ZFS For Newbies

Dan Langille
SE Linux Fest: 2026
Charlotte, NC, USA

Twitter @dlangille
Mastadon dvl@bsd.network
https://dan.langille.org/

Disclaimer

- This is ZFS for newbies
  - grossly simplified
    - stuff omitted
      - options skipped
        - because newbies….

What?

- a short history of the origins
- an overview of how ZFS works
- replacing a failed drive
- why you don’t want a RAID card
- scalability
- data integrity (detection of file corruption)
- why you’ll love snapshots
- sending of filesystems to remote servers
- creating a mirror
- how to create a ZFS array with multiple drives which can lose up to 3 drives without loss of data.
- mounting datasets anywhere in other datasets
- using zfs to save your current install before upgrading it
- simple recommendations for ZFS arrays
- why single drive ZFS is better than no ZFS
- no, you don’t need ECC
- quotas
- monitoring ZFS

Origins

- 2001 - Started at Sun Microsystems
- 2005 - released as part of OpenSolaris
- 2008 - released as part of FreeBSD
- 2010 - OpenSolaris stopped, Illumos forked
- 2013 - First stable release of ZFS On Linux
- 2013 - OpenZFS umbrella project
- 2016 - Ubuntu includes ZFS by default

Stuff you can look up

- ZFS is a 128-bit file system
- 2^48: number of entries in any individual directory
- 16 exbibytes (2^64 bytes): maximum size of a single file
- 256 quadrillion zebibytes (2^128 bytes): maximum size of any zpool
- 2^64: number of zpools in a system
- 2^64: number of file systems in a zpool

Gross simplification

- the next few slides are overly simplified

zfs

- zfs is both a file system
- and a volume management tool
- /var/log filled up that drive?
- That other drive is nearly empty
- enter, the zpool - a collection of places to write

UFS example

```
[dan@laptop:~] $ df -h
Filesystem     Size    Used   Avail Capacity  Mounted on
/dev/ad0s2a    496M    141M    315M    31%    /
devfs          1.0K    1.0K      0B   100%    /dev
/dev/ad0s2e    496M    1.1M    455M     0%    /tmp
/dev/ad0s2f     15G     13G    680M    95%    /usr
/dev/ad0s2d    1.2G    413M    715M    37%    /var
[dan@laptop:~] $
```

- From 6 August 2007 -> https://www.freebsddiary.org/ibm-thinkpad-t41-hardware-upgrades-pics.php
- 30GB 4200RPM IDE drive

When /var fills up…

- Your PostgreSQL db is huge
- `service postgresql stop`
  `cd /var/db`
  `mv postgres /usr/local/postgres`
  `ln -s /usr/local/postgres .`
- Historically inaccurate : https://www.freebsddiary.org/postgresql.php - PostgreSQL by default used `/usr/local/pgsql/data`

Must be a better way

- spoiler: there is now

zpool

- Group your drives together: pool -> **zpool**

- **zpool create** - operates on drives (vdevs - virtual devices)

zpool variations

- create a mirror, stripe, or raidz
- mirror from 2..N drives
- create a raidz[1..3] from 4+ drives
- stripe 1+ drives

file systems

- **zfs create** - operates on a zpool, creates filesystems
- filesystems can contain filesystems - hierarchy with inherited properties
- e.g. **`zroot/users/dan/projects/foo`**
- mounted at **`/usr/home/dan/projects/foo`**
- Based on pathname, you don’t always know zfs name

pooling your drives

- remember partitions, with fixed limits?
- no more:
- out of space on **`/var/db`**
- loads of free space on **`/usr`**
- I know, symlink it…

zpool

```
$ zpool list
NAME    SIZE  ALLOC   FREE    FRAG    CAP  DEDUP  HEALTH  ALTROOT
zroot  17.9G  8.54G  9.34G     47%    47%  1.00x  ONLINE  -
```

JBOD

zpool

The highest level of the ZFS storage hierarchy is the zpool. A zpool consists of one or more vdevs. Data is distributed across the vdevs. There is no fault tolerance at the pool level—only within individual vdevs.

