CS447/647

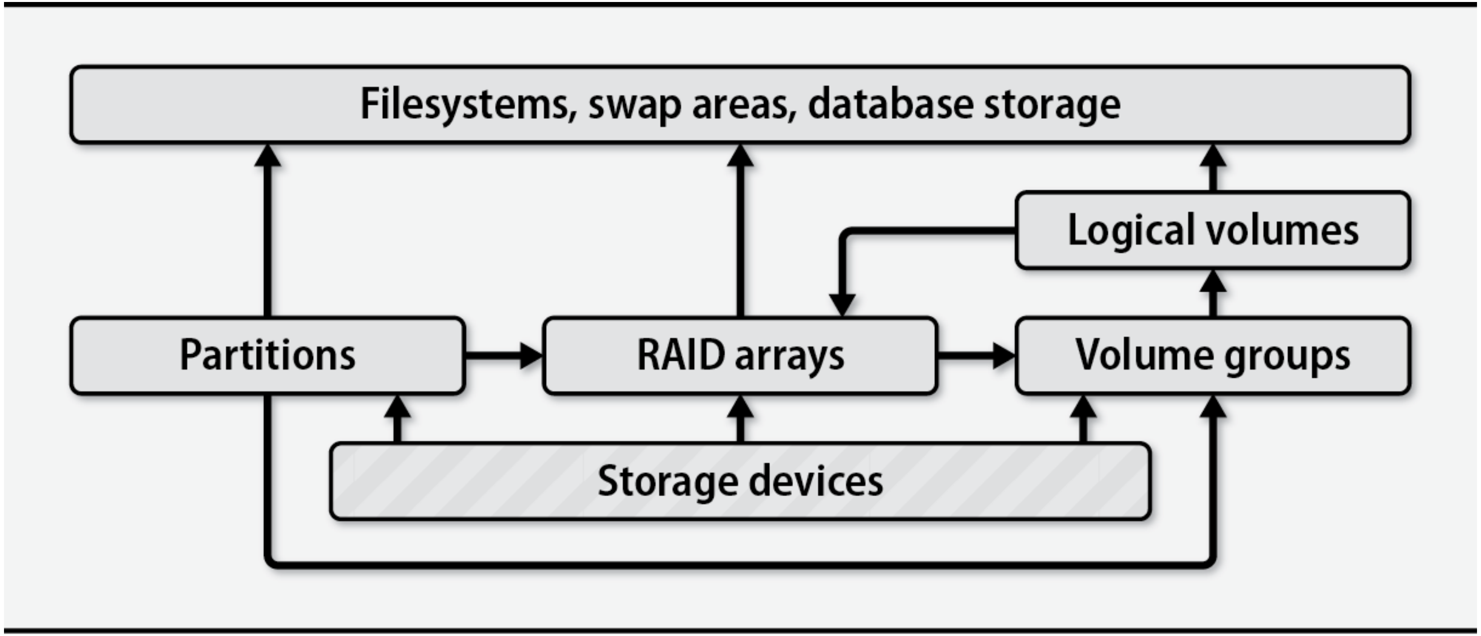
Storage
LVM and RAID

	Cloud Provider 1		Cloud Provider 2		Cloud Provider 3		WhiteBox	
Cost per GB	$	0.02	$	0.02	$	0.02	$	0.01
Ingress Cost	$	-	$	-	$	-		
Egress Cost	$	0.08	$	0.09	$	0.09	$	-
Monthly Cost	$	2,048.00	$	2,048.00	$	2,048.00	$	-
20T Egress	$	1,638.40	$	1,843.20	$	1,843.20	$	-
1st Year Cost	$	24,576.00	$	24,576.00	$	24,576.00	$	5,688.00
5 Years Cost	$	124,518.40	$	124,723.20	$	124,723.20	$	5,688.00

