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OpenZFS Performance Analysis and Tuning

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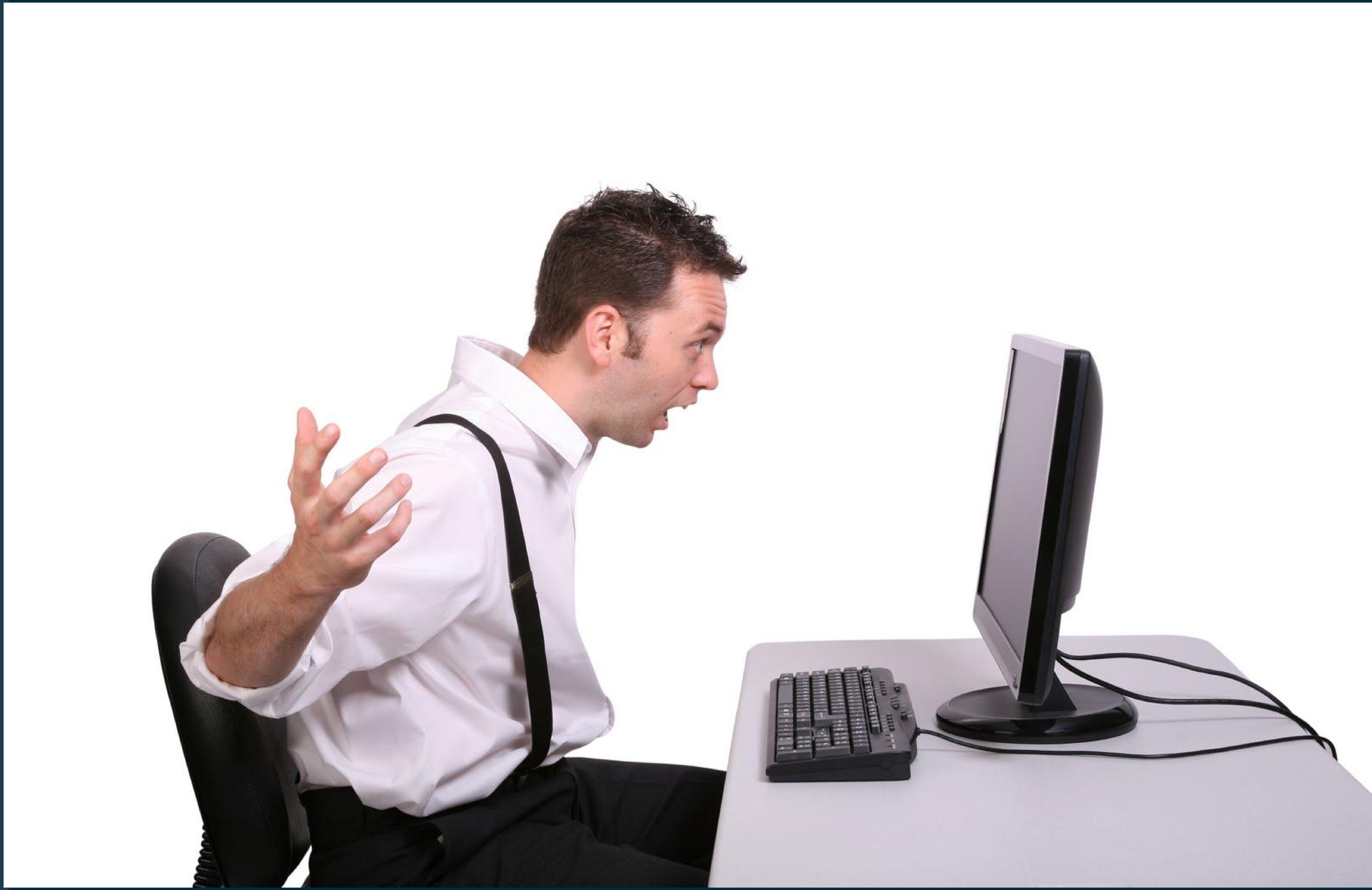
What is performance analysis and tuning?

