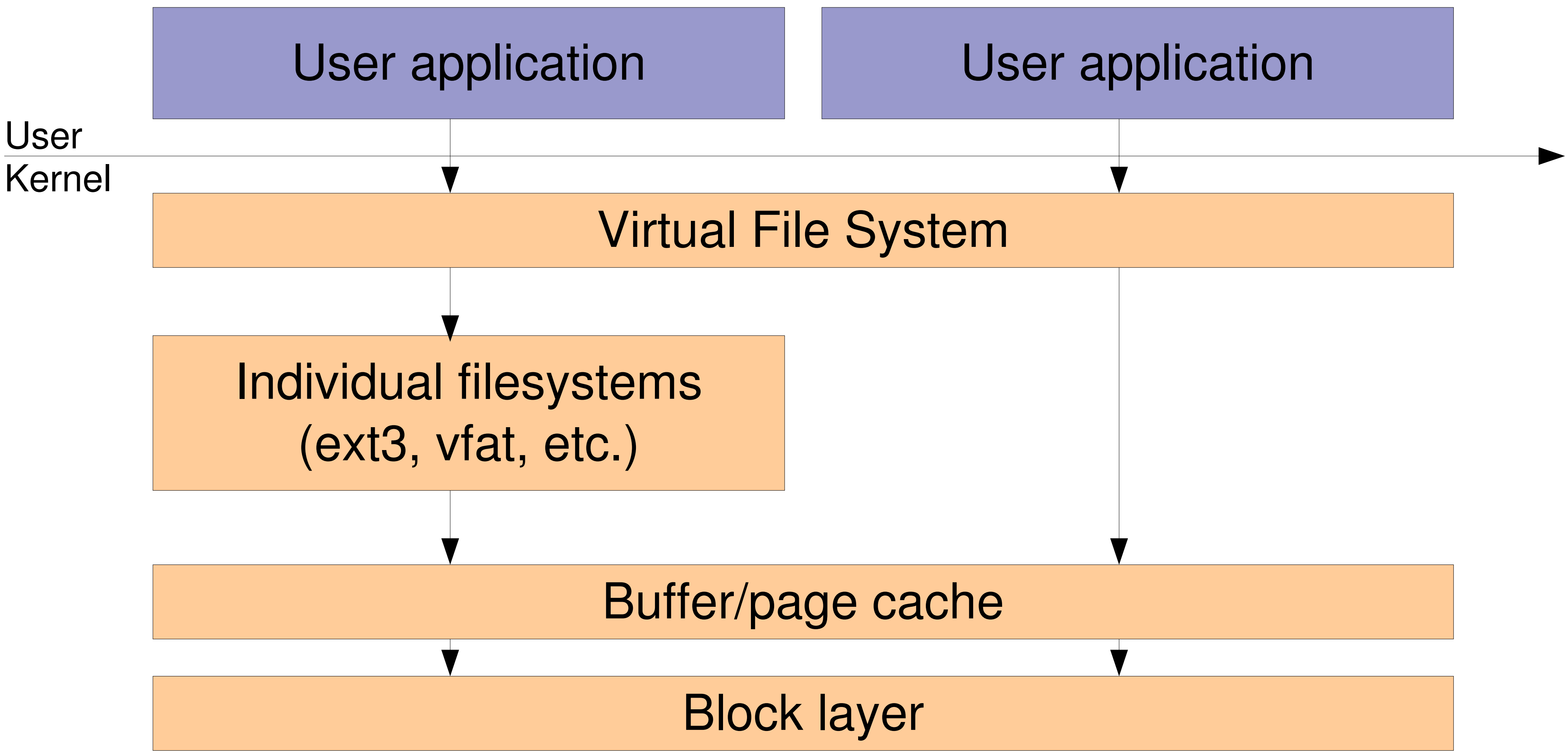
From userspace

- From userspace, block devices are accessed using device files, usually stored in `/dev/`
  - Created manually or dynamically by udev
- Most of the time, they store filesystems : they are not accessed directly, but rather *mounted*, so that the contents of the filesystem appears in the global hierarchy of files
- Block devices are also visible through the sysfs filesystem, in the `/sys/block/` directory

```
$ ls /sys/block/
dm-0   dm-2   loop0   loop2   ram0   ram2   ram4   ram6   sda
dm-1   dm-3   loop1   loop3   ram1   ram3   ram5   ram7
```

