Unix Internals

Module 07

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Unix Internals, Module 07

- Device Drivers
- Streams

Device Drivers

- Device Drivers
  - Part of Kernel
  - Collection of Data structures & Functions
  - Only module that may interact with a device
- Benefits
  - Isolation of device specific code
  - Easy to add new devices
  - Devices can be developed without kernel code
  - Consistent view of devices to kernel (and hence to users)

Hardware Configuration

- Devices are connect thru Controllers (Adapters)
- A Controller may connect more than one device
  - Has "Control and Status Registers" for each device
  - Control Registers used to perform actions on devices
    - Repeatability of actions?
    - Value written might not be same as value read
  - Status registers used to get status
- Device Data Transfers
    - Programmed I/O
    - DMA
    - DVMA

Device Interrupts

- Devices use interrupts to get CPU attention
- Unix defines ipls (Interrupt Priority LevelS)
  - Ranges from zero (lowest) to above
  - Kernel/User code runs at ipls of zero
  - Each Controller/Device uses a fixed ipl to interrupt

Device Driver Framework

- Driver Classification
  - Character Devices: Transfer arbitrary sized data
    - Typically interrupt driven
  - Block Devices: Transfer data in fixed sizes
    - Typically do I/O to paged memory
    - Use buf structures
- Special Drivers:
  - drivers without devices (pseudo drivers)
  - Mem driver: Access physical memory
  - Null driver: data sink, used to write anything to a black hole

Driver Code

- Driver Code
  - Configuration: Boot time, to initialize
  - I/O: by I/O subsystem to read/write
  - Control: control operations like open/close/rewind
  - Interrupts: Device to CPU communication (I/O completion, error status etc.)
- Synchronous
  - I/O & Control Code
- Asynchronous
  - Interrupts

Driver Code

- Driver Routines
  - Top Half: Synchronous Code
    - Execute in Process Context
    - Acess address space and u area of the process
    - May result in a sleep if needed
  - Bottom Half: Asynchronous Code
    - Mostly not related to current process
    - Not allowed to access address space and u area of the process
    - Not allowed to sleep

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Device Switches

- Block Device

```
struct bdevsw {
    int (*d_open)();
    int (*d_close)();
    int (*d_strategy)();
    int (*d_size)();
    int (*d_xhalt)();
} bdevsw[];
```

Device Switches

- Character Device

```
struct cdevsw {
        int (*d_open)();
        int (*d_close)();
        int (*d_read)();
        int (*d_write)();
        int (*d_ioctl)();
        int (*d_mmap)();
        int (*d_segmap)();
        int (*d_xpoll)();
        int (*d_xhalt)();
        struct streamtab *d_str;
} cdevsw[];
```

I/O Subsystem

- Major/Minor Device Numbers
- Device Files
- The specfs filesystem
- Common s-node
- Device Cloning
- I/O to a character device

Major/Minor Device Numbers

- Major device number
  - Identifies the type of device (i.e. Driver to be used)
  - Typical Usage

```
(*bdevsw[getmajor(dev)].d_open)(dev,....)
```

- Minor device number
  - Identifies specific instance of device
- dev_t is a combination of major/minor device numbers
- A single driver may be given multiple major numbers
- A single device may be given multiple minor numbers

Major/Minor Device Numbers

- SVR4 dev_t: 32 bit info
  - 14 bits for major device number
  - 18 bits for minor device number
  - Internal device numbers
    - Identify the driver (index to driver switches)
    - getmajor(), getminor()
  - External device numbers
    - User visible representation of the device
    - Stored in i-node (i_rdev field) of the device special file
    - getemajor(), geteminor()

Device Files

- Kernel view: Device Numbers
- User view: device files
  - Part of file system name space
  - By convention, use /dev/....
  - Has inode, but no blocks on file system
  - Only super user creates these files using mknod()
    - IFBLK, IFCHR
  - Advantages
    - User programs use same routines for devices and files
    - Device file access thru regular file access control

The specfs File System

- File system is accessed thru vfs/v-node interface
- Vnode of a ufs file points to a vector ufsops
  - Ufsops has pointers to ufslookup(), ufsclose() etc.
- When device files reside on a vfs managed filesystem, how to handle device file info?
  - Vnode for /dev/lp has file type IFCHR
    - Get device numbers from inode
    - Pass them to specvp()
    - Specvp() finds snode for file

I/O to character device

- Driver does most of the work
- When a user opens the file
  - Create snode & common snode
- When a user makes a read
  - From file descriptor, dereference vnode
  - Do VOP_READ on vnode, resulting a call to spec_read()
  - spec_read() uses cdesw[] table because its a character device, and calls d_read() routine
  - d_read() for character device is a synchronous operation

The poll() system call

- To multiplex I/O over several descriptors
  - Checking each file descriptor will block until that descriptor is ready
  - What happens if other descriptors have data before the one you are checking
- Poll() system call

```
poll(struct pollfd *fds, int nfds, int
  timeout);
   struct pollfd {
      int fd;
      short events;
      short revents;
   };
```

