SCSI Multipathing in OpenBSD

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Introduction

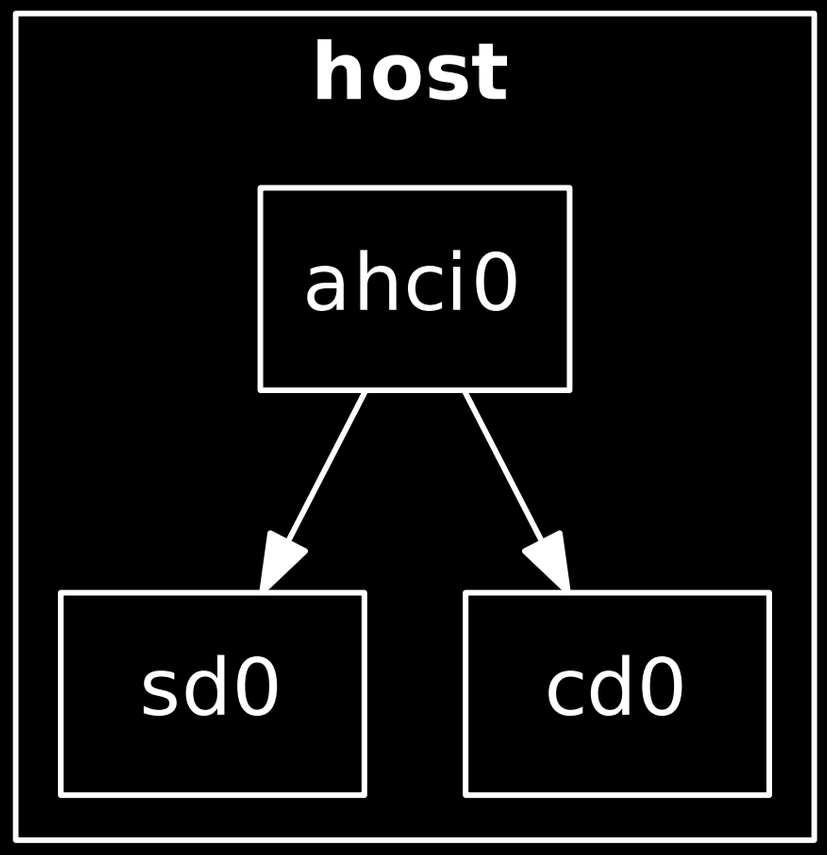
- who am I?
- what's the problem?
- what was the problem in OpenBSD?
- who has already solved it and how?
- how did I solve it?

Who am I?

- Infrastructure Architect in the Faculty of Engineering, Architecture and Information Technology at The University of Queensland in Australia
  - tl;dr: I'm dlg@uq.edu.au in EAIT at UQ
- a core developer^W^Wrecent slacker in OpenBSD