Global architecture

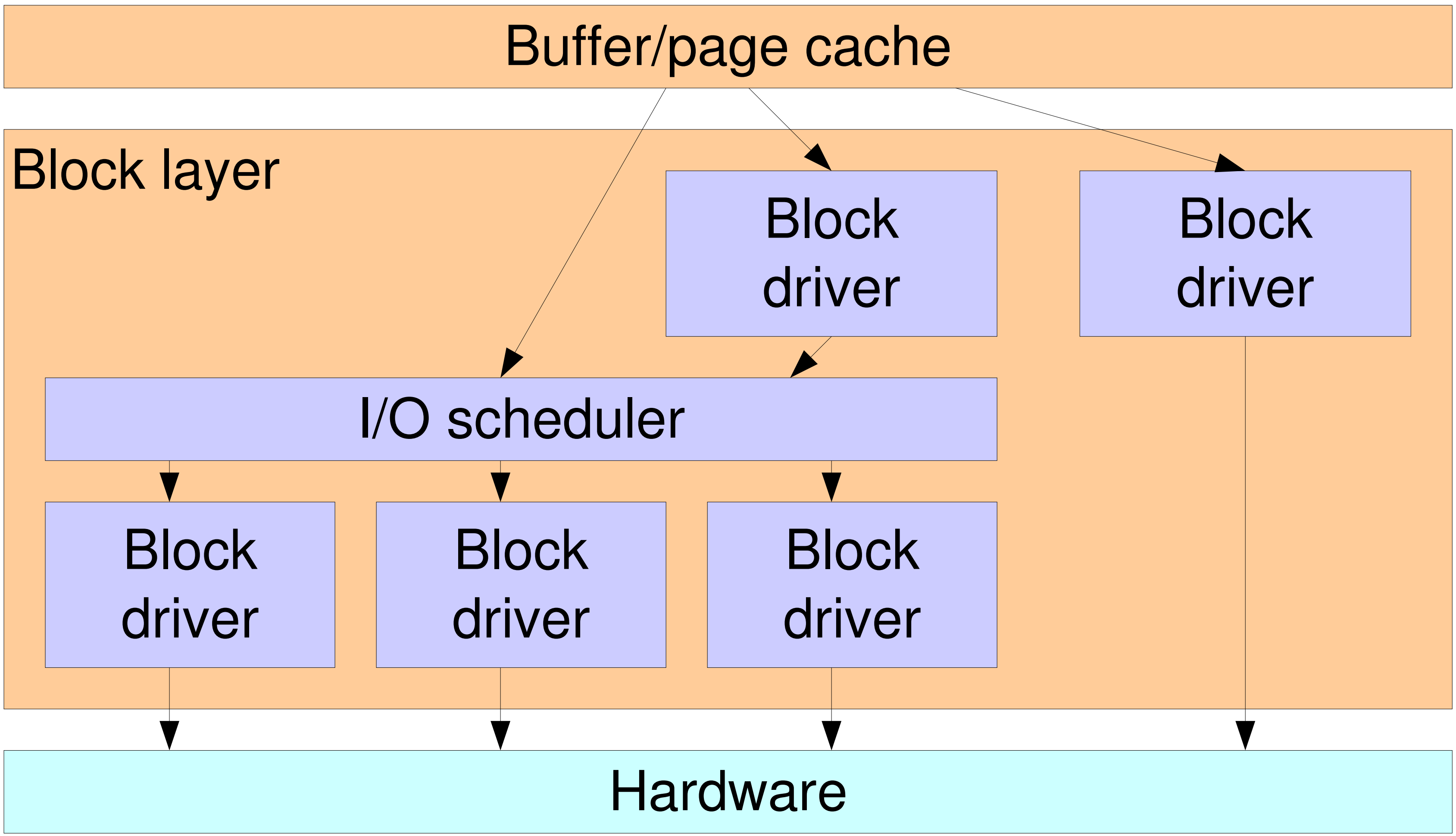
Nishil: very imp look into the steps flow to understand the driver flow.



Global architecture (2)

- An user application can use a block device
  - Through a filesystem, by reading, writing or mapping files
  - Directly, by reading, writing or mapping a device file representing a block device in `/dev`
- In both cases, the VFS subsystem in the kernel is the entry point for all accesses
  - A filesystem driver is involved if a normal file is being accessed
- The buffer/page cache of the kernel stores recently read and written portions of block devices
  - It is a critical component for the performance of the system

Inside the block layer



Inside the block layer (2)

- The *block layer* allows block device drivers to receive I/O requests, and is in charge of I/O scheduling
- I/O scheduling allows to
  - Merge requests so that they are of greater size
  - Re-order requests so that the disk head movement is as optimized as possible
- Several I/O schedulers with different policies are available in Linux.
- A block device driver can handle the requests before or after they go through the I/O scheduler

Two main types of drivers

- Most of the block device drivers are implemented below the I/O scheduler, to take advantage of the I/O scheduling
  - Hard disk drivers, CD-ROM drivers, etc.
- For some drivers however, it doesn't make sense to use the IO scheduler
  - RAID and volume manager, like md
  - The special loop driver
  - Memory-based block devices

Available I/O schedulers

- Four I/O schedulers in current kernels
  - Noop, for non-disk based block devices
  - Anticipatory, tries to anticipate what could be the next accesses
  - Deadline, tries to guarantee that an I/O will be served within a deadline
  - CFQ, the *Complete Fairness Queuing,* the default scheduler, tries to guarantee fairness between users of a block device
- The current scheduler for a device can be get and set in `/sys/block/<dev>/queue/scheduler`

Kernel options

- `CONFIG_BLOCK`
  - Allows to selectively enable or disable the block layer. A kernel without the block layer can be useful if using MTD devices, storage over the network, or a filesystem in initramfs
  - Only available if `CONFIG_EMBEDDED` is set
- `CONFIG_IOSCHED_NOOP`, `CONFIG_IOSCHED_AS`, `CONFIG_IOSCHED_DEADLINE`, `CONFIG_IOSCHED_CFQ`
  - Allows to enable or disable different I/O schedulers. They can be compiled as module, loaded and changed dynamically, on a per-device basis.