The poll() system call

- Poll() system call

  `poll(struct pollfd *fds, int nfds, int timeout);`

  – `fds:` array of pollfd struct elements

  – `events: POLLIN, POLLOUT, POLLERR`

  – `timeout:` if 0, return immediately

  – `timeout:` if `INFTIM` or -1, wait until an event happens

The poll() implementation

- Two key data structures
  - Pollhead: Associated with each device file, maintains a queue of polldat structures
  - Polldat: identifies a process waiting for that device file and interested events.
- Poll() system call implementation
  - First, loop thru all vnodes of device files and do a

```
error = VOP_POLL(vnp, events, anyyet,
  &revents, &php);
```

    - If there is an event, then call pollwakeup() with pollhead of the device
    - If there is no event, add a polldat for current process to the pollhead

The poll() implementation

- Poll() system call implementation
  - pollwakeup() traverses thru the polldat chain for the pollhead and wakesup each process with event info.

The select() system call

- 4.3 BSD has a select() system call similar to that of poll()
  - Select(nfds, readfds, writefds, exceptfds, timeout);
  - Readfds, writefds exceptfds are pointers to descriptor sets
    - Fixed size arrays (size nfds) where non-zero values indicate file descriptors of interest
    - Operations on descriptor sets
      - FD_SET(fd, fdset)
      - FD_CLR(fd, fdset)
      - FD_ISSET(fd, fdset)
      - FD_ZERO(fdset)

Block I/O

- Block I/O has more involvement of I/O subsystem
- Two types of block devices
  - raw/unformatted
    - Direct access thru device files
  - Those that contain unix filesystems
    - Reading/writing to a ordinary file
    - Reading/writing to a device file
    - Accessing a memory mapped file
    - Paging to/from a swap device

The buf structure

- The buf structure has the following data
    - Major/Minor device number
    - Starting block number of data on device
    - Number of bytes to transfer (multiples of sector size)
    - Location of data in memory
    - Flags (read/write, synchronous or not)
    - Address of completion routine to be called from interrupt handler

The buf structure

- Modern Unix Systems also have
  - Pointer to the vnode of the device file
  - Flags that state the state of the buffer (free/busy, dirty)
  - Aged flag
  - Pointers to keep buffer in on an LRU free list
  - Pointers to chain the buffer in hash queue (vnode/block number)

Device access methods

- Pageout operations
  - Pagedaemon flushes dirty pages to disk (keep mostly used pages in memory) regulary
  - Locates vnode from page structure, invokes VOP_PUTPAGE
    - For device files, it calls spec_putpage(), resulting in d_strategy() call
    - For ordinary files, it calls ufs_putpage(), which calls ufs_bmap() (to compute physical block number) and then d_strategy()

Device access methods

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Device access methods

- Mapped I/O to a file
  - Whenever a process accesses a mmap()ed area and the page is NOT already in memory, a pague fault occurs
  - The fault is handled by segvn_fault(), which invokes VOP_GETPAGE()

Device access methods

- Ordinary File I/O
  - Reading a file using read() results in an VOP_READ.
  - For ordinary files, VOP_READ() translates to file system specific read, e.g. ufs_read()
    - ufs_read() calls segmap_getmap() to get the data mapping
    - Calls uiomove() to transfer data from file to user space
    - Calls segmap_release() to free the mapping. This mapping is cached for any subsequent use of the same page

Device access methods

- Direct I/O to block device
  - Reading a block device using read() results in an VOP_READ.
  - For device files, VOP_READ results in spec_read()
  - spec_read() behaves almost similar to ufs_read()
- Direct I/O to block device using mmap()ed I/O
  - Not having a page in memory causes segvn_fault(), which would invoke VOP_GETPAGE
  - VOP_GETPAGE calls spec_getpage()
  - spec_getpage() calls d_strategy() of the device

Raw I/O to block device

- Regualr read()/write() calls copy the data twice
  - Once between user process & kernel and then to device
- Raw I/O to device is handled by character interface
  - Do raw i/o using character switch entry of the device
  - Result in calling the d_read() or d_write() (which calls physiock() of kernel)
    - Validates I/O parameters, allocates buf struct
    - Calls as_fault() to cause fault and lock the pages
    - Calls d_strategy() of the device and sleep until I/O completes
    - Unlock user pages and return results