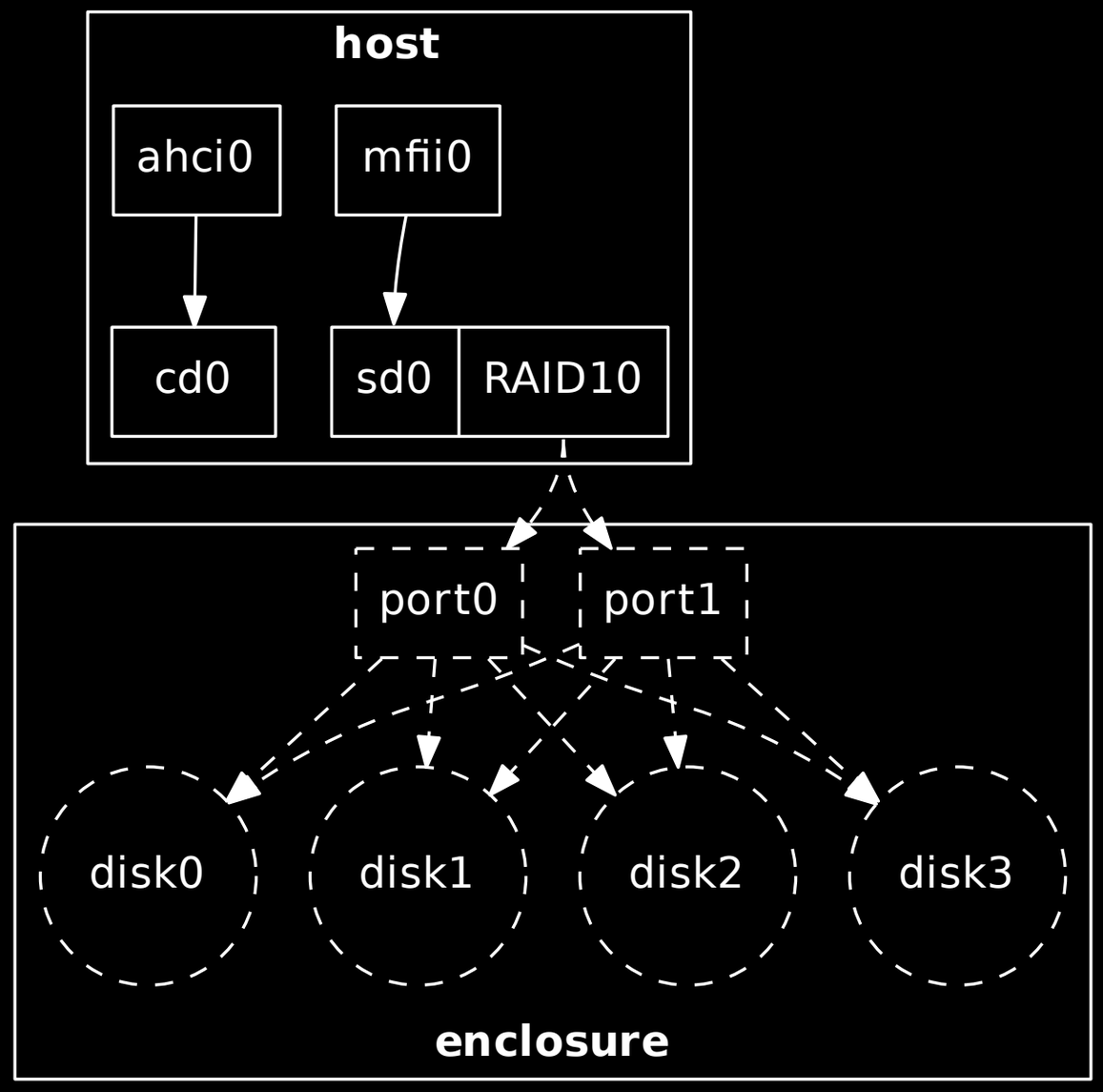
What's the problem?

- we all have something like this:



What's the problem?