References

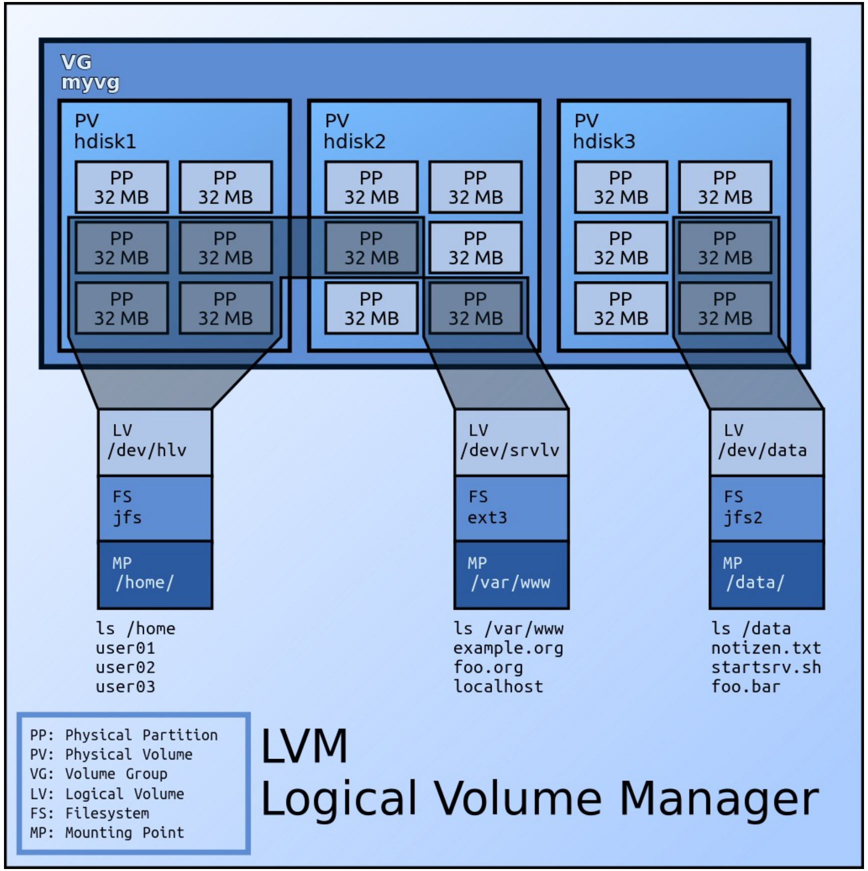
Nemeth, Evi, et al. *UNIX and Linux System Administration Handbook*. Addison-Wesley, 2018.

Remzi H., et al. *Operating Systems: Three Easy Pieces*, Arpaci-Dusseau Books, August, 2018 (Version 1.00)
https://pages.cs.wisc.edu/~remzi/OSTEP/


Filesystems, swap areas, database storage
Logical volumes
Partitions
RAID arrays
Volume groups
Storage devices

LVM - Logical Volume Management

- Provides tools to create virtual block devices from physical devices
- Virtual devices are <u>easier to manage</u> than physical devices
- Three requirements
  - Device-mapper kernel module
  - Userspace device-mapper
  - Userspace lvm2 tools
- Three components
  - Physical Volume
  - Volume Group
  - Logical Volume



https://en.wikipedia.org/wiki/Logical_Volume_Manager

RAID

- We often want disks to be
  - faster
  - larger
  - more reliable
- Redundant Array of Inexpensive Disks (RAID)
  - Developed in the late 1980’s by the CS department at Berkeley
  - Technique to make multiple disks to appear as a single disk
    - More storage, better performance and reliability
  - Complex
    - Multiple Disks
    - RAM
    - Processors

RAID

- Advantages
  - Performance
  - Capacity
  - Reliability
    - Redundancy - Tolerate the loss of a disk
- Transparency - Easing Deployment
  - New functionality
  - Demands no changes to the rest of the system
  - RAID is a perfect example
    - Looks like one big disk
  - Solved the deployment problem