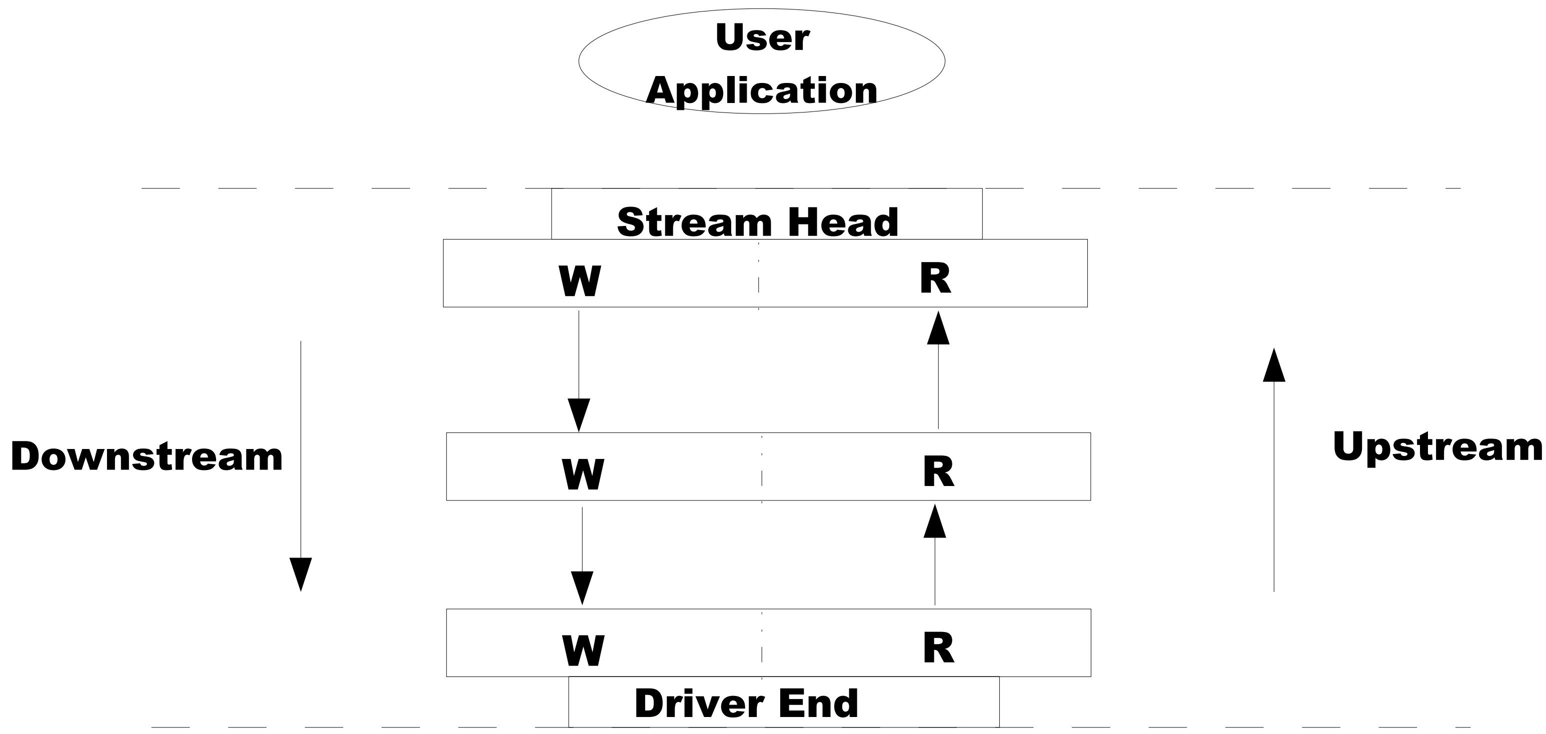
Streams

- Classic Character Drivers have limitations
  - Different vendors (drivers) may replicate the same code, resulting in large size kernels
  - Not buffered and hence inefficient for modern character devices (network interfaces)
  - Limited facilities to applications
- Streams address many of these issues
  - Consist of multiple modules, which can be shared among multiple devices
  - Can provide application level features
  - Provide buffering abilities