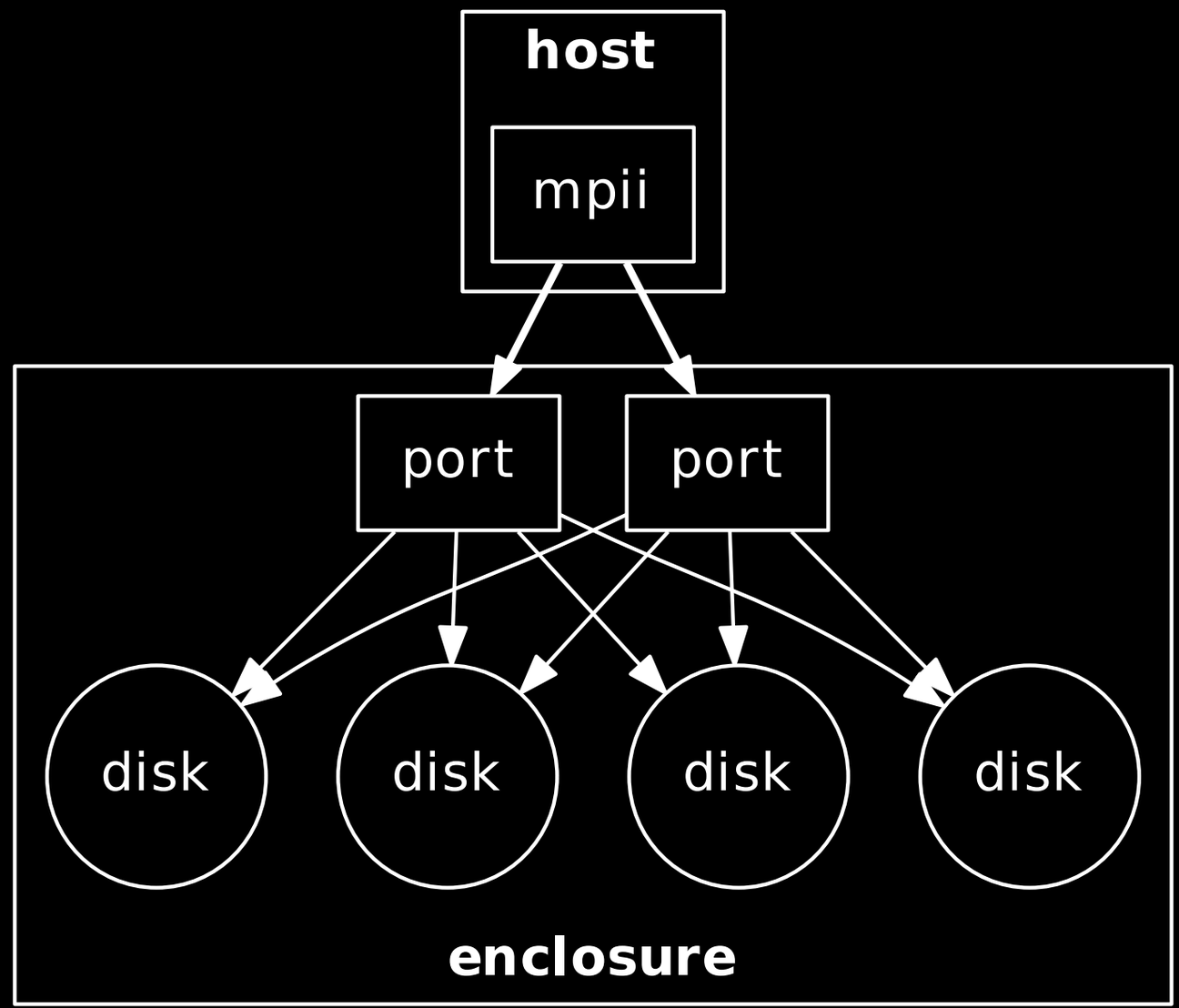
- ... or if we're lucky something like this:



What's the problem?

- in both those cases the hosts have adapters that wired straight to to SCSI devices
  - the RAID controller hides the physical complexity
  - the SCSI you see is only visible on one adapter
- but what if we replaced that mfii (hardware RAID) with an mpii (vanilla SAS adapter)?

What's the problem?



What's the problem?

- now we see each disk twice
  - a single physical disk will attach as two separate sd(4) instances in OpenBSD
  - once per path
  - that is the problem
- so what does that mean?
- and what can we do with or about it?

SCSI Basics

- SCSI is a family of standards defined by T10
- roughly split between commands and transports
- commands are the messages between initiators (hosts) and logical units (eg, disks, tape drives)
- transports are the wires and stuff you run the commands over

SCSI Commands

- surprisingly sane
- separate command and data payload
- only the initiator (client or host) sends commands to LUs (server or device)
- commands are stateless
- targets can complete commands with extra info called sense data

SCSI Transports

- commands sit on top of transport protocols like SPI, FC, SAS, iSCSI, USB, FireWire, ATAPI, etc
  - or a RAID implementation
  - or an emulation/translation layer (eg, SATL)
- surprisingly transparent to the command layer
  - except for USB and ATAPI

SCSI Topologies

- the simplest is a target plugged into an initiator
  - but...
- a computer can have multiple SCSI adapters
- a adapters and disks can have multiple ports
- you can put switches in between them
- you can put RAID in with a box full of disks
- that RAID can be "highly available"

SCSI Topologies

- yet SCSI as a protocol only cares about links between initiators and a logical units
  - SBC/RBC/SES etc don't really care
  - T10 didn't really address this until recently
- so multiple paths are a software problem
- multipath is historically expensive, complicated, and very proprietary
  - OpenBSD just isn't in that space

SCSI in OpenBSD

- *"Originally written by Julian Elischer for TRW Financial Systems for use under the MACH(2.5) operating system"*
  - from 1992 or earlier - this comment still exists
- largely unchanged in OpenBSD for 15 or 17 years
- assumed LUs were only visible to a single adapter
- the SCSI stack was cut into three layers: adapters, midlayer, and targets

SCSI Adapters

- attaches the midlayer to hardware controllers
  - or SCSI command "sinks"
- takes SCSI commands from the midlayer and moves them on and off the hardware
  - isn't required to maintain target state
  - really just command transport

