illumos Brings the SAS!

Kody Kantor - Joyent

Fault tolerance, forecasting, avoidance

Tolerance

- RAID (mirroring, striping)
- Hot spare disks
- Data checksums

Forecasting

- SMART data
- Checksum, read/write error counters
- Phy link state error counters (SMP)

Avoidance

- Using the tools
- Developing a thoughtful storage topology

Operator error can be a software problem

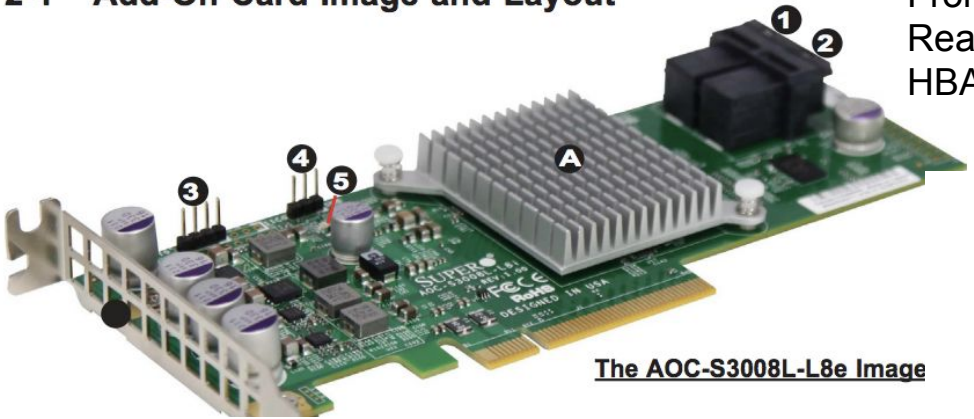
- OS identifies checksum errors in multiple disks, OS swaps in hot spares
- Operator replaces disks
  - loss of redundancy while file system is repairing
- More checksum errors on more disks
- Operator replaces those disks too → loss of data

The operator didn’t do anything that the software didn’t want to do, but history remembers this as operator error.

Hardware failure is complicated!

4U chassis: `CSE-847BE1C-R1K28LPB`

2-1 Add-On Card Image and Layout



The AOC-S3008L-L8e Image

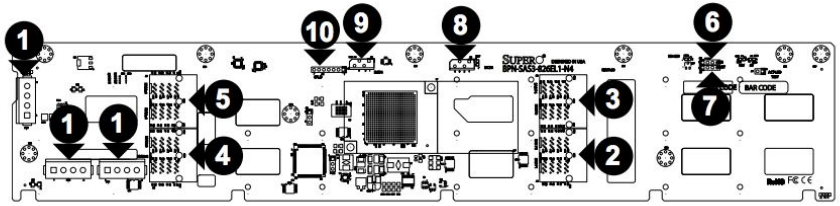


Figure 2-1. Rear Connectors

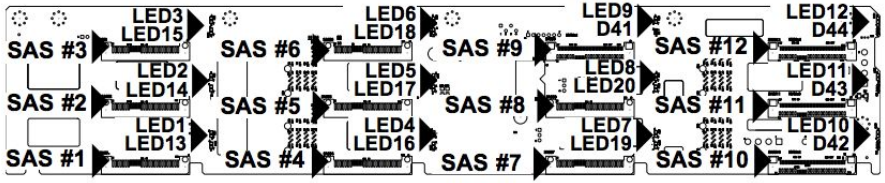


Figure 2-4. Front Connectors and LEDs

Front expander/backplane: BPN-SAS3-846EL1
Rear expander/backplane: BPN-SAS3-826EL1-N4
HBA: AOC-S3008L-L8E-O-P