The blue drives indicate how many drives can be lost without losing data.

vdev

Each vdev consists of one or more actual disks. Storage vdev topologies are single disk, mirror, RAIDz1, RAIDz2, and RAIDz3. A pool may contain any number of vdevs; their topologies and sizes are not required to match. This is a RAIDz3 vdev[redacted]

vdev

[redacted]RAIDz2[redacted]

vdev

This is a three-wide mirror vdev.

Blue does not indicate parity drives or specific drives which can be lost.

filesystems

```
[22:44 r7425-01 dvl ~] % zfs list
NAME                  USED  AVAIL  REFER  MOUNTPOINT
zroot                2.14G   420G    96K  /zroot
zroot/ROOT           2.13G   420G    96K  none
zroot/ROOT/default   2.13G   420G  2.13G  /
zroot/home            376K   420G   104K  /home
zroot/home/dvl        272K   420G   168K  /home/dvl
zroot/tmp             240K   420G   240K  /tmp
zroot/usr             288K   420G    96K  /usr
zroot/usr/ports        96K   420G    96K  /usr/ports
zroot/usr/src          96K   420G    96K  /usr/src
zroot/var            1.23M   420G    96K  /var
zroot/var/audit        96K   420G    96K  /var/audit
zroot/var/crash        96K   420G    96K  /var/crash
zroot/var/log         696K   420G   696K  /var/log
zroot/var/mail        160K   420G   160K  /var/mail
zroot/var/tmp         120K   420G   120K  /var/tmp
[22:44 r7425-01 dvl ~] %
```

vdev?

- What’s a vdev?
- a single disk
- a mirror: two or more disks
- a **`raidz`**: group of drives in a **`raidz`**

Terms used here

- filesystem ~== dataset

interesting properties

- `compression=lz4 (now I prefer zstd)`
- `atime=off`
- `exec=no`
- `reservation=10G`
- `quota=5G`

Replacing a failed drive

1. identify the drive
2. add the new drive to the system
3. `zpool replace zroot gpt/disk6 gpt/disk_Z2T4KSTZ6`
4. remove failing drive

160607DE 1W7

160607DE 1W7

160607DE 1W7

EVGA SUPERNOVA 850 G2

80 PLUS GOLD

850W GOLD POWER SUPPLY

	+50°C ambient @ full load					
AC Input	100-240 VAC, 10A, 50/60 Hz					
DC Output	+5V	+3.3V	+12V	-12V	+5Vsb	
Max Output, A	24A	24A	70.8A	0.5A	3.0A	
Combined, W	120W		849.6W	6W	15W	
Output Power, P_{cont}	850W @ +50°C					

25740 ZZT Tube

SUPERMICRO X10SRA

MONOPRICE


160607DE
1W71
01 SAS V1.0
TOSHIBA
5TB
NIC SLED

Just say NO! to RAID cards

- RAID hides stuff
- The RAID card will try try try to fix it then say, it’s dead
- ZFS loves your drives
- ZFS will try to fix it, and if it fails, will look elsewhere
- Use HBA, not RAID cards

Scalability

- Need more space
- UPGRADE ALL THE DRIVES!
- add a new vdev
- add more disk banks

Data Integrity

- ZFS loves metadata
- hierarchical checksumming of all data and metadata
- ZFS loves checksums & hates errors
- ZFS will tell you about errors
- ZFS will look for errors and correct them if it can

enable scrubs

- there is no fsck on zfs
- on FreeBSD, I do this:

```
$ grep zfs /etc/periodic.conf
daily_scrub_zfs_enable="YES"
daily_scrub_zfs_default_threshold="7"
```

Mirrors

- two or more drives with duplicate content
- Create 2 or more mirrors, stripe over all of them

raidz[1-3]