The SCSI Midlayer

- appears as scsibus(4) in the device tree
- target probing/attachment
- basic management of openings per LU
- API for command submission
  - biased to block I/O
  - completely synchronous unless you were doing block I/O
- grew hotplug and different sized busses

SCSI targets

- target drivers (sd/cd/st/etc) got support for modern commands (eg, big read/writes, read capacity 16, etc)
- ses was replaced with new ses/safte drivers
- had to grow hotplug like the midlayer
- ...but everything worked pretty well so didn't need fixing and nothing significant changed

Multipath gear

- at my job I get to replace expensive, complicated, and very proprietary equipment, and keep the old bits as toys
- I get to play with a lot of "big" hardware and a handful of different operating systems
- multipath gear is relatively cheap now
  - iSCSI, SAS, and 2nd hand FC gear is easy to get, but you have to want it

Multipath gear

- I decommissioned an EMC CX-500 and then a StorageTek STK6140 (both FC)
- sun servers generally don't need RAID because Solaris is good
  - I have spare v880s with two FC loops
- we've bought a Dell MD3000i and MD3200i
- lots of JBODs with redundant SAS backplanes
- accepted old FC kit and using bits as JBODs now

What do others do?

- "serious" operating systems have proper stacks
- wikipedia has a list
- however, the ones I'm going to talk about
  - GEOM_MULTIPATH and GEOM_FOX in FreeBSD
  - dm-mpio in Linux (and NetBSD?)
  - mpxio and scsi_vhci in Solaris

GEOM Multipathing

- works at the block level - no SCSI knowledge
- the same LU will appear multiple times out of the SCSI layer as separate GEOM instances
- GEOM will recognise this and consume all the paths, and will make a single producer appear
- Only one path is used until it goes away or fails IO

GEOM Multipathing

- I can't see a significant difference between MULTIPATH and FOX from the documentation
- GEOM requires a label on disk to recognise multiple paths, doesn't use hardware/LU IDs
  - the hardware can tell you this stuff, requiring a human to press buttons makes it error prone and harder than it should be to use
- some hardware will accept I/O on secondary controllers without errors, but go slower

dm-mpio

- works at the block layer again
- but issues SCSI commands to paths (via ioctl)
  - has vendor specific code to make decisions
    - checkers ask if the path can accept I/O
    - prioritizers ask how good a path is
- will use all available paths for I/O and do failover and failback etc

GEOM and dm

- working at the block layer means only block devices get multipathing
  - enclosures, tapes, libraries, etc miss out
  - relies on I/O failure or path removal for failover
    - I/O failure can mean more than a bad path
- however, doesn't require more from a stack
  - if block I/O, hotplug, and failure handling are there, then GEOM and dm-mpio should be fine

mpxio and scsi_vhci

- Multiplexed I/O and SCSI Virtual Host Controller Interface
- multipathing done at the SCSI layer, not block
- scsi_vhci acts like a normal SCSI adapter driver in the Solaris kernel
- SCSI requests against scsi_vhci end up in mpxio which routes them to paths on real adapters

mpxio

- real adapter drivers have to be modified to support mpxio
- mpxio requires alternate hotplug and command handling to normal SCSI stack
  - new devices get presented to mpxio first which can decline taking them
  - alternate SCSI command paths

mpxio

- mpxio builds groups of paths and handles scheduling of I/O within those groups
- vendor specific handling is implemented in modules which a third party can supply
- the modules handle claiming of paths, testing of paths, interpretation of sense data, path prioritisation, and activation of paths

Multipath in OpenBSD

- so I had equipment and interest
  - but not a lot of time :(
- I started in 2008 and "finished" it a month ago
  - but effectively rewrote most of the SCSI midlayer along the way and touched most SCSI adapters
  - mostly inspired by mpxio with help from dm-mpio

SCSI Device IDS - devids

- modern SCSI devices provide identifiers via VPD page 83 (or we fake them with serials or bus IDs)
- made up of a type and a buffer, eg
  - naa.500000e010902de0
  - t10.ATA_ST3320620AS_5QF075CF
  - serial.0781556b420F0AC34077
- a LU will present the same devid no matter where or how many times it gets attached

mpath(4)

- a virtual SCSI adapter (like scsi_vhci)
  - presents a single SCSI device to the kernel
  - sends commands down paths
  - an API for paths to register with (along with a bunch of callbacks)
    - path registration is voluntary (ie, mpath doesn't go and look for paths itself)
    - relies on devids to identify and collect paths