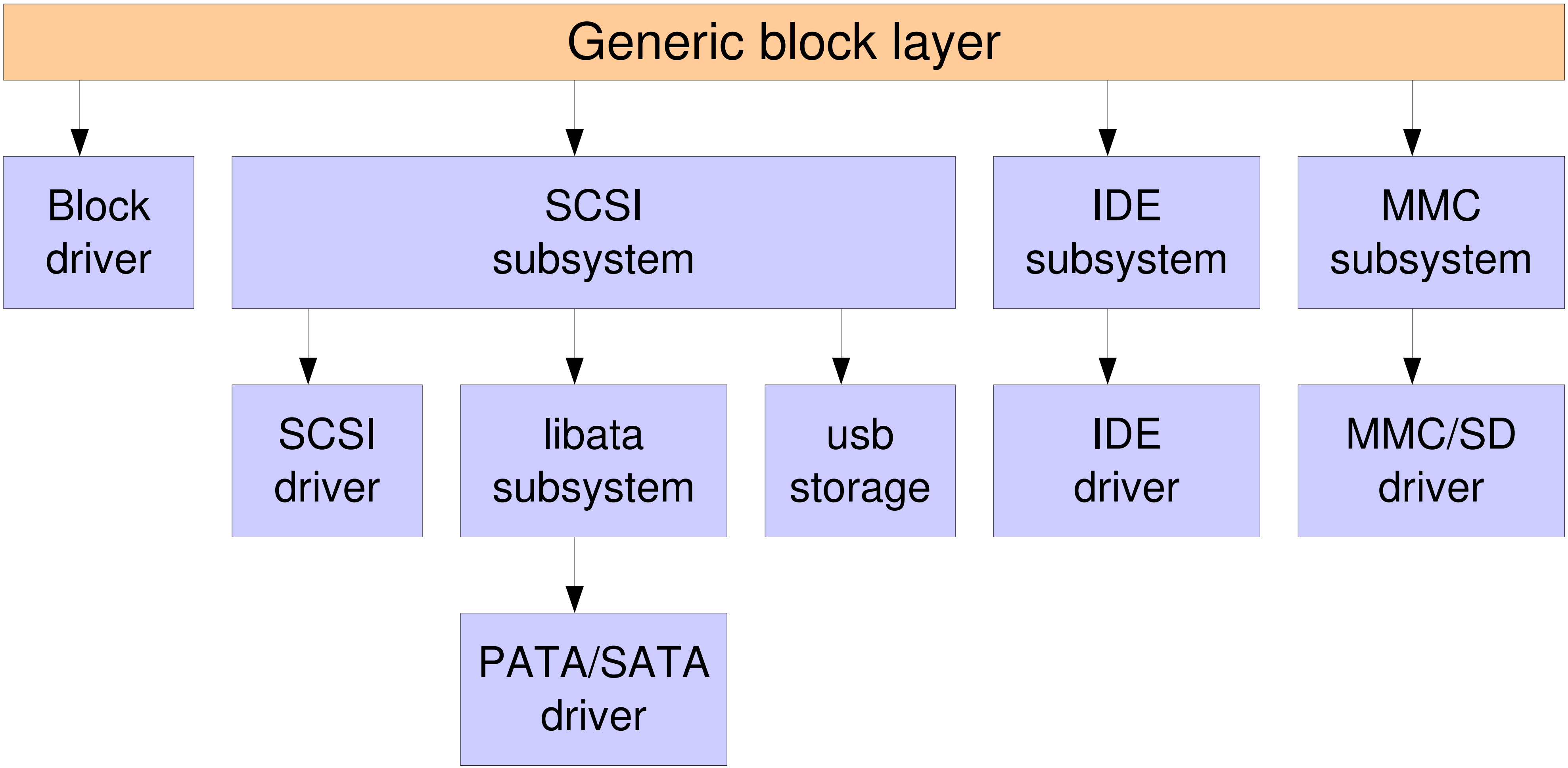
Looking at the code

- The block device layer is implemented in the `block/` directory of the kernel source tree.
  - This directory also contains the I/O scheduler code, in the `*-iosched.c` files.
- A few simple block device drivers are implemented in `drivers/block/`, including
  - `loop.c`, the loop driver that allows to see a regular file as a block device
  - `brd.c`, a ramdisk driver
  - `nbd.c`, a network-based block device driver

Implementing a block device driver

- A block device driver must implement a set of operations to be registered in the *block layer* and receive requests from the kernel
- A block device driver can directly implement this set of operation. However, as in many areas in the kernel, subsystems have been created to factorize common code of drivers for devices of the same type
  - SCSI devices
  - PATA/SATA devices
  - MMC/SD devices
  - etc.