Interface and RAID Internals

- Filesystem sees one big disk
- When a logical IO request is made, a RAID must:
  - Calculate which disk
  - Issue physical IO request
    - Mirroring results is 2 physical writes for 1 logical
- SATA, SCSI or NVME
  - NVME is software RAID only
    - mdraid
  - Hardware RAID for SATA and SCSI

RAID0 - Striping

- Upper Bound of Performance and Capacity
- “Perfect reliability”
  - One disk fails the whole array fails
- Excellent Performance
  - All disks are utilized
  - Often parallel
- Best Capacity
  - All Disks combined

Disk 0	Disk 1	Disk 2	Disk 3
0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

Figure 38.1: **RAID-0: Simple Striping**

RAID Mapping Problem

- How does the RAID map logical blocks to physical disks?
  - Logical Block A
  - `Disk = A % number_of_disk`
  - `Offset = A / number_of_disks`
- So, a write to A = 14 with a 4 disk RAID
  - `Disk: 14 % 4 = 2`
  - `Offset: 14 / 4 = 3`

Chunk Size

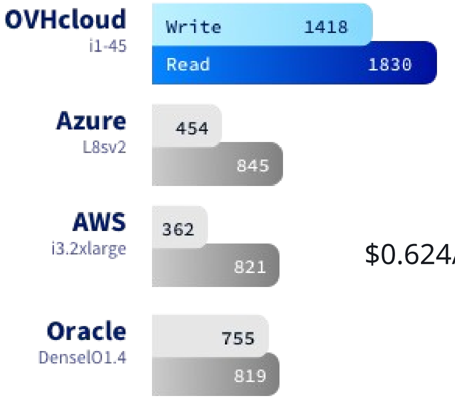
- Affects performance
  - 64Kb, 512Kb (common)
- Group blocks together on a single disk
- Small chunks means files are striped across many disks
- Large chunks reduce intra-file parallelism
- Art more than a science

RAID0 - Performance

- Sequential Workload - Large continuous chunks
- Random Workload - Small requests for random disk locations (blocks)
  - Databases
- In general Sequential > Random
- Number of Disks * Random Rate
- Number of Disks * Sequential Rate
- Full Bandwidth

How do we benchmark?

- `dd(1)` - Basic Sequential Read\Write
- `hdparm(1)` - Basic buffered reads test
- `fio(1)` - synthetic benchmarks, ‘real world’ workloads



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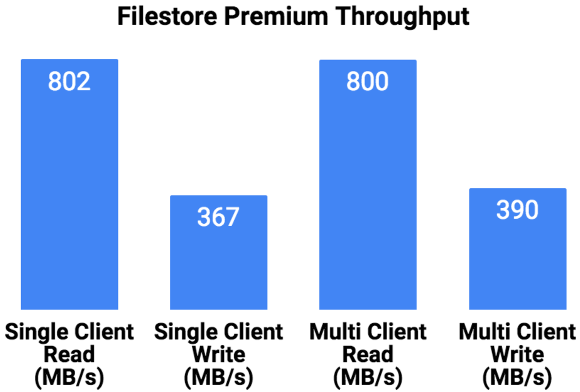


RAID1 - Mirroring

- Copy of each block on a different disk
- Each logical write is two physical writes
  - Slowest of the two
  - Happen in parallel
- Sequential Performance: (N/2) * Sequential Rate
- Random Performance: (N/2) * Random Rate

Disk 0	Disk 1	Disk 2	Disk 3
0	0	1	1
2	2	3	3
4	4	5	5
6	6	7	7

Figure 38.3: **Simple RAID-1: Mirroring**

RAID4 - Parity

- Each stripe has a parity block
- Parity calculated using XOR
- Can lose 1 disk
  - Replacement has to be rebuilt
- Performance
  - (N - 1) * Rate
  - Random write does not improve when you add disks

Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
0	1	2	3	P0
4	5	6	7	P1
8	9	10	11	P2
12	13	14	15	P3