- four or more drives (min 4 drives for raidz1)
- parity data
- raidzN == can loose any N drives and still be operational
- avoiding lost data is great
- staying operational is also great <= **This. This is key.**

simple configurations

- to get you started

disk preparation

```
gpart create -s gpt da0
gpart add -t freebsd-zfs -a 4K -l S3PTNF0JA705A da0
```

```
$ gpart show da0
=>        40  468862048  da0  GPT  (224G)
          40  468862048    1  freebsd-zfs  (224G)
```

standard partitions

```
[22:50 r7425-01 dvl ~] % gpart show da13
=>        40  937703008  da13  GPT  (447G)
          40     532480     1  efi  (260M)
      532520       2008        - free -  (1.0M)
      534528   16777216     2  freebsd-swap  (8.0G)
    17311744  920389632     3  freebsd-zfs  (439G)
   937701376       1672        - free -  (836K)
```

- For FreeBSD boot drives EFI specific
- partition sizes vary

mirror

mydata zpool

vdev


```
zpool create mydata mirror da0p1 da1p1
```

zpool status

```
$ zpool status mydata
  pool: data
 state: ONLINE
  scan: scrub repaired 0 in 0 days 00:07:03
with 0 errors on Tue Aug 13 03:54:42 2019
config:

   NAME          STATE     READ WRITE CKSUM
   nvd           ONLINE       0     0     0
     mirror-0    ONLINE       0     0     0
       da0p1     ONLINE       0     0     0
       da1p1     ONLINE       0     0     0

errors: No known data errors
```

raidz1

mydata zpool

vdev

da0p1 da1p1 da2p1 da3p1

```
zpool create mydata raidz1 \
da0p1 da1p1 \
da2p1 da3p1
```

raidz2

mydata zpool

vdev

da0p1

da1p1

da2p1

da3p1

da4p1

```
zpool create mydata raidz2 \
da0p1 da1p1 da2p1 da3p1 da4p1
```

raidz3

mydata zpool

vdev

da0p1

da1p1

da2p1

da3p1

da4p1

```
zpool create mydata
raidz3 \
da0p1 da1p1 \
da2p1 da3p1 \
da4p1 da5p1
```

da5p1

zpool status

```
$ zpool status system
  pool: system
 state: ONLINE
  scan: scrub repaired 0 in 0 days 03:01:47 with 0
errors on Tue Aug 13 06:50:10 2019
config:

  NAME                      STATE     READ WRITE CKSUM
  system                    ONLINE       0     0     0
    raidz2-0                ONLINE       0     0     0
      da3p3                 ONLINE       0     0     0
      da1p3                 ONLINE       0     0     0
      da6p3                 ONLINE       0     0     0
      gpt/57NGK1Z9F57D      ONLINE       0     0     0
      da2p3                 ONLINE       0     0     0
      da5p3                 ONLINE       0     0     0

errors: No known data errors
```

raid10

tank_fast zpool

mirror-0 vdev

da0p1

da1p1

mirror-1 vdev

da2p1

da3p1

```
zpool create tank_fast \
mirror da0p1 da1p1 \
mirror da2p1 da3p1
```

zpool status

```
$ zpool status tank_fast
  pool: tank_fast
 state: ONLINE
  scan: scrub repaired 0 in 0 days 00:09:10 with 0
errors on Mon Aug 12 03:14:48 2019
config:

  NAME          STATE     READ WRITE CKSUM
  tank_fast     ONLINE       0     0     0
    mirror-0    ONLINE       0     0     0
      da0p1     ONLINE       0     0     0
      da1p1     ONLINE       0     0     0
    mirror-1    ONLINE       0     0     0
      da2p1     ONLINE       0     0     0
      da3p1     ONLINE       0     0     0

errors: No known data errors
```

so what?

mounting in mounts

- Bunch of slow disks for the main system
- Fast SSD for special use
- create **`zpool`** on SSD
  - mount them in **`/var/db/postgres`**
  - **`/var/db`** is part of **`zroot/var`**

```
# zfs list zroot data01/pg02/postgres
NAME                      USED  AVAIL  REFER  MOUNTPOINT
data01/pg02/postgres      450G   641G   271G  /var/db/postgres
zroot                    33.1G  37.1G    88K  /zroot
```

bectl (also beadm)