Implementing a block device driver (2)



Registering the major

- The first step in the initialization of a block device driver is the registration of the major number
  - ```
    int register_blkdev(unsigned int major,
                        const char *name);
    ```
  - Major can be 0, in which case it is dynamically allocated
  - Once registered, the driver appears in /proc/devices with the other block device drivers
- Of course, at cleanup time, the major must be unregistered
  - ```
    void unregister_blkdev(unsigned int major, const
    char *name);
    ```
- The prototypes of these functions are in <linux/fs.h>

struct gendisk

- The structure representing a single block device, defined in `<linux/genhd.h>`
  - `int major`, major of the device driver
  - `int first_minor`, minor of this device. A block device can have several minors when it is partitionned
  - `int minors`, number of minors. 1 for non-partitionable devices
  - `struct block_device_operations *fops`, pointer to the list of block device operations
  - `struct request_queue *queue`, the queue of requests
  - `sector_t capacity`, size of the block device in sectors

Initializing a disk

- **Allocate a gendisk structure**

  ```
  struct gendisk *alloc_disk(int minors)
  ```

  `minors` tells the number of minors to be allocated for this disk. Usually 1, unless your device can be partitionned

- **Allocate a request queue**

  ```
  struct request_queue *blk_init_queue
                (request_fn_proc *rfn, spinlock_t *lock)
  ```

  `rfn` is the request function (covered later). `lock` is a optional spinlock needed to protect the request queue against concurrent access. If `NULL`, a default spinlock is used

Initializing a disk (2)

- **Initialize the gendisk structure**
  Fields `major`, `first_minor`, `fops`, `disk_name` and `queue` should at the minimum be initialized
  `private_data` can be used to store a pointer to some private information for the disk
- **Set the capacity**
  `void set_capacity(struct gendisk *disk, sector_t size)`

  The size is a number of 512-bytes sectors. `sector_t` is 64 bits wide on 64 bits architectures, 32 bits on 32 bits architecture, unless `CONFIG_LBD` (large block devices) has been selected

Initializing a disk (3)

- **Add the disk to the system**

```
void add_disk(struct gendisk *disk);
```

The block device can now be accessed by the system, so the driver must be fully ready to handle I/O requests before calling `add_disk()`. I/O requests can even take place during the call to `add_disk()`.

Unregistering a disk

- **Unregister the disk**
  ```
  void del_gendisk(struct gendisk *gp);
  ```
- **Free the request queue**
  ```
  void blk_cleanup_queue(struct request_queue *);
  ```
- **Drop the reference taken in alloc_disk()**
  ```
  void put_disk(struct gendisk *disk);
  ```

block_device_operations

- A set of function pointers
  - `open()` and `release()`, called when a device handled by the driver is opened and closed
  - `ioctl()` for driver specific operations. `unlocked_ioctl()` is the non-BKL variant, and `compat_ioctl()` for 32 bits processes running on a 64 bits kernel
  - `direct_access()` required for XIP support, see http://lwn.net/Articles/135472/
  - `media_changed()` and `revalidate()` required for removable media support
  - `getgeo()`, to provide geometry informations to userspace

