

# The Magic Which Makes macos Volumes Fast

## Tim Standing

Vice President Software Engineering - Mac Other World Computing, Inc.







# The Magic Which Makes macos Volumes Fast and Reliable



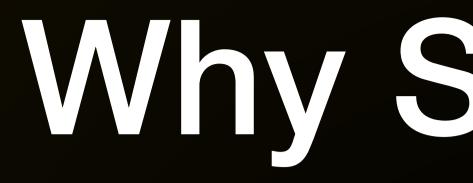
# Storage Speed Increases PCle Gen4 Thunderbolt 5

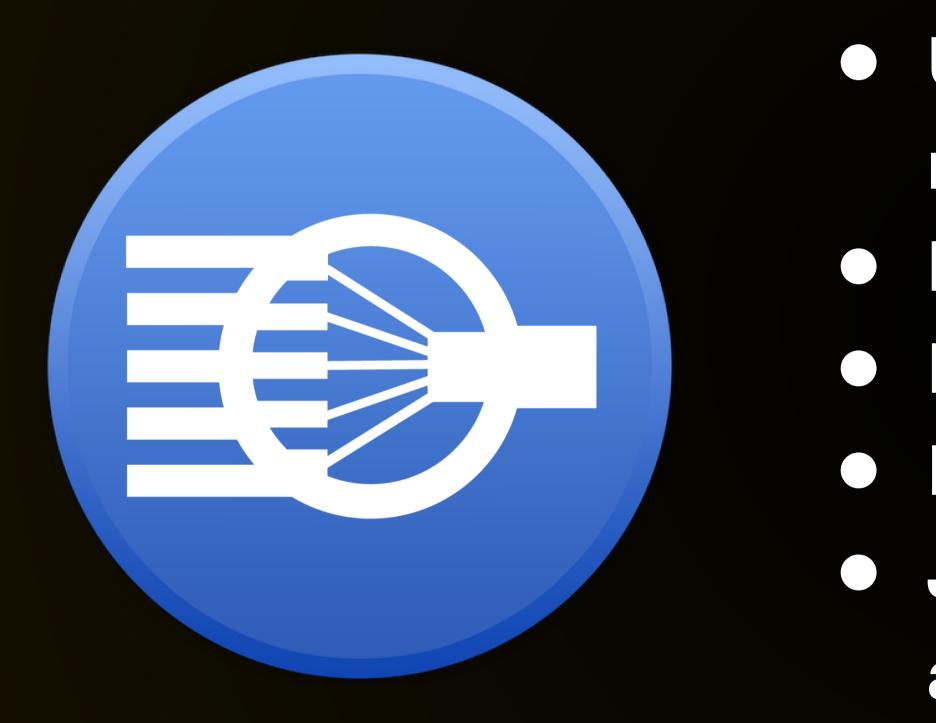
### Fast



## Storage Speed Increases Year After Year





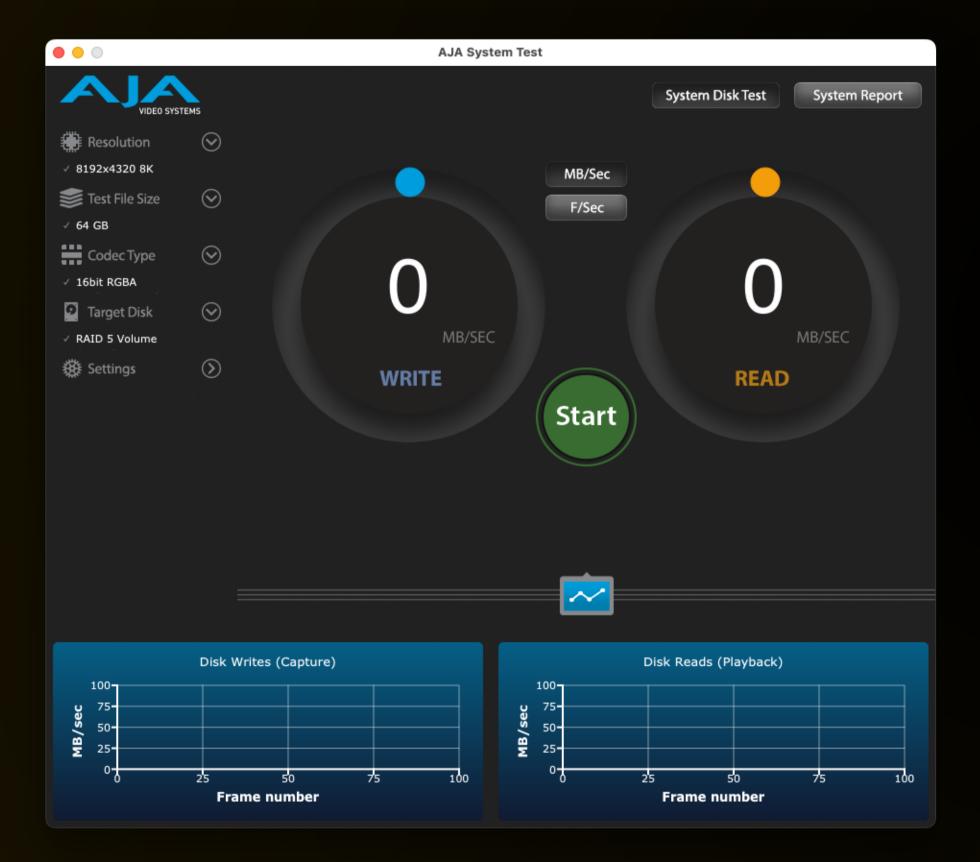


# Why SoftRAID?

- Used in all OWC enclosures with 4 or
- more disks
- No hardware dependencies
- Much better performance
- Better disk health tracking
- Just plug in and go (with macOS 13.3) and later)



# Testing Speed



#### AJA System Test Settings

- 64 GB Test File