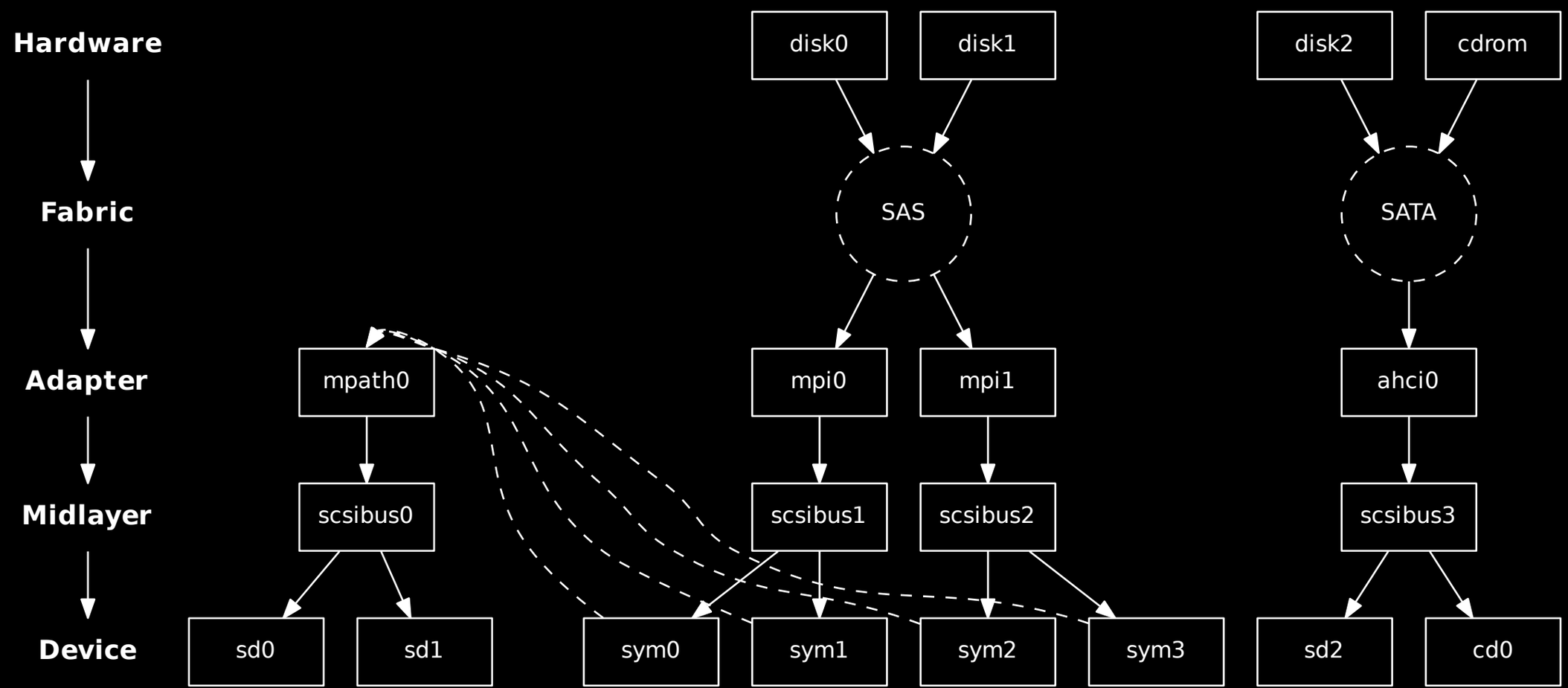
mpath(4)

- I did the original mpath at f2k9
- had the midlayer intercept paths and give them to mpath before normal autoconf
  - easy support for symmetric access devices
  - had to special case a bunch of stuff in attach/detach paths, but it worked and was reliable
  - started on LSI/Engenio support then realised I was rewriting autoconf inside scsibus(4)

mpath path drivers

- vendor/device specific knowledge is now implemented as a traditional device driver
  - eg sym(4), rdac(4), hds(4), emc(4)
  - uses autoconf *foo*_match() to claim a path
  - path drivers implement the callbacks mpath needs to work with too
  - *foo*_attach() registers the device as a path with mpath_attach_path()

mpath stack


Hardware
Fabric
Adapter
Midlayer
Device
disk0
disk1
disk2
cdrom
SAS
SATA
mpath0
mpi0
mpi1
ahci0
scsibus0
scsibus1
scsibus2
scsibus3
sd0
sd1
sym0
sym1
sym2
sym3
sd2
cd0

mpath vs the midlayer

- at f2k9 I discovered that the synchronous behaviour of the API the SCSI midlayer provided was really annoying, almost soul destroying
- mpath(4) acts as a proxy
  - requests to it are done by issuing new requests over paths with lots of copied values
  - to get async or concurrent commands I would have had to reuse or fake a struct buf