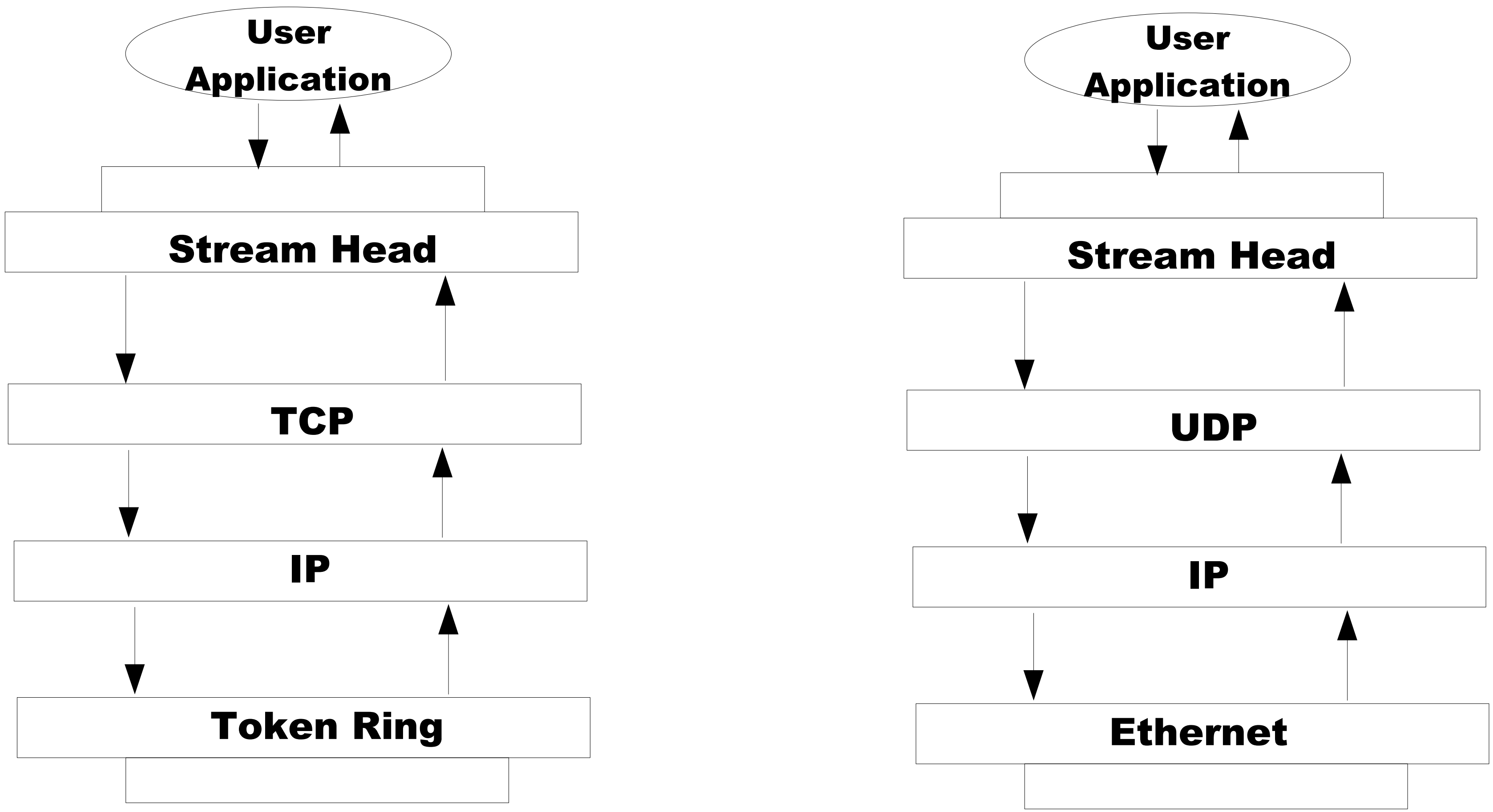
Streams Overview

- Stream Head
  - Interaction with user applications, part of kernel space
- Modules
  - One or more components of the stream
  - Reusable across multiple streams
  - Each module contains a pair of queues
    - Write Queue & Read Queue
- Driver End
  - Interface to the hardware
- Upstream & Downstream
  - Combination of Read Queues & Write Queues of ALL modules