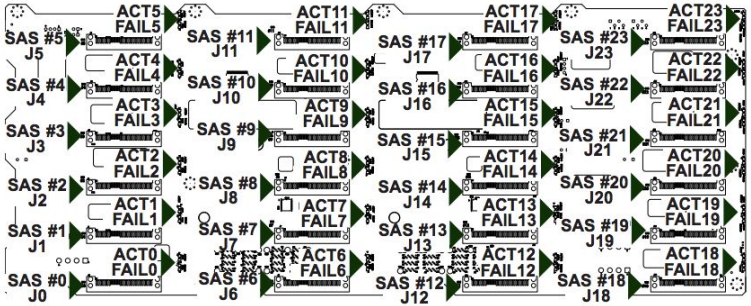


Figure 2-5: Rear Connectors and LEDs

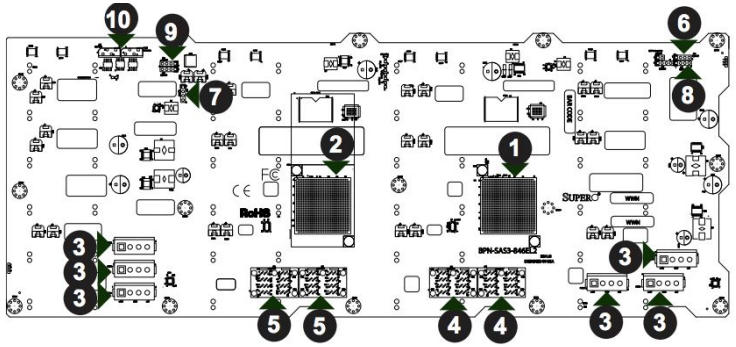


Figure 2-1: BPN-SAS3-846EL1/EL2 Connectors and Components

```
        NAME                        STATE     READ WRITE CKSUM
         zones                       DEGRADED     0     0  783K
           raidz2-0                  ONLINE       0     0     0
             c1t5000CCA2663E6415d0   ONLINE       0     0     0
             c1t5000CCA266432349d0   ONLINE       0     0     0
             c1t5000CCA26643D0C5d0   ONLINE       0     0     0
             c1t5000CCA266599ACDd0   ONLINE       0     0     0  (resilvering)
             c1t5000CCA2664783F9d0   ONLINE       0     0     0
             c1t5000CCA26648B331d0   ONLINE       0     0     0
             c1t5000CCA26648B359d0   ONLINE       0     0     0
             c1t5000CCA2664FDC91d0   ONLINE       0     0     0  (resilvering)
             c1t5000CCA2664BD67Dd0   ONLINE       0     0     0
             c1t5000CCA2664D2F19d0   ONLINE       0     0     0
             c1t5000CCA2664DDF09d0   ONLINE       0     0     0
           raidz2-1                  DEGRADED     0     0 3.04M
             spare-0                 UNAVAIL      0     0     0  insufficient replicas
               5992632002359937610   UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA2664DFA49d0s0
               11916840635972238483  UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA2664E75DDd0s0
             c1t5000CCA2664EEC99d0   ONLINE       0     0     0  (resilvering)
             c1t5000CCA2664EFC65d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA2664FDA09d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA2664FE111d0   ONLINE       0     0     0
             c1t5000CCA2664FE53Dd0   ONLINE       0     0     0
             c1t5000CCA2664FE749d0   ONLINE       0     0     0
             c1t5000CCA2664FED7Dd0   ONLINE       0     0     0
             c1t5000CCA266522C59d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA26652B471d0   DEGRADED     0     0     0  too many errors
             spare-10                DEGRADED     0     0   428
               5360842042799015803   UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA266543AE9d0s0
               c1t5000CCA26650D481d0  ONLINE       0     0     0  (resilvering)
           raidz2-2                  DEGRADED     0     0 9.66K
             c1t5000CCA26659A6B5d0   DEGRADED     0     0 80.8K  too many errors  (resilvering)
             c1t5000CCA266547191d0   DEGRADED     0     0     0  too many errors  (resilvering)
             c1t5000CCA26656A5Dd0   DEGRADED     0     0     0  too many errors
             c1t5000CCA2665683B9d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA2665689F1d0   ONLINE      15     0     0  (resilvering)
             c1t5000CCA26656F471d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA266571B91d0   DEGRADED     0     0     0  too many errors
             spare-7                 DEGRADED     0     0   278
               c1t5000CCA2665798A1d0  ONLINE       0     0     0  (resilvering)
               7600520275299671621   UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA2664D9679d0s0
               11916840635972238483  UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA2664E75DDd0s0
               6056727710802418975   UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA25108D9EDd0s0
               c1t5000CCA26650D889d0  ONLINE       0     0     0  (resilvering)
             spare-8                 DEGRADED     0     0 81.1K
               5913986742299566777   UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA26657BAADd0s0
               13546154985645721239  UNAVAIL      0     0     0  was /dev/dsk/c1t5000CCA266585819d0s0
               c1t5000CCA2665424D5d0  ONLINE       0     0     0  (resilvering)
               c1t5000CCA26653C93Dd0  ONLINE       0     0     0  (resilvering)
               c1t5000CCA2664DC13Dd0  ONLINE       0     0     0  (resilvering)
             c1t5000CCA26657D941d0   DEGRADED     0     0     0  too many errors
             c1t5000CCA266587581d0   DEGRADED     0     0     0  too many errors
         logs
           c1t5000CCA0496FA57Dd0      ONLINE       0     0     0
         spares
           c1t5000CCA2664D9679d0      UNAVAIL   cannot open
           c1t5000CCA2664E75DDd0      UNAVAIL   cannot open
           c1t5000CCA266585819d0      UNAVAIL   cannot open
           c1t5000CCA25108D9EDd0      UNAVAIL   cannot open
           c1t5000CCA26650D889d0      INUSE     currently in use
          c1t5000CCA2665424D5d0      INUSE     currently in use
           c1t5000CCA26653C93Dd0      INUSE     currently in use
           c1t5000CCA2664DC13Dd0      INUSE     currently in use
           c1t5000CCA26650D481d0      INUSE     currently in use

errors: 2088 data errors, use '-v' for a list
```