Going from this



To this

Analyzing and benchmarking performance

- Benchmarking a filesystem or block device usually mean running synthetic workload generators like FIO or Vdbench
  - Synthetic workload generators try to approximate a production workload
  - Usually done at the POC stage of deployment
- When analyzing performance in production a synthetic benchmark doesn’t help, we need performance monitoring tools
  - arcstat
  - zilstat (needs DTrace so not supported on Linux)
  - zpool iostat
  - dstat --zfs-zil --zfs-arc --zfs-l2arc (Linux only, not part of dstat package)
  - DTrace Tool Kit (DTT)

Quantifying Storage Performance

- What do we need to know to design a system to perform at some level?
  - Ideally we want the “workload” parameters
    - Average transfer size (aka block size or xfersize)
    - R/W mix
    - Sync or Async writes
    - Access pattern - mostly sequential or random
    - Expected utilization - thread count, queue lengths, etc (rarely known)
- These workload parameters aren’t always provided by vendors making it hard to design a system based on vendor quoted numbers alone

The need to verify vendor provided numbers

- In addition vendor quoted numbers may be
  - Simply inflated
  - Obtained with specialized “benchmarking” HW
  - Obtained with a synthetic benchmark that is unrealistically tuned for performance (working set always fits into cache for example)
  - Impossible to sustain over time

- Bottom line is we need to verify performance or find a resource that provides performance numbers we can trust

Common performance drainers

- Workload vs. HW capability mismatch
- HW going bad - disk, controller, loose SAS cable etc
- Highly uneven space utilization on vdevs or pool almost full
- Fragmentation - “zpool get fragmentation pool_name”
- Background deletion - “zpool get freeing pool_name”
- Silly pool geometry - mixing RAIDZs, mirrors and drive types

USE - Performance Analysis approach

- USE - a methodology for analyzing system performance by Brendan Gregg
  - Utilization - e.g. busy %
  - Saturation - e.g. queue length
  - Errors

Common OpenZFS tuning knobs

Recordsize / Volblocksize

- Defines the largest block that can be written to the dataset or zvol
- Is the unit that ZFS compresses and checksums
- zfs get recordsize pool_name/fs
  - 128k default
  - If changed will affects only new writes
    - zfs set recordsize=32k pool_name/fs
- zfs get volblocksize pool_name/zvol
  - Is a block device that is commonly shared through iSCSI or FC
  - 8k default and is set at creation time
  - Cannot change after creation

Recordsize / Volblocksize tuning

- Create a dataset / zvol for each application or for applications working with the same data
- For random workloads try to have recordsize/volblocksize match the average transfer size of your application(s)
  - Reduces wasting of bandwidth when recordsize >> xfersize
  - Reduces metadata overhead when recordsize << xfersize

ARC and L2ARC

- Adaptive Replacement Cache is ZFS’s much celebrated in-RAM read cache
  - Caches both MRU and FRU blocks
  - Dynamically balances between caching more FRU or more MRU blocks
  - Sometimes it’s useful to put a cap on the ARC’s maximum size with zfs_arc_max
  - In general the more RAM you have the better the read performance will be
  - Observe utilization with ”arcstat.pl/.py” or “dstat --zfs-arc”
- L2ARC is the Level 2 ARC that can be added per pool
  - It’s usually a single SSD device
  - Currently doesn’t save state on reboot
- L2ARC isn’t free and isn’t always needed - more ARC (RAM) may be better

Why adding L2ARC device isn’t “free”

- Each block cache in the L2ARC requires a header to be added to the ARC
  - This mean you’re using a bit of space in the ARC to be able to cache in L2ARC
  - If you're working set size is around the size of the ARC adding an L2ARC device may hurt read performance
- OpenZFS header sizes per cached block
  - ARC only header - 176 bytes
  - ARC + L2ARC header - 208 bytes
  - L2ARC only header - 128 bytes
- Observe L2ARC utilization with ”arcstat.pl/.py” or “dstat --zfs-l2arc”
- zfs set secondarycache=<all | metadata | none> pool/dataset

ZIL

- The ZFS Intent Log ensures filesystem consistency
- ZIL will satisfy the POSIX synchronous write requirement by storing write records to an on-disk log before completing the write
- ZIL is only read in an event of a crash
- Two modes for ZIL commits
  - Immediate - write user’s data into ZIL, later write into final resting place
  - Indirect - write user’s data into final resting place, ZIL gets a pointer to the data
- Don’t turn off ZIL if you are not ok with losing a TXG worth of data in the event of a power failure or crash