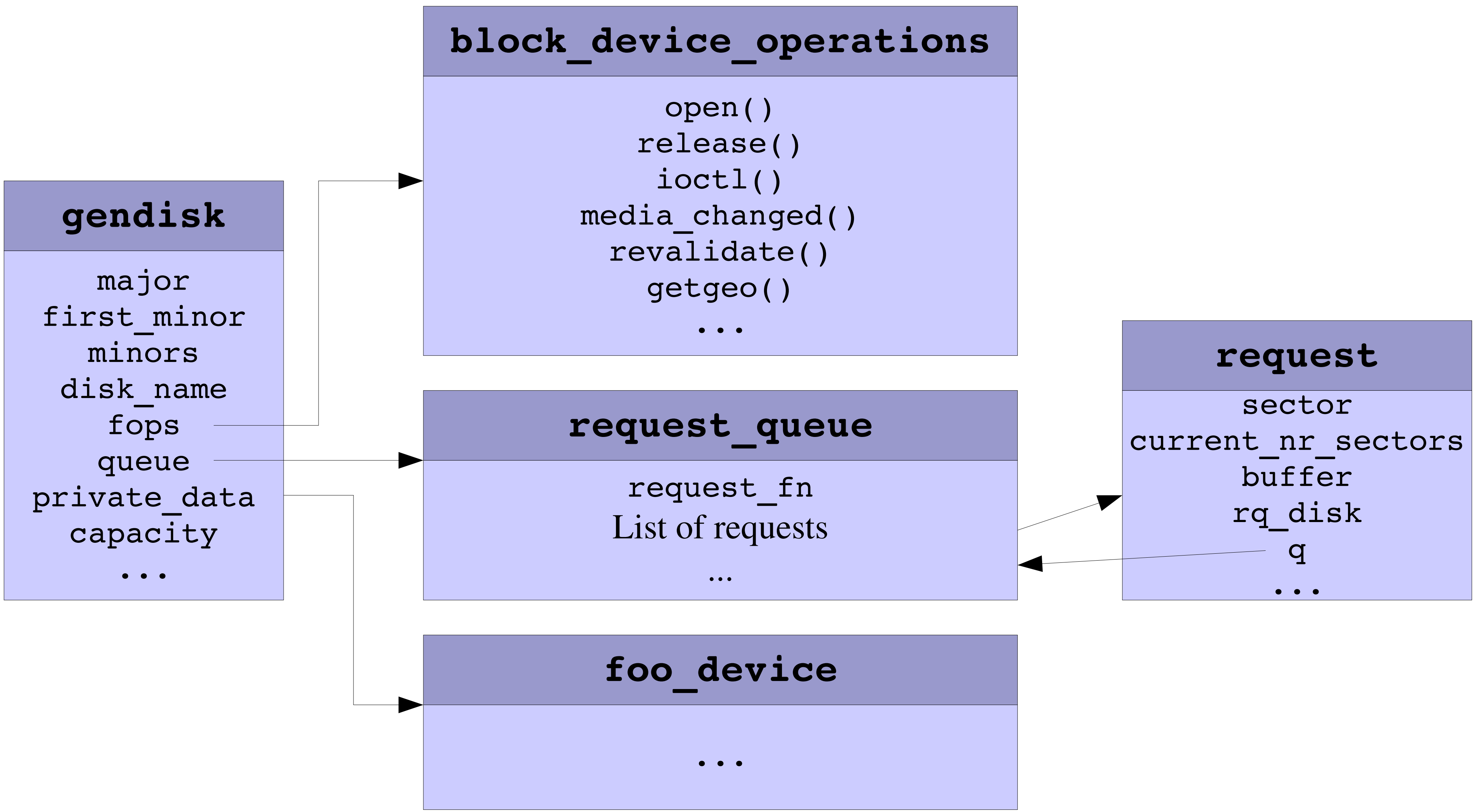
A simple request() function

```
static void foo_request(struct request_queue *q)
{
    struct request *req;
    while ((req = elv_next_request(q)) != NULL) {
        if (! blk_fs_request(req)) {
            __blk_end_request(req, 1, req->nr_sectors << 9);
            continue;
        }
        /* Do the transfer here */
        __blk_end_request(req, 0, req->nr_sectors << 9);
    }
}
```

A simple request() function (2)

- Information about the transfer are available in the `struct request`
  - `sector`, the position in the device at which the transfer should be made
  - `current_nr_sectors`, the number of sectors to transfer
  - `buffer`, the location in memory where the data should be read or written to
  - `rq_data_dir()`, the type of transfer, either READ or WRITE
- `__blk_end_request()` or `blk_end_request()` is used to notify the completion of a request. `__blk_end_request()` must be used when the queue lock is already held

Data structures in a nutshell



Request queue configuration (1)

- `blk_queue_bounce_limit(queue, u64)`
  Tells the kernel the highest physical address that the device can handle. Above that address, bouncing will be made. `BLK_BOUNCE_HIGH`, `BLK_BOUNCE_ISA` and `BLK_BOUNCE_ANY` are special values
  - HIGH: will bounce if the pages are in high-memory
  - ISA: will bounce if the pages are not in the ISA 16 Mb zone
  - ANY: will not bounce

Request queue configuration (2)

- `blk_queue_max_sectors(queue, unsigned int)`
  Tell the kernel the maximum number of 512 bytes sectors for each request.
- `blk_queue_max_phys_segments(queue, unsigned short)`
  `blk_queue_max_hw_segments(queue, unsigned short)`
  Tell the kernel the maximum number of non-memory-adjacent segments that the driver can handle in a single request (default 128).
- `blk_queue_max_segment_size(queue, unsigned int)`
  Tell the kernel how large a single request segment can be