Bad cable

lsiutil

```
Port Name  Chip Vendor/Type/Rev  MPT Rev  Firmware Rev  IOC
 1.  mpt_sas0  LSI Logic SAS2308 D1  200  0e000000      0
 2.  mpt_sas1  LSI Logic SAS2308 D1  200  0e000000      0

 1.  Identify firmware, BIOS, and/or FCode
 2.  Download firmware (update the FLASH)
 4.  Download/erase BIOS and/or FCode (update the FLASH)
 8.  Scan for devices
 801.  Scan for 1 LUN
 810.  Scan for 10 LUN's
10.  Change IOC settings (interrupt coalescing)
13.  Change SAS IO Unit settings
16.  Display attached devices
20.  Diagnostics
21.  RAID actions
23.  Reset target
```

```
Diagnostics menu, select an option:  [1-99 or e/p/w or
0 to quit] 12
Adapter Phy 0:  Link Up, No Errors
Adapter Phy 1:  Link Up, No Errors
Adapter Phy 2:  Link Up, No Errors
Adapter Phy 3:  Link Up, No Errors
Adapter Phy 4:  Link Up, No Errors
Adapter Phy 5:  Link Up, No Errors
Adapter Phy 6:  Link Up, No Errors
Adapter Phy 7:  Link Up, No Errors
```

```
SAS2308's links are 6.0 G, 6.0 G, 6.0 G, 6.0 G, 6.0 G, 6.0 G, 6.0 G, 6.0 G

 B___T     SASAddress     PhyNum  Handle  Parent  Type
       5003048011281c00           0001          SAS Initiator
       5003048011281c01           0002          SAS Initiator
       5003048011281c02           0003          SAS Initiator
       5003048011281c03           0004          SAS Initiator
       5003048011281c04           0005          SAS Initiator
       5003048011281c05           0006          SAS Initiator
       5003048011281c06           0007          SAS Initiator
       5003048011281c07           0008          SAS Initiator
 0   9 5000cca0168d4889     0     0009    0001   SAS Target
 0  10 5000cca0168ced49     1     000a    0002   SAS Target
 0  11 5000cca0168dc181     2     000b    0003   SAS Target
 0  12 5000cca0168c6411     3     000c    0004   SAS Target
 0  13 5000cca0168d6825     4     000d    0005   SAS Target
 0  14 5000cca0168c73bd     5     000e    0006   SAS Target
 0  15 5000cca0168c63b5     6     000f    0007   SAS Target
 0  16 5000cca0168dc651     7     0010    0008   SAS Target

Type      NumPhys    PhyNum  Handle      PhyNum  Handle  Port  Speed
Adapter      8          0     0001  -->    0     0009     0    6.0
                        1     0002  -->    0     000a     1    6.0
                        2     0003  -->    0     000b     2    6.0
                        3     0004  -->    0     000c     3    6.0
                        4     0005  -->    0     000d     4    6.0
                        5     0006  -->    0     000e     5    6.0
                        6     0007  -->    0     000f     6    6.0
                        7     0008  -->    0     0010     7    6.0

Enclosure Handle   Slots       SASAddress       B___T (SEP)
           0001      8      5003048011281c00
```

Problems

- Some dangerous tooling
- Need an understanding of physical device layouts to identify some problems

What do we do? Step one: build better tools.