SLOG

- Unless a Separate Log device is added, the ZIL will be stored on the pool’s vdevs
- If SLOG is added to a pool the ZIL will be stored on these added devices
- To speed up sync writes we can choose to put the ZIL on a Separate LOG device
- Typically a SLOG will be two small mirrored latency optimized SSD devices
  - Small because it only needs to hold < 2 TXGs (zfs_dirty_data_max) worth of data
  - Mirrored since we need redundancy to protect from data loss
  - Latency optimized because the faster we can write to it the faster we can tell the application that we have it’s data on stable storage

ZIL and SLOG tuning

- Use '"zilstat.ksh" (DTrace based) or "dstat --zfs-zil" (Linux kstat based) to see if a workload is sync write heavy
  - Helps determine if SLOG is needed
- Indirect vs Immediate affected by
  - logbias property
  - zfs_immediate_write_sz and zvol_immediate_write_sz (both 32k by default)
  - zil_slog_limit (1mb by default)
- SLOG can be tuned with logbias=latency (default) vs logbias=throughput
  - "throughput" setting will bypass SLOG and is useful for large sync streaming workloads

ashift

- Alignment shift defines the size of the smallest block that we will send to disk
  - ashift of 9 means 2^9 = 512 bytes is the smallest block
- Currently once it’s set it can not change
- ashift should match the physical block size (PBS aka sector size) reported by the drive
- Be careful, some “Advanced Format” drives lie about their PBS
  - This means that when we send a 512 byte I/O to one of these drives, it is wasting bandwidth since it’s is working with 4k PBS internally
- Query ashift with zdb: zdb | egrep 'ashift| name'