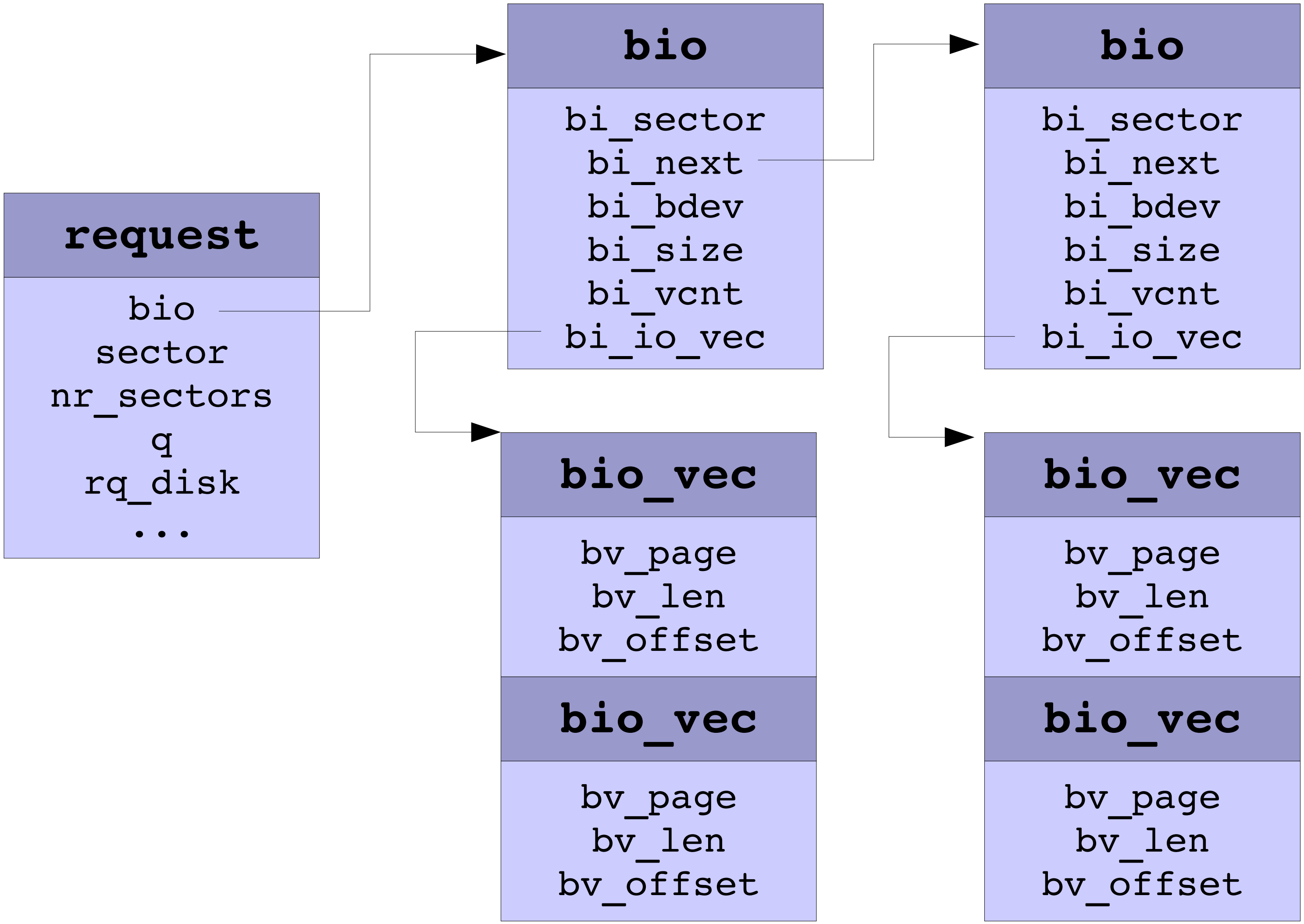
Request queue configuration (3)

- `blk_queue_segment_boundary(queue, unsigned long mask)`
  Tell the kernel about memory boundaries that your device cannot handle inside a given buffer. By default, no boundary.
- `blk_queue_dma_alignement(queue, int mask)`
  Tell the kernel about memory alignment constraints of your device. By default, 512 bytes alignment.
- `blk_queue_hardsect_size(queue, unsigned short max)`
  Tell the kernel about the sector size of your device. The requests will be aligned and a multiple of this size, but the communication is still in number of 512 bytes sectors.