Mapping SAS topologies

Hard to get right!

vs

vs

Anything doing multipathing

ht supermicro website

Work in illumos

- SAS topologies may not look like a tree
  - Rob Johnston implemented prototype support for directed graphs
- Use SM-HBA API to discover HBAs and attached devices
- Run a bunch of SMP commands if any expanders with SMP ports are found
- Link up matching WWNs in a directed graph
  - Not so easy! Wide ports, interconnected expanders
- Draw a picture
  - Rob implemented a tool to convert directed graphs to interactive images

sastopo

- A new CLI tool to display SAS topology details
- Discovers paths from initiators to targets in the directed graph
- Optionally prints properties of SAS topology nodes
  - Port PHY link state errors, OS device names, chassis locations
- Optionally serialize topology into XML document

sastopo

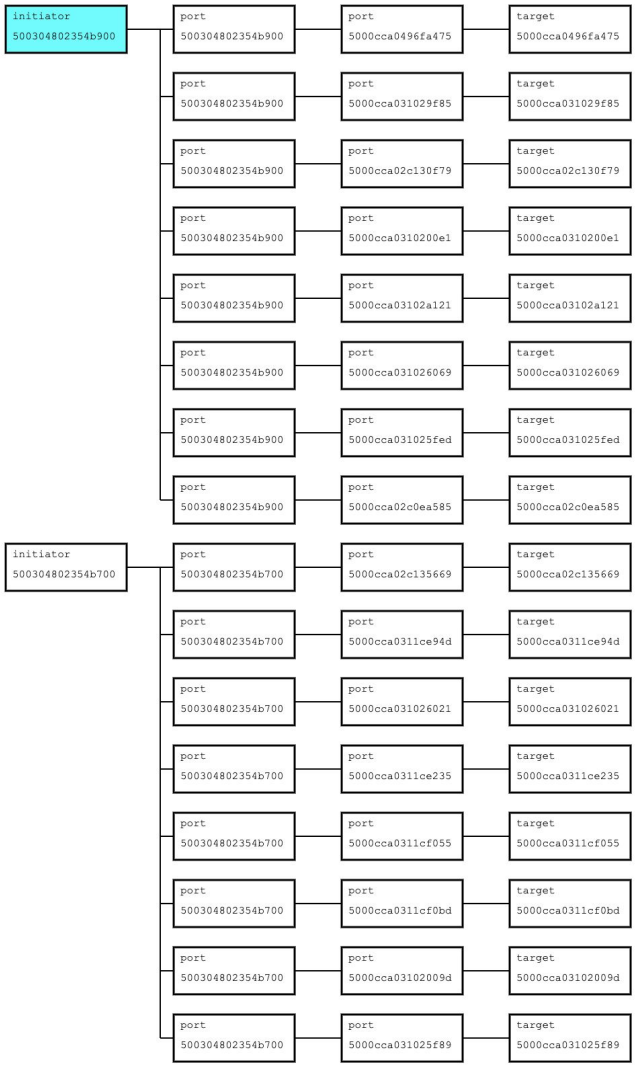
```
$ ./sastopo
sas://type=pathnode/initiator=5003048023567a00
sas://type=pathnode:start-phy=0:end-phy=7/port=5003048023567a00
sas://type=pathnode/expander=500304801861347f
sas://type=pathnode:start-phy=0:end-phy=0/port=500304801861347f
sas://type=pathnode:start-phy=0:end-phy=0/port=5000c500adc881d5
sas://type=pathnode/target=5000c500adc881d5
...

sas://type=path/initiator=5003048023567a00/port=5003048023567a00/port=500304801861347f/expander=500304801861347f/port=500304801861347f/port=5000c500a
dc881d5/target=5000c500adc881d5

$ ./sastopo -V
sas://type=pathnode:start-phy=0:end-phy=0/port=5000c500adc881d5
  group   : port-properties
    local-sas-address    uint64    0x5000c500adc881d5
    attached-sas-address uint64    0x500304801861347f
  group   : protocol
    resource             fmri      sas://type=pathnode:start-phy=0:end-phy=0/port=5000c500adc881d5

sas://type=pathnode/target=5000c500adc881d5
  group   : target-properties
    hc-fmri              string
hc://:product-id=SMC-SC846P:server-id=:chassis-id=500304801861347f:serial=ZL200LB0000000F:part=SEAGATE-ST16000NM002G:revision=E002/ses-enclosure=0/ba
y=0/disk=0
    manufacturer         string    SEAGATE
    model                string    ST16000NM002G
    serial               string    ZL200LB0000000F
    label                string    Slot00
  group   : protocol
    resource             fmri      sas://type=pathnode/target=5000c500adc881d5
```

sastopo2svg

- Written in Rust, cross platform
- Given a serialized XML SAS topology, produces a website bundle (html, svg, js, css)
- Makes it trivial to see how downstream devices can be affected by upstream problems