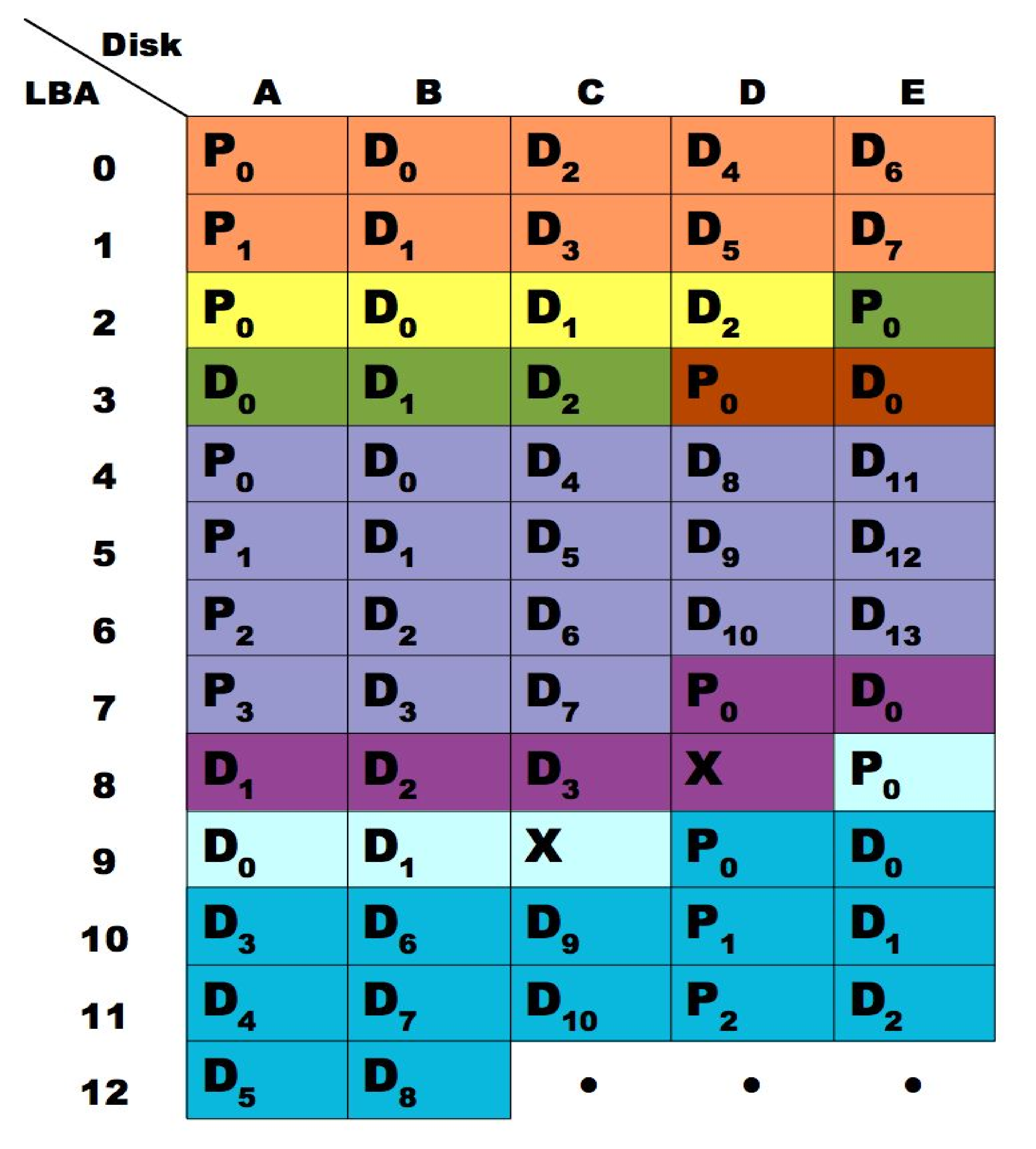
RAIDZ

- RAIDZ is is ZFS’s software RAID technology
  - Data + parity like standard RAID
  - Dynamic stripe width eliminating the write hole
- RAIDZ1 - single parity drive
  - Is able to deal with a single drive failure
- RAIDZ2 - double parity
  - Is able to deal with any two drives failing
- RAIDZ3 - triple parity
  - Is able to deal with 3 drives failing from a single stripe

RAIDZ block layout

- Each (post compression) block write sent to a RAIDZ group will be spread across the drives
  - Assuming a PBS of 4k and a 16k write onto a 6-wide RAIDZ2 we will write 4k of data to 4 drives and the other 2 drives will get 4k parity each
- To prevent holes, each allocation is a multiple of # of parity + 1
  - For RAIDZ1 each allocation will be a multiple of 2
  - For RAIDZ2 each allocation will be a multiple of 3
  - For RAIDZ3 each allocation will be a multiple of 4
- Consider 5-wide RAIDZ1 in the following example
  - A single square is one sector

5 drive wide RAIDZ1



LBA \ Disk	A	B	C	D	E
0	P_0	D_0	D_2	D_4	D_6
1	P_1	D_1	D_3	D_5	D_7
2	P_0	D_0	D_1	D_2	P_0
3	D_0	D_1	D_2	P_0	D_0
4	P_0	D_0	D_4	D_8	D_{11}
5	P_1	D_1	D_5	D_9	D_{12}
6	P_2	D_2	D_6	D_{10}	D_{13}
7	P_3	D_3	D_7	P_0	D_0
8	D_1	D_2	D_3	X	P_0
9	D_0	D_1	X	P_0	D_0
10	D_3	D_6	D_9	P_1	D_1
11	D_4	D_7	D_{10}	P_2	D_2
12	D_5	D_8	•	•	•

Block Color	Data	Padding	Parity	Total Written	% used for parity + pad
Orange	8	0	2	10	20%
Yellow	3	0	1	4	25%
Green	3	0	1	4	25%
Red	1	0	1	2	50%
Lavender	14	0	4	18	~22%
Purple	4	1	1	6	~33%
Cyan	2	1	1	4	50%
Blue	11	0	3	14	~21%

RAIDZ performance considerations

- In general for a random access pattern workload
  - Mirror beats RAIDZ in performance
  - RAIDZ group will perform at the speed of the slowest drive in the group
  - For more IOPS - use fewer disks per group (and more groups)
  - For more usable space - use more disk per group
- Don’t use small recordsizes with devices that aren’t 512 PBS
- ashift, recordsize and RAIDZ width will define usable space availability
- Don’t worry about exact alignment since you’ll probably have compression enabled so the post compression block sizes will vary