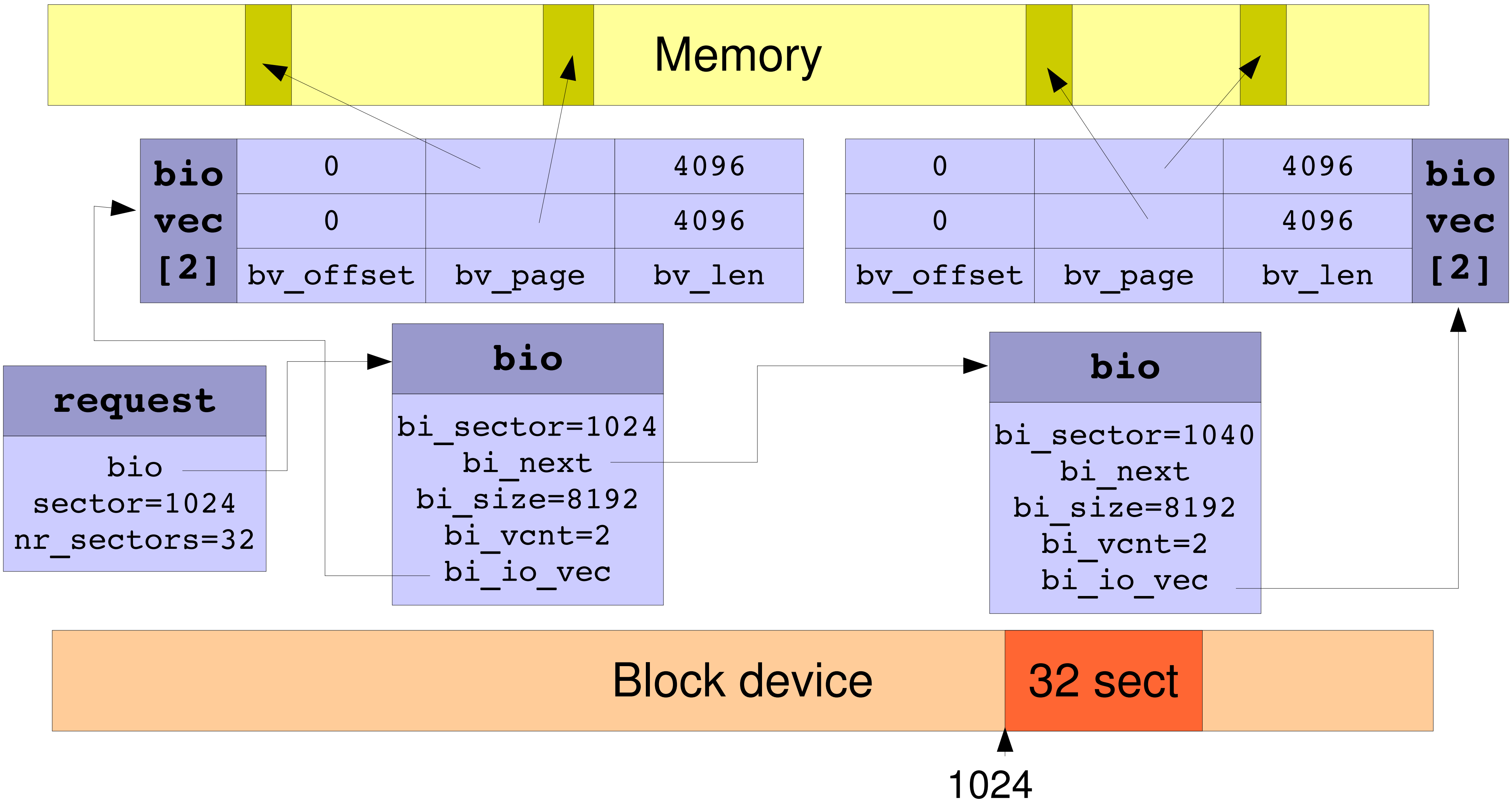
Inside a request

- A request is composed of several segments, that are contiguous on the block device, but not necessarily contiguous in physical memory
- A `struct request` is in fact a list of `struct bio`
- A `bio` is the descriptor of an I/O request submitted to the block layer. `bio`s are merged together in a `struct request` by the I/O scheduler.
- As a `bio` might represent several pages of data, it is composed of several `struct bio_vec`, each of them representing a page of memory

Inside a request (2)



Request example



Asynchronous operations

- If you handle several requests at the same time, which is often the case when handling them in asynchronous manner, you must dequeue the requests from the queue :
`void blkdev_dequeue_request(struct request *req);`

- If needed, you can also put a request back in the queue :
`void elv_requeue_request(struct request_queue *queue, struct request *req);`

Asynchronous operations (2)

- Once the request is outside the queue, it's the responsibility of the driver to process all segments of the request
- Either by looping until `blk_end_request()` returns 0
- Or by using the `rq_for_each_segment()` macro

```
struct bio_vec *bvec;
struct req_iterator iter;
rq_for_each_segment(bvec, rq, iter)
{
    /*  rq->sector contains the current sector
        page_address(bvec->bv_page) + bvec->bv_offset points to the data
        bvec->bv_len is the length */

    rq->sector += bvec->bv_len / KERNEL_SECTOR_SIZE;
}

blk_end_request(rq, 0, rq->nr_sectors << 9);
```

DMA

- The block layer provides an helper function to « convert » a request to a scatter-gather list :

```
int blk_rq_map_sg(struct request_queue *q,
                  struct request *rq,
                  struct scatterlist *sglist)
```

- `sglist` must be a pointer to an array of `struct scatterlist`, with enough entries to hold the maximum number of segments in a request. This number is specified at queue initialization using `blk_queue_max_hw_segments()`.
- The function returns the actual number of scatter gather list entries filled.

DMA (2)

- Once the scatterlist is generated, individual segments must be mapped at addresses suitable for DMA, using :

```
int dma_map_sg(struct device *dev,
               struct scatterlist *sglist,
               int count,
               enum dma_data_direction dir);
```

- `dev` is the device on which the DMA transfer will be made
- `dir` is the direction of the transfer (`DMA_TO_DEVICE`, `DMA_FROM_DEVICE`, `DMA_BIDIRECTIONAL`)
- The addresses and length of each segment can be found using `sg_dma_addr()` and `sg_dma_len()` on scatterlist entries.