Host Information	
Nodename	sky1
OS Version	joyent_20191011T170811Z
Snapshot Time	2019-10-22T21:40:04Z

Node Information	
fmri	sas://type=pathnode/initiator=500304802354b900
hc-fmri	hc:///motherboard=0/hostbridge=5/pciexrc=5/pciexbus=134/pciexdev=0/pciexfn=0
devfs-name	/devices/pci@7d,0/pci8086,2030@0/pci15d9,808@0
name	initiator
manufacturer	Broadcom / LSI
model	SAS3008 PCI-Express Fusion-MPT SAS-3
serial	
label	CPU2 SLOT 2 PCI-E 3.0 X16



System info

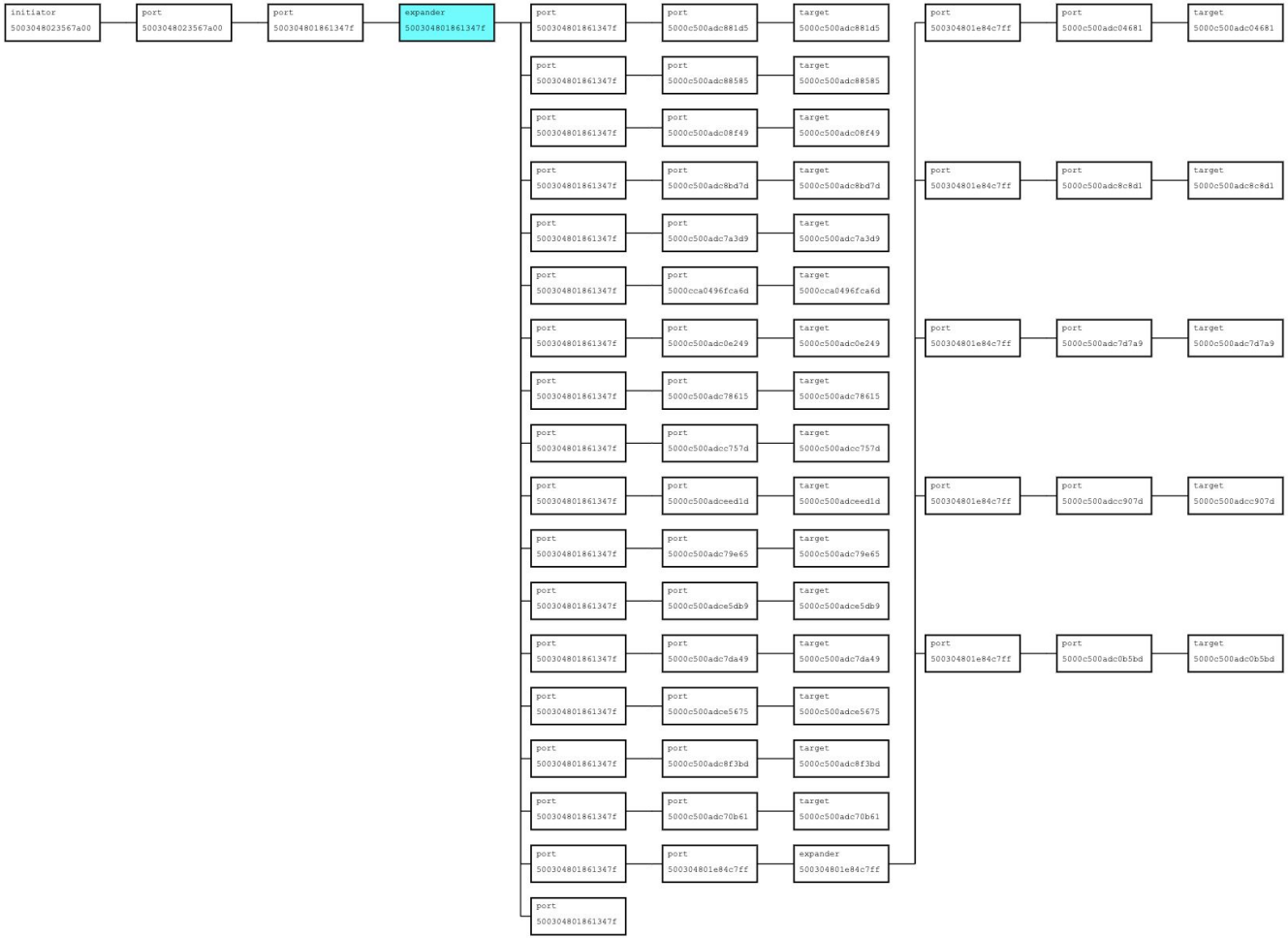
2U, dual HBA, 16 direct-attached disks

Host Information	
Nodename	magma
OS Version	joyent_20191011T170811Z
Snapshot Time	2019-10-28T21:41:51Z

Node Information	
fmri	sas://type=pathnode/expander=500304801861347f
name	expander
devfs-name	/devices/pci@7e,0/pci8086,2030@0/pci15d9,808@0/iport@ff/smp@w500304801861347f:smp

System info

4U system, one HBA, two daisy-chained expanders, direct-attached disks



Goals

Short term:

- More accessible operator tooling (sastopo, sastopo2svg)

Longer term:

- Enhance FMA with ability to provide more targeted diagnosis and suggested actions
- Make better zpools
- Prevent ZFS Retire Agent from swapping out drives when a shared component is at fault

Further reading

- illumos WIP:
  - https://github.com/joyent/illumos-joyent/tree/sastopo
  - https://github.com/joyent/sastopo2svg
  - https://github.com/joyent/topo-digraph-xml
- Original ZFS + FMA integration: https://illumos.org/opensolaris/ARChive/PSARC/2006/139/index.html
- BoM for 4U server (HBA + two expander backplanes): https://docs.joyent.com/private-cloud/hardware#joyent-mantis-shrimp-mk-iii
- SM-HBA driver support in illumos: https://github.com/illumos/illumos-gate/blob/master/usr/src/uts/common/io/scsi/adapters/mpt_sas/mptsas_smhba.c

A catastrophe timeline

- **December 18, 2018**: '**MS1000 vanished**'
- December 19, 2018: Chassis swap
  - New chassis is dead on arrival (bad CPU)
  - No spare CPUs on hand, cannibalize CPU from the old machine.