I/O scheduler

- There are 5 I/O classes that control the number of I/Os issued to each drive
  - 1 - sync (normal demand) reads
  - 2 - async (prefetch) reads
  - 3 - sync (ZIL) writes
  - 4 - async (dirty data) writes
  - 5 - scrub / resilver
- Each class has a tunable min and max for outstanding I/Os per leaf vdev
- The scheduler will issue the min number of I/O from each class
- Then the scheduler will in the order above will try issue up to max from each class
- There is also a per vdev cap for all outstanding I/Os - zfs_vdev_max_active

I/O scheduler tuning

- Using the I/O scheduler tunables we can prioritize certain classes of I/O
- Tuning an I/O class's max higher should lead to higher throughput and maybe higher latency for that class
- Tuning an I/O class's min higher will make the scheduler issue more I/O before considering the class's priority
  - Used to prioritize faster scrubs and resilvers at the expense of other I/O

Write throttle (WT)

- WT introduces artificial delays to the time it takes a TX to get assigned to a TXG
- Needed when the client application is giving us more data than we can write
  - We’ve been issuing the max from the async write I/O class but can’t keep up
- The goal is to provide consistent latency
- WT starts adding small delays when the amount of dirty data in the pool reaches 60% (by default) of the zfs_dirty_data_max
- After the 60% threshold WT becomes more and more aggressive as more dirty data is added and we stop accepting new writes when we exceed zfs_dirty_data_max

Write throttle (WT) tuning

- Observe by DTracing dmu_tx_delay or watching it in /proc/spl/kstat/zfs/dmu_tx
- Tuning zfs_dirty_data_max to be larger will allow the system to absorb bigger write spikes at the expense of having a smaller ARC
  - Will also lead to higher TXG sync times which adds latency to sync context operations like snapshotting
- WT has other knobs and tuning it is usually done per specific set of HW

Turn dedup on? Probably not

- Sounds good on paper since it decreases space utilization
- Rarely used in practice in production since it has some sharp corners as it relates to performance
- Deduped blocks are tracked in a DeDuplication Table (DDT) that essentially map a block’s checksum to a refcount and location on disk
- DDT will grow every time we write a unique (never before seen) block
- If DDT is small and cached we will be ok
- Once dedup is on to reverse it you have to copy data to a dedup=off dataset
- Only turn on dedup if you are sure the dataset will be very highly dedupable
  - Even VMs spawned from the same image will diverge over time
- “zdb -S pool_name” will simulate dedup on an existing pool

Common dataset settings

- ARC works well, most of the time we tune for better write performance
- zfs set atime=off pool/ds
  - don’t modify access time to reduce write inflation
- zfs set redundant_metadata=most pool/ds
  - Reduces write inflation by storing less metadata. Metadata is still stored redundantly due to pool layout (e.g. RAIDZ) and the copies property
- zfs set xattr=sa pool/ds (Linux only)
  - Needed when using POSIX ACLs
  - Decreases the amount of disk IO required to access extended attributes
- zfs set primarycache=metadata pool/ds
  - May be useful when an application does it’s own read caching

Where to tune global settings

ZFS on Linux	illumos	FreeBSD	OpenZFS on OS X
/etc/modprobe.d/zfs.conf	/etc/system	/etc/sysctl.conf	/etc/zfs/zsysctl.conf

References to resources

What	Where
USE performance analysis methodology	http://www.brendangregg.com/usemethod.html
RAIDZ width - usable space vs IOPS	https://www.delphix.com/blog/delphix-engineering/zfs-raidz-stripe-width-or-how-i-learned-stop-worrying-and-love-raidz https://blogs.oracle.com/roch/entry/when_to_and_not_to
I/O scheduler and write throttle	https://www.delphix.com/blog/delphix-engineering/tuning-openzfs-write-throttle
On recordsize	https://www.joyent.com/blog/bruning-questions-zfs-record-size
ARC stat	http://www.c0t0d0s0.org/archives/5329-Some-insight-into-the-read-cache-of-ZFS-or-The-ARC.html https://github.com/zfsonlinux/zfs/blob/master/cmd/arcstat/arcstat.py https://github.com/illumos/illumos-gate/blob/master/usr/src/cmd/stat/arcstat/arcstat.pl
ZIL	http://www.richardelling.com/Home/scripts-and-programs-1/zilstat https://github.com/dagwieers/dstat/blob/master/plugins/dstat_zfs_zil.py

Thank you

- Questions?!