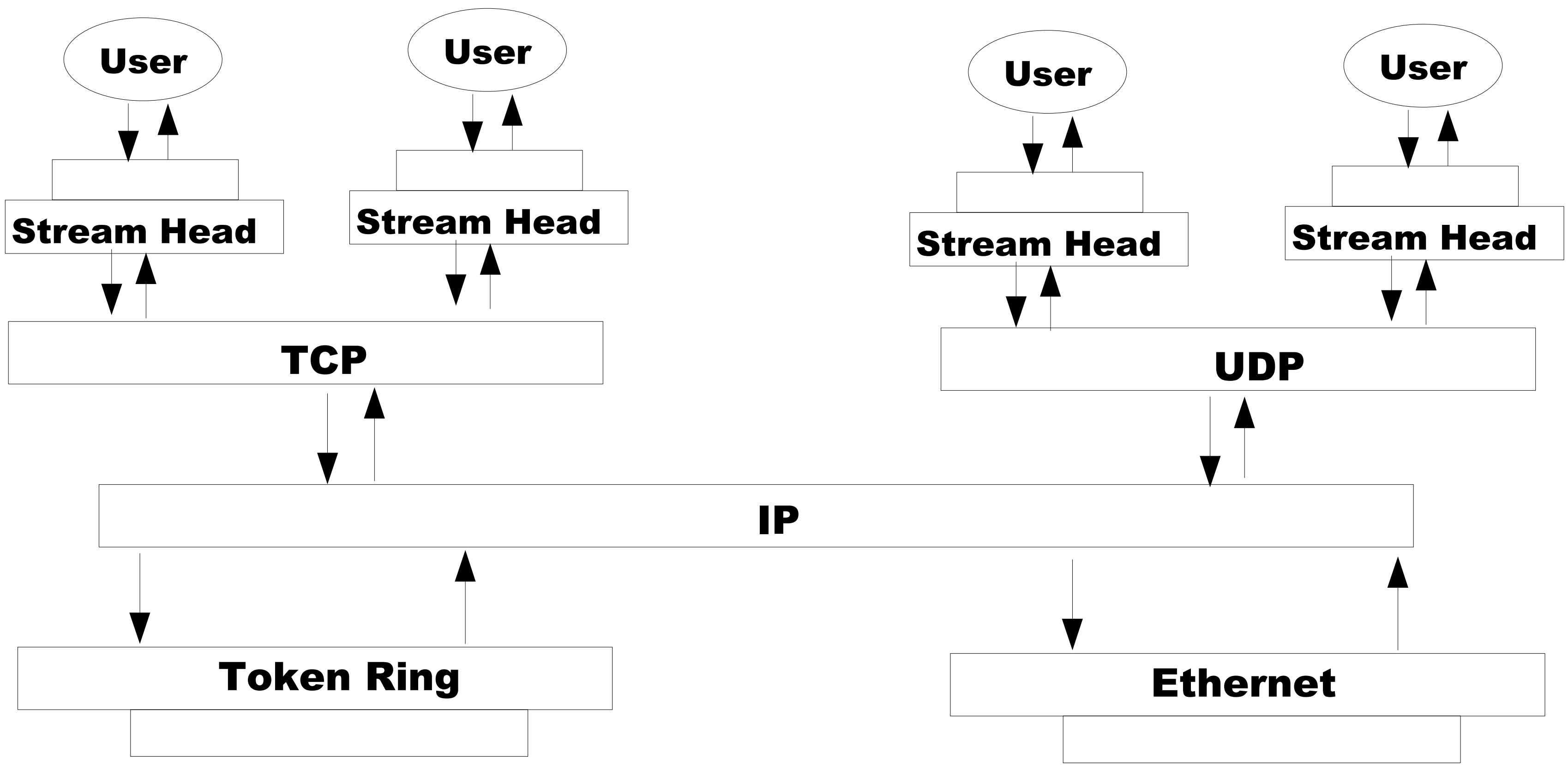
Streams Overview



Reusable Modules



Reusable Modules



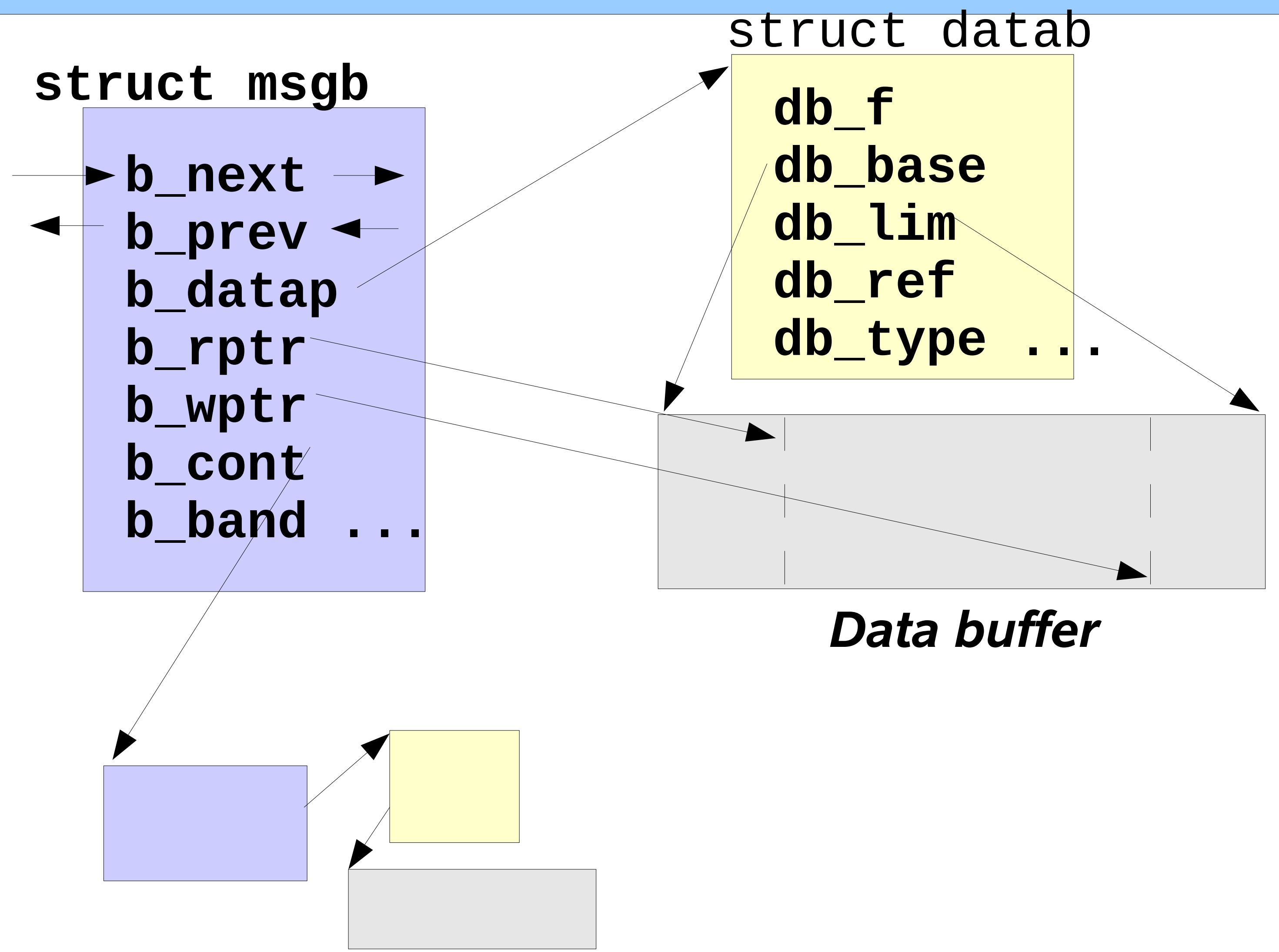
Streams Overview

- Multiplexing Modules/Drivers
  - Drivers/Modules that can connect to more than one Driver/Module at the top or bottom
  - Fan-in (Upper) multiplexer
    - One that can connect to more than one modules above it
  - Fan-out (Lower) multiplexer
    - One that can connect to more than one modules below it
- Messages & Queues
  - Passing messages is the only form of communication
  - Messages are processed thru queues at each module

Messages

- Simplest Message
  - struct msgb
  - struct datab
  - Data buffer
- Multipart messages
  - Several of above triplets
  - Useful in layered protocol implementations where each layer adds/removes a message triplet
- Virtual copying
  - Struct datab has a reference count field (db_ref) and this struct can be used by multiple msgb structures

Messages


struct datab
struct msgb
b_next
b_prev
b_datap
b_rptr
b_wptr
b_cont
b_band ...
db_f
db_base
db_lim
db_ref
db_type ...
Data buffer