  - Machine boots! Numerous disk and memory errors
    - Memory Error BIOS OEM Memory signal is too marginal. (P1-DIMMD1) - Assertion
  - Still many errors attempting to access disks
  - No spare chassis available (to replace HBA, expander, cables, etc. all at once)
  - Order backup parts (motherboards, CPUs) from vendor
- January 2, 2019: Replacement parts have not arrived (had to be imported)
- January 8, 2019: Replacement parts clear customs and are delivered to DC
- March 4, 2019: Guess-and-checking each disk reveals that 20 disks failed
- March 8, 2019: Root cause discovered: PSU blew - literally - destroyed much of the machine
- Replaced all 20 failed drives and things are 'fine' again

Misconfigured pool

```
NAME                        STATE     READ WRITE CKSUM
zones                       ONLINE       0     0     0
  mirror-0                  ONLINE       0     0     0
    c1t5000CCA080730AE9d0   ONLINE       0     0     0
    c1t5000CCA08077FD25d0   ONLINE       0     0     0
  mirror-1                  ONLINE       0     0     0
    c1t5000CCA080780225d0   ONLINE       0     0     0
    c1t5000CCA080793CDDd0   ONLINE       0     0     0
  c1t5000CCA08078D9F9d0     ONLINE       0     0     0
  mirror-3                  ONLINE       0     0     0
    c1t5000CCA08078F339d0   ONLINE       0     0     0
    c1t5000CCA08078F46Dd0   ONLINE       0     0     0
  c1t5000CCA08079089Dd0     ONLINE       0     0     0
  c1t5000CCA080793329d0     ONLINE       0     0     0
  mirror-6                  ONLINE       0     0     0
    c1t5000CCA08079346Dd0   ONLINE       0     0     0
    c1t5000CCA080793675d0   ONLINE       0     0     0
  c1t5000CCA02D77D355d0     ONLINE       0     0     0
  c1t5000CCA02D7756F1d0     ONLINE       0     0     0
  c1t5000CCA02D773F1Dd0     ONLINE       0     0     0
logs
  c1t5000CCA0496F99C1d0     ONLINE       0     0     0
spares
  c1t5000CCA02D7746F1d0     AVAIL
```