Old SCSI API

- the midlayer tried to be helpful by calling biodone() on behalf of sd(4), cd(4), etc
  - so couldn't reuse the buf cos it would get completed twice
- async completions only got block I/O state
  - so couldn't copy SCSI state from path xfer into the mpath xfer to provide total transparency

Old SCSI API

- async path completion would have caused mpath I/O to restart from interrupt context, and we have to try and do it because of the contract between layers
  - we would end up doing synchronous and polled SCSI xfers for multipath targets
- so I rewrote the guts of the midlayer
  - krw@ has talked this a couple of years ago

New SCSI API

- totally event driven (except for autoconf)
  - even resource allocation is via callbacks
  - command submission from any context
  - completion via callbacks with complete scsi_xfer state intact until explicitly freed
- no midlayer knowledge of block I/O anymore
  - all contained in sd(4), cd(4), st(4) now

New SCSI API

- improved command scheduling
  - round-robin access to contended resources
- simplified midlayer and adapter interactions
  - introduced a lot of fine grained locking
  - provided compat via wrappers, but that's all gone
    - new sync API on top of the callback ones

mpath(4) and new SCSI

- mpath(4) I/O path got rewritten against a midlayer that was rewritten largely cos mpath(4) needed it
- now supports asynchronous and concurrent command submission and can intercept sense data for failure detection
- has had solid support for symmetric and asymmetric devices in sym(4) for a year or three

"finishing" mpath(4)

- this talk got accepted so I had to finish mpath(4)
- it lacked support for controller failover
  - it only attached paths on active controllers
    - if LUN ownership in an array changed mpath(4) wouldn't notice and I/O would fail or stop
- only supported paths on a device

"finishing" mpath(4)

- implemented groups between paths and devices
  - groups identified by path driver at attach time usually by querying which controller they're on
    - groups are either active or inactive
    - all paths in the active group get I/O
      - round-robin in the active group
- asym devices add each path to different groups so mpath(4) doesnt have to do MRU anymore

"finishing" mpath(4)

- implemented detection of LUN ownership change by fleshing out path drivers sense callback
  - intercepted on the way back from normal I/O
- groups are queried for their active state until one is found, then I/O resumes as normal
- querying is implemented as a state machine
  - originally as a task in a thread but OMG PAIN
  - event based with callbacks now

mpath(4) in practice

- multipathing exists to increase availability of SCSI devices and hide transient failures or topology changes from things using them
- ie, mpath(4) is there to tell lies
  - eg, don't panic if you unplug the disk / is on
- increased bandwidth is nice, but meh
- to lie well it needs to trust what it sits on top of

mpath(4) in practice

- you need adapter drivers that handle failures and timeouts, and do hotplug really well
  - that means mpi(4), mpii(4), and vscsi(4)
  - isp(4) resists us at the moment
- I've been extremely conservative about which devices path drivers claim
  - might make it conditional adapter driver too

mpath(4) in practice

- you need very intimate detail about your devices
  - sym(4) is free
  - dm-mpio is the best reference we have :(
  - rdac(4) is working great cos I have it plugged in
  - I will update hds(4) and emc(4)
  - path drivers are easy if you can get the hardware knowledge, so please help

mpath(4) in reality

- mpath(4) is not enabled in GENERIC yet
- very solid on top of mpi(4), mpii(4), vscsi(4)+iscsid(8)
  - but iscsid(8) is not enabled or finished really
- sym(4) support likely to be the most popular
  - the hardware is cheap
  - but people will expect a lot from software RAID

mpath(4) in the future

- enable mpath(4) and sym(4) at least
- logical-block I/O scheduling is necessary
  - difference between 10MB/s and 120MB/s writes
    - may improve path utilisation too
- add path drivers as hardware and time permits
- mpath ahci(4)?
- mpath on clustered RAID?

Questions?