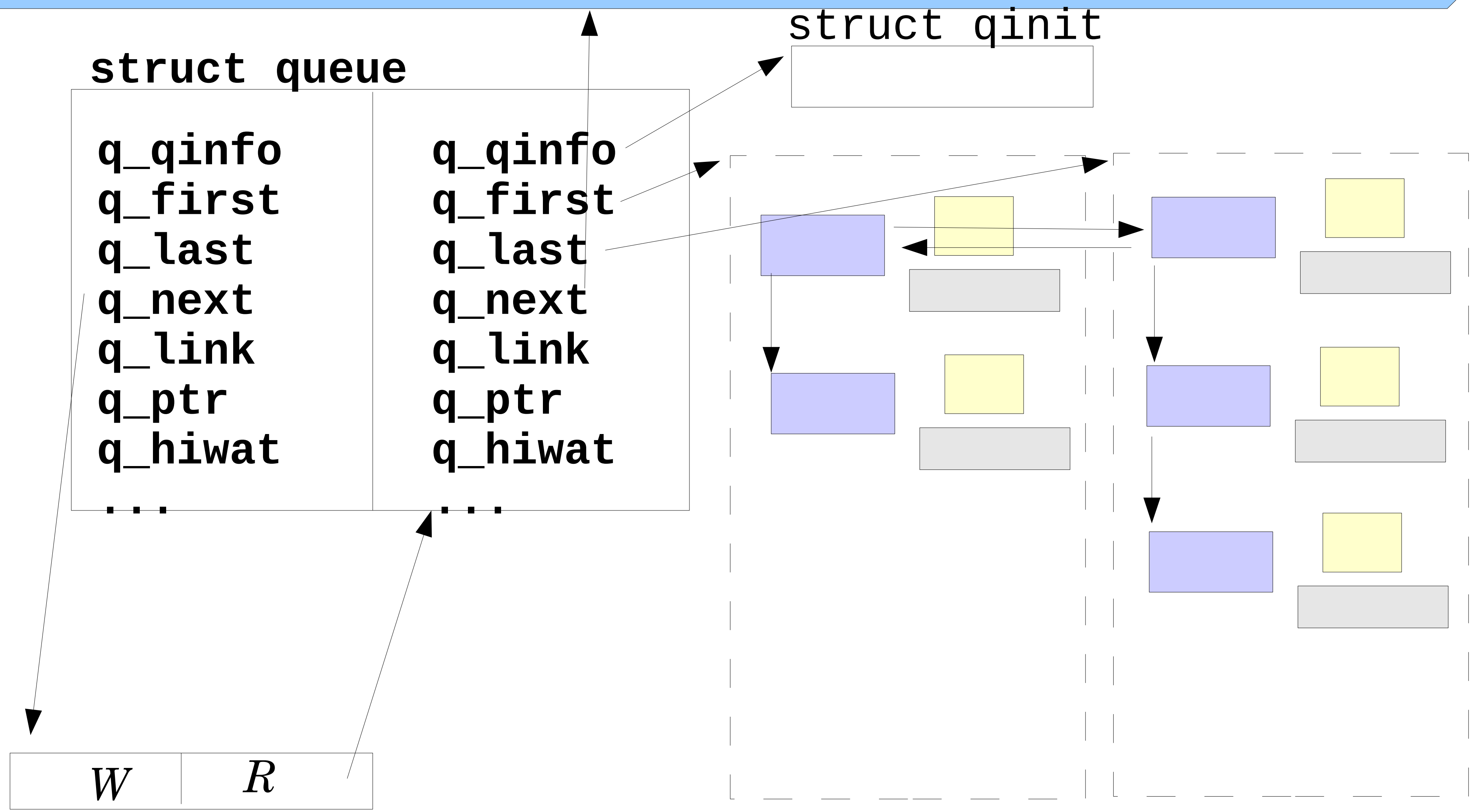
Messages

- Message Types
  - Some types are for upstream, some are for downstream
  - For full list, refer to p553-554 of “Unix Internals”

Queues

- Each module has two queues
- Each queue consists of zero or more messages lined up (message queue) for processing
- Struct qinit
  - Has a set of methods & pointers (qi_putp, qi_srvp, qi_qopen, qi_qclose, qi_mstat, qi_minfo)
    - Open and close are called by processes synchronously
    - Put processes the message immediately, when possible. Else, adds message to message queue
    - Service method handles messages in message queue (delayed processing)

Queues


struct qinit
struct queue
q_qinfo
q_first
q_last
q_next
q_link
q_ptr
q_hiwat
...
q_qinfo
q_first
q_last
q_next
q_link
q_ptr
q_hiwat
...
W
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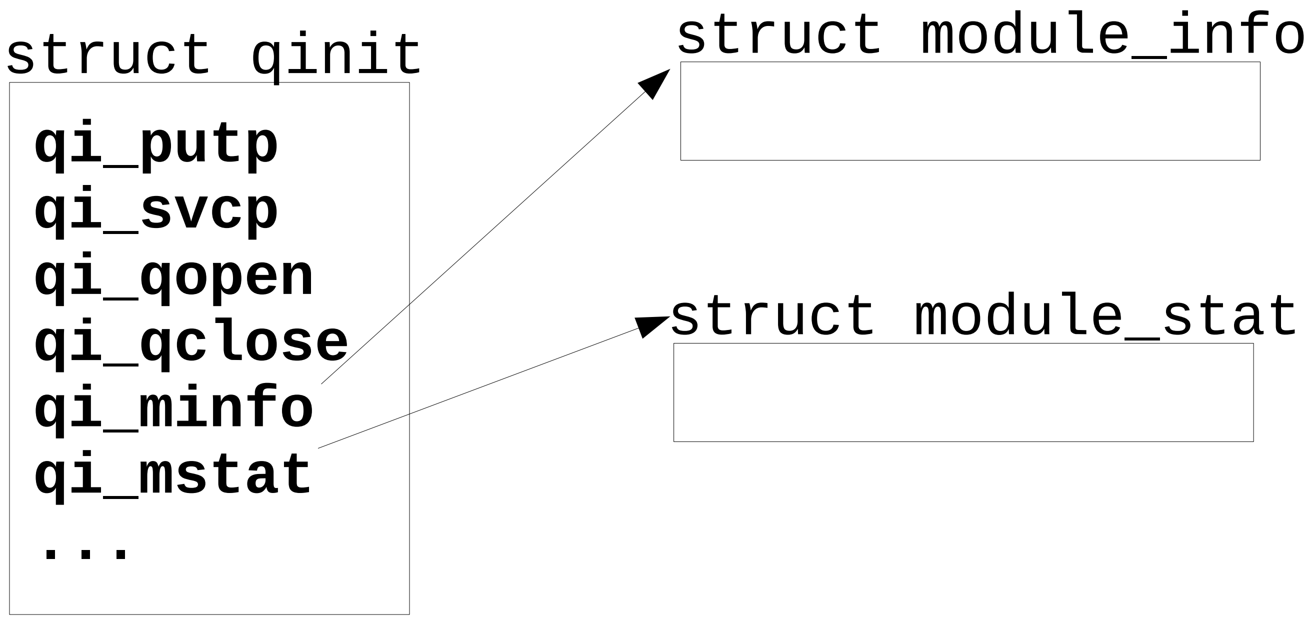
Queues


struct qinit
qi_putp
qi_svcp
qi_qopen
qi_qclose
qi_minfo
qi_mstat
...
struct module_info
struct module_stat

Stream I/O

- User does a write/putmsg system call for writing to device
    - Stream head allocates a message and copies data to it
    - Sends it downstream to the next queue
    - Eventually, data reaches driver
- Queues pass message to the next one using putnext()
    - Identify the next queue using q_next
    - Results in invoking put procedure of the next queue