Figure 38.4: **RAID-4 With Parity**

C0	C1	C2	C3	P
0	0	1	1	XOR(0,0,1,1) = 0
0	1	0	0	XOR(0,1,0,0) = 1

Disk and Flash Drive Rebuild Times

RAID	Capacity TB	Capacity GB	Capacity MB	Seq Write Speed MB/sec	Rebuild Time Minimum secs	Minutes	Hours
Disk	0.72	72	72,000	80	900	15	0.25
	1	1,000	1,000,000	115	8,696	145	2.42
	4	4,000	4,000,000	115	34,783	580	9.66
SSD FlashMax III	2.2	2,200	2,200,000	1,400	1,571	26	0.44
Intel D3600	2	2,000	2,000,000	1,500	1,333	22	0.37
Micron 9100	3.2	3,200	3,200,000	2,000	1,600	27	0.44
Intel DC P3608	4	4,000	4,000,000	3,000	1,333	22	0.37

https://www.theregister.com/2016/05/13/disak_versus_ssd_raid_rebuild_times/

RAID5 - Rotating Parity

- Operates identically to RAID4
- Random read performance slightly better
- Random Write: (N/4) * R

Disk 0	Disk 1	Disk 2	Disk 3	Disk 4
0	1	2	3	P0
5	6	7	P1	4
10	11	P2	8	9
15	P3	12	13	14
P4	16	17	18	19

Figure 38.7: **RAID-5 With Rotated Parity**

	RAID-0	RAID-1	RAID-4	RAID-5
Capacity	$N \cdot B$	$(N \cdot B)/2$	$(N-1) \cdot B$	$(N-1) \cdot B$
Reliability	0	1 (for sure) $\frac{N}{2}$ (if lucky)	1	1
Throughput				
Sequential Read	$N \cdot S$	$(N/2) \cdot S^1$	$(N-1) \cdot S$	$(N-1) \cdot S$
Sequential Write	$N \cdot S$	$(N/2) \cdot S^1$	$(N-1) \cdot S$	$(N-1) \cdot S$
Random Read	$N \cdot R$	$N \cdot R$	$(N-1) \cdot R$	$N \cdot R$
Random Write	$N \cdot R$	$(N/2) \cdot R$	$\frac{1}{2} \cdot R$	$\frac{N}{4} R$
Latency				
Read	T	T	T	T
Write	T	T	$2T$	$2T$

Figure 38.8: **RAID Capacity, Reliability, and Performance**

mdraid - Linux Software Raid

- RAID devices are virtual devices created from two or more block devices
- Many devices to one virtual device
- RAID Levels offer performance and redundancy
- Levels
    - **LINEAR** - concatenates devices in a single device. Like LVM Volume Group
    - **RAID0** (striping) - No redundancy, performance
      RAID1 (mirroring) - Mirror disks
    - **RAID4** - RAID0 plus a parity disk
    - **RAID5** - RAID4 with parity spread across disks, lose 1 disk
    - **RAID6** - RAID5 with two parity segments, lose two disks
    - **RAID10** - striped mirroring
    - MULTIPATH - Not a RAID. Multiple paths to same storage device. iSCSI
    - FAULTY - provides a layer over a true device that can be used to inject faults
    - CONTAINER - Set of devices