- manage BE - boot environments
- save your current BE
- upgrade it
- reboot
- All OK? Great!
- Not OK, reboot & choose BE via bootloader

see also nextboot

- specify an alternate kernel for the next reboot
- Great for trying things out
- automatically reverts to its previous configuration

Welcome to FreeBSD

1. Boot Multi user [Enter]
2. Boot Single user
3. Escape to loader prompt
4. Reboot

Options:
5. Kernel: default/kernel (1 of 2)
6. Boot Options
7. Boot Environments

Welcome to FreeBSD

1. Back to main menu [Backspace]
2. Active: zfs:zroot/ROOT/default (1 of 2)
3. bootfs: zfs:zroot/ROOT/default

Welcome to FreeBSD

1. Back to main menu [Backspace]
2. Active: zfs:zroot/ROOT/11.1-RELEASE (2 of 2)
3. bootfs: zfs:zroot/ROOT/default

Quotas

- property on a dataset
- limit on space used
- includes descendants
- includes snapshots
- see also:
  - **`reservation`** - includes descendents, such as snapshots and clones
  - **`refreservation`** - EXCLUDES descendents

Monitoring ZFS

- **`scrub`**
- Nagios monitoring of **`scrub`**
- **`zpool`** status
- **`quota`**
- **`zpool`** capacity

semi-myth busting

single drive ZFS

- single drive ZFS > no ZFS at all

ECC RAM not required

- ZFS without ECC > no ZFS at all

High-end hardware

- Most of my drives are consumer grade drives
- HBA are about $100 off ebay
- Yes, I had some SuperMicro chassis
- Look at FreeNAS community for suggestions

LOADS OF RAM!

- I had ZFS systems running with 1GB of RAM (now it’s 8GB)
- runs with 3GB free
- That was the Digital Ocean droplet used in previous examples - it’s now a Microsoft Azure host

Myths end here

Things to do

Snapshots

- read-only
- immutable : cannot be modified
- therefore: FANTASTIC for backups - by that I mean files are in a consistent state
- snapshots on the **same host** are not backups

Sending snapshots

- share your snapshots
- send them to another host
- send them to another data center
- snapshots on another host ARE backups

Use snapshots for clones

- snapshot your database at rest, then clone it
- snapshot a dev environment
- fixed set of files you give out to a new dev

zfs create all the things!

- got photos? `zfs create`
- got a project? `zfs create`
- Instead of mkdir, think `zfs create`

Other tips

- OS on a ZFS mirror, all your data on rest of drives
- OS on something else, say UFS, data on rest of drives
- don't boot from HBA if you can avoid it