Stream I/O

- Nature of procedures
  - Put and service procedures are non-blocking
  - Both of them keep the messages in queue if processing cannot be done rightaway
  - Need own memory allocation procedures that are non-blocking
    - allocb()
    - bufcall()
  - Service procedures are scheduled in system context, not the process context

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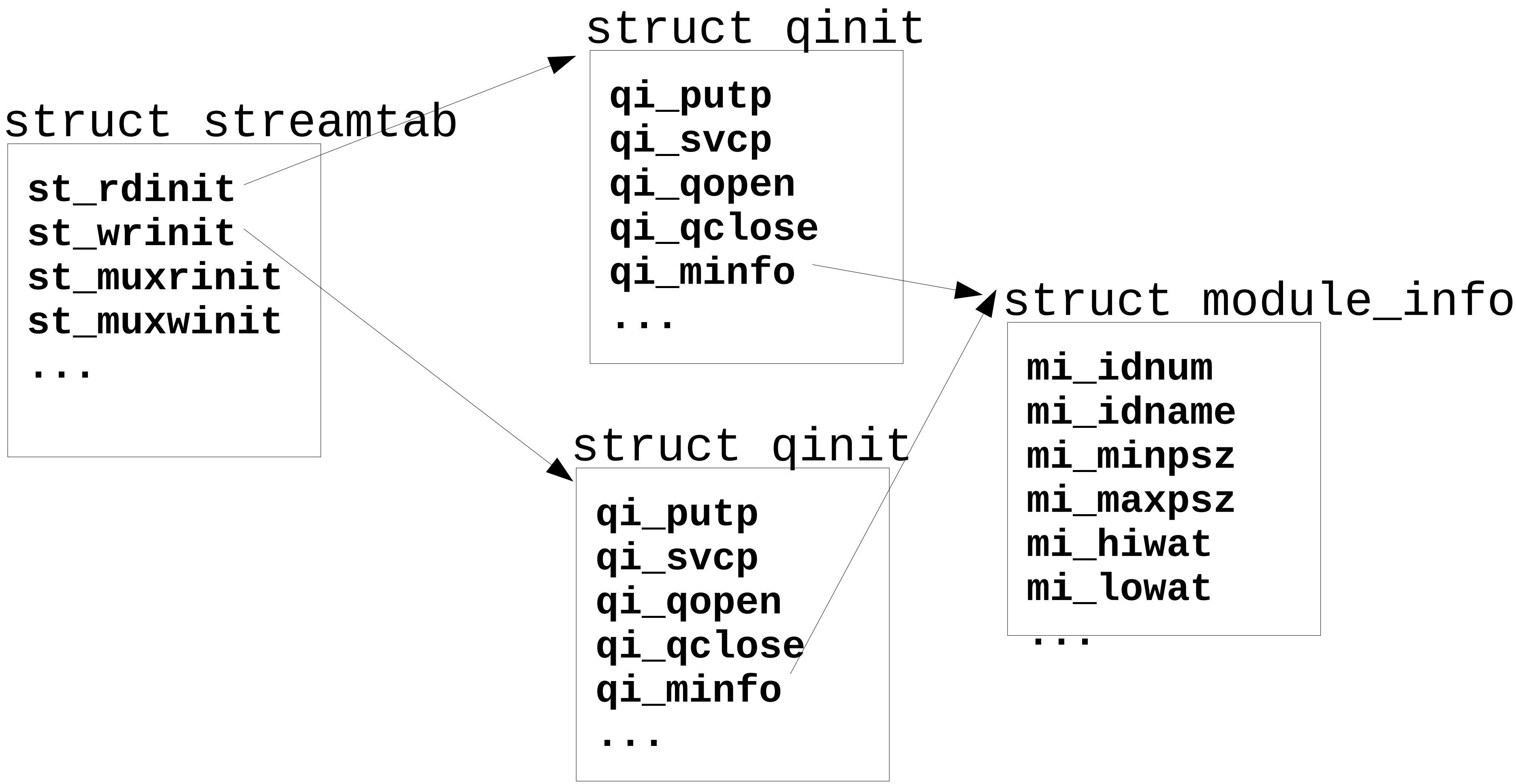
Configuration and Setup

- Each module has three configuration structures
  - streamtab, qinit, module_info
  - Streamtab contains two pointers to qinit structures
  - Qinit structures point to module_info
    - module_info contains default parameters of the module, which are copied to the queue structures upon opening the module.
    - These parameters in queue structures can be overwritten later by ioctl() calls
  -

Structs for Configuring a Module/Driver



Configuration and Setup

- Streams modules
  - Managed by fmodsw[] switch
  - Identified by f_name (mi_idname of the module_info)
  - f_str pointer points to related streamtab
- Streams drivers
  - The d_str pointer in cdevsw is NOT NULL and points to the streamtab structure
  - Configuration includes
    - Create appropriate device files
    - Use right device numbers

Configuring a Module/Driver