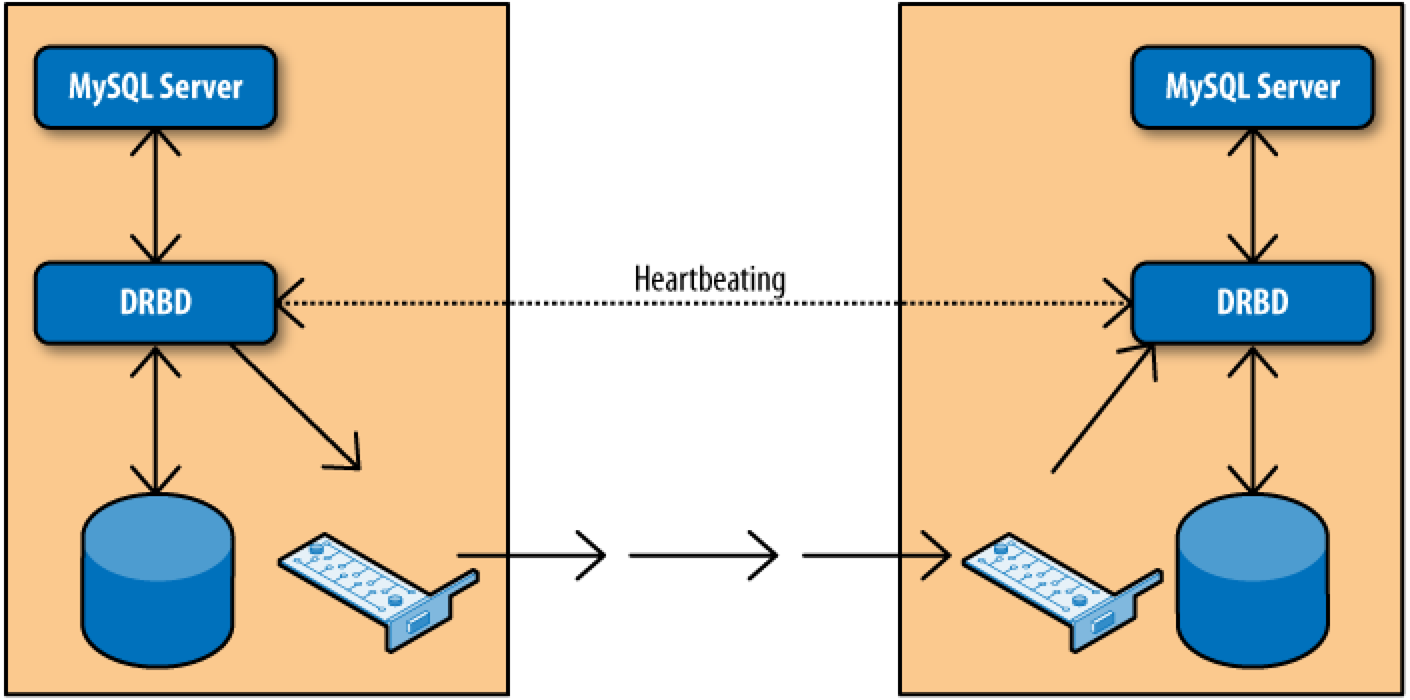
```
.config - Linux/x86 4.15.18 Kernel Configuration
> Device Drivers > Multiple devices driver support (RAID and LVM)
                  Multiple devices driver support (RAID and LVM)
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty
  submenus ----).  Highlighted letters are hotkeys.  Pressing <Y> includes, <N>
  excludes, <M> modularizes features.  Press <Esc><Esc> to exit, <?> for Help,
  </> for Search.  Legend: [*] built-in  [ ] excluded  <M> module  < > module

    --- Multiple devices driver support (RAID and LVM)
    {*}   RAID support
    [*]     Autodetect RAID arrays during kernel boot
    <M>     Linear (append) mode
    {M}     RAID-0 (striping) mode
    {M}     RAID-1 (mirroring) mode
    {M}     RAID-10 (mirrored striping) mode
    {M}     RAID-4/RAID-5/RAID-6 mode
    <M>     Multipath I/O support
    <M>     Faulty test module for MD
    <M>     Cluster Support for MD
    <M>   Block device as cache
    [ ]     Bcache debugging
    [ ]     Debug closures
    <*>   Device mapper support
    [ ]     request-based DM: use blk-mq I/O path by default
    [ ]     Device mapper debugging support
    [ ]     Block manager locking
    <M>     Crypt target support
    <M>     Snapshot target
    (+)

      <Select>    < Exit >    < Help >    < Save >    < Load >
```

drbd

- Distributed Replicated Block Device
- High-Availability Storage
- RAID1 over the network
- Active/Passive Setup



MySQL High Availability

Why does this matter?

Complex container and virtual machine managers use LVM, mdadm and drbd extensively. They are heavily scripted.