Tips from @Savagedlight

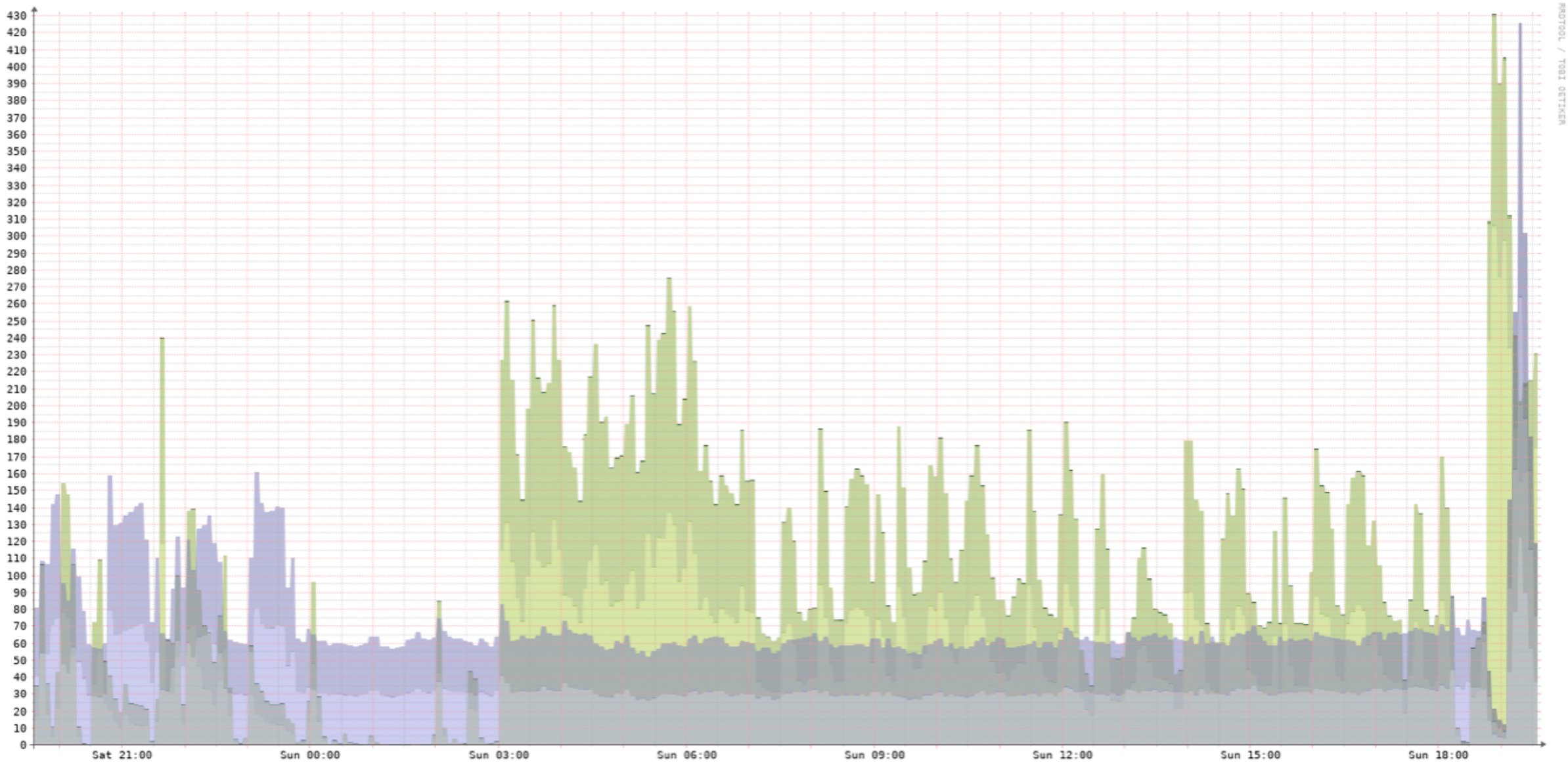
- Tell your BIOS to ignore the HBA. (fewer drives to scan, faster boot)
- You can safely partition the SSD's used in the OS mirror pool so that they can be used for l2arc/cache of the data pool. (Also log device)
- Lots of large files on a dataset? **`recordsize=1m`**

What we covered

- lots of amazing stuff, see original slide

From 2019-07-20 15:35 To 2019-07-21 15:35 Update

Hide Legend | Show Previous | Show RRD Command



Operations/sec		Now	Avg	Max	
ada0	In	174.86	55.36	306.28	
	Out	37.11	35.37	122.34	
ada1	In	55.12	49.79	138.25	
	Out	38.48	35.53	141.98	
ada2	In	982.80m	52.75m	2.26	
	Out	43.53	2.01	161.52	
ada3	In	0.00	8.90m	822.06m	
	Out	0.00	243.06u	20.08m	
pass0	In	67.72m	71.76m	89.36m	
	Out	0.00	0.00	0.00	
pass1	In	67.77m	73.99m	138.29m	
	Out	0.00	0.00	0.00	
pass2	In	0.00	0.00	0.00	
	Out	0.00	0.00	0.00	
pass3	In	0.00	0.00	0.00	
	Out	0.00	0.00	0.00	
Total	In	0.00	839.91	3.45k	9.10MB
	Out	0.00	581.28	3.41k	6.30MB
	Agg	0.00	1.42k	5.03k	15.40MB

Disk activity during ‘zfs replace’ on a mirror