DMA (3)

- After the DMA transfer completion, the segments must be unmapped, using

```
int dma_unmap_sg(struct device *dev,
                 struct scatterlist *sglist,
                 int hwcount,
                 enum dma_data_direction dir)
```

MMC / SD

Block layer

↓

MMC block device driver

`CONFIG_MMC_BLOCK`

`drivers/mmc/card/{block,queue}.c`

↓

MMC Core

`CONFIG_MMC`

`drivers/mmc/core/`

↓

MMC Host Driver

`CONFIG_MMC_...`

`drivers/mmc/host/...`

MMC host driver

- For each host
  - `struct mmc_host *mmc_alloc_host(int extra, struct device *dev)`
  - Initialize `struct mmc_host` fields: `caps`, `ops`, `max_phys_segs`, `max_hw_segs`, `max_blk_size`, `max_blk_count`, `max_req_size`
  - `int mmc_add_host(struct mmc_host *host)`
- At unregistration
  - `void mmc_remove_host(struct mmc_host *host)`
  - `void mmc_free_host(struct mmc_host *host)`

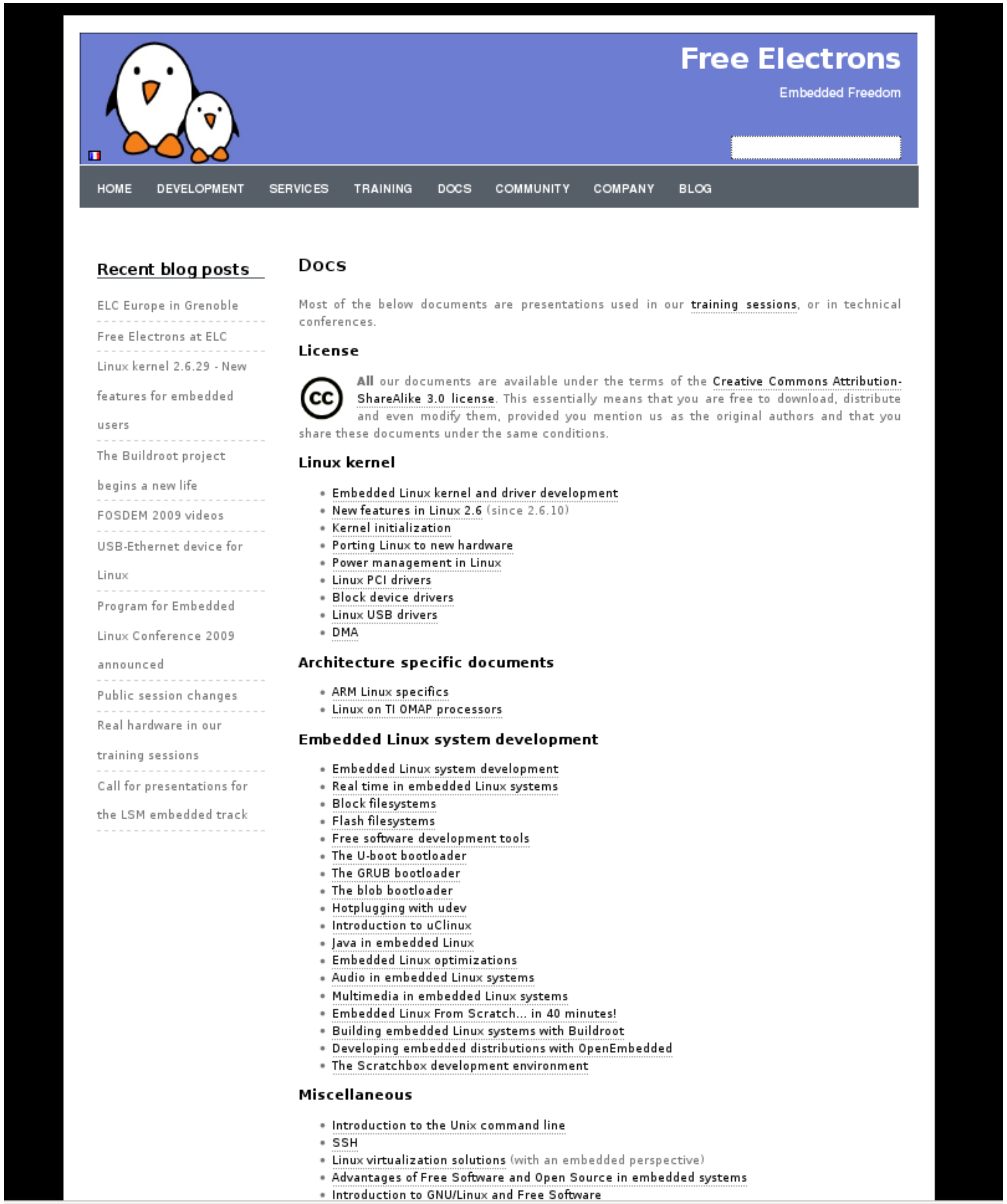
MMC host driver (2)

- The `mmc_host->ops` field points to a `mmc_host_ops` structure
  - Handle an I/O request
    ```
    void (*request)(struct mmc_host *host,
                    struct mmc_request *req);
    ```
  - Set configuration settings
    ```
    void (*set_ios)(struct mmc_host *host,
                    struct mmc_ios *ios);
    ```
  - Get read-only status
    ```
    int (*get_ro)(struct mmc_host *host);
    ```
  - Get the card presence status
    ```
    int (*get_cd)(struct mmc_host *host);
    ```

Time to start `Lab` !

- Register your block device
- Create your request handling function
- Make your request function asynchronous

Related documents



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