- 16 bit RGBA
- 8192x4320 8K
- DMA Mode: Dual Engines





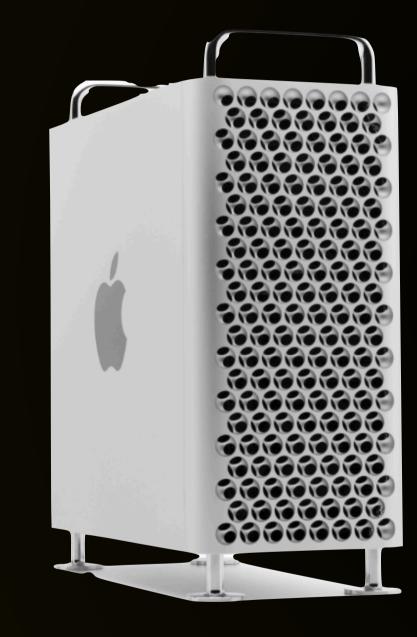


# 









#### Accelsior 4M2 + 2019 Mac Pro, RAID 0 = 6 GB/sec

# 2019





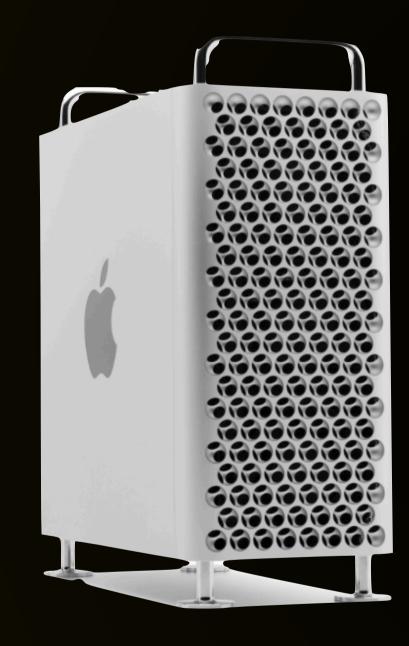


#### 4 Thunderblades + Mac Studio, RAID 0 = 10 GB/sec

# 2022







#### Accelsior 8M2 + 2019 Mac Pro, RAID 0 = 12 GB/sec

# 2022

# A constant and a Mo

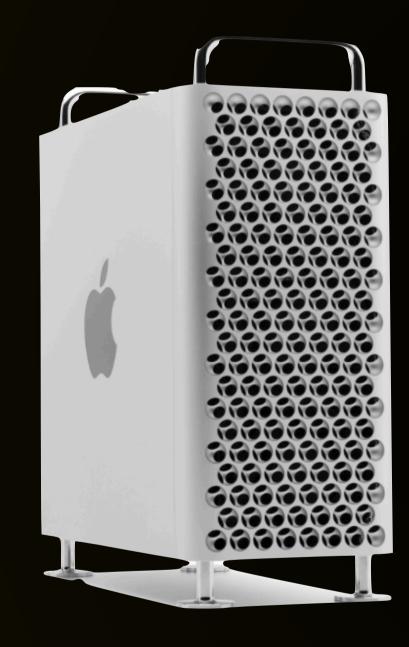


# Accelsior 8M2



# 16 Lane - PCle Gen 4 Sizes up to 64 TB 8 NVMe blades





#### Accelsior 8M2 + 2023 Mac Pro, RAID 0 = 24 GB/sec

# 2023

# A contraction of the second se



# Accelsior 8M2



#### RAID 0



#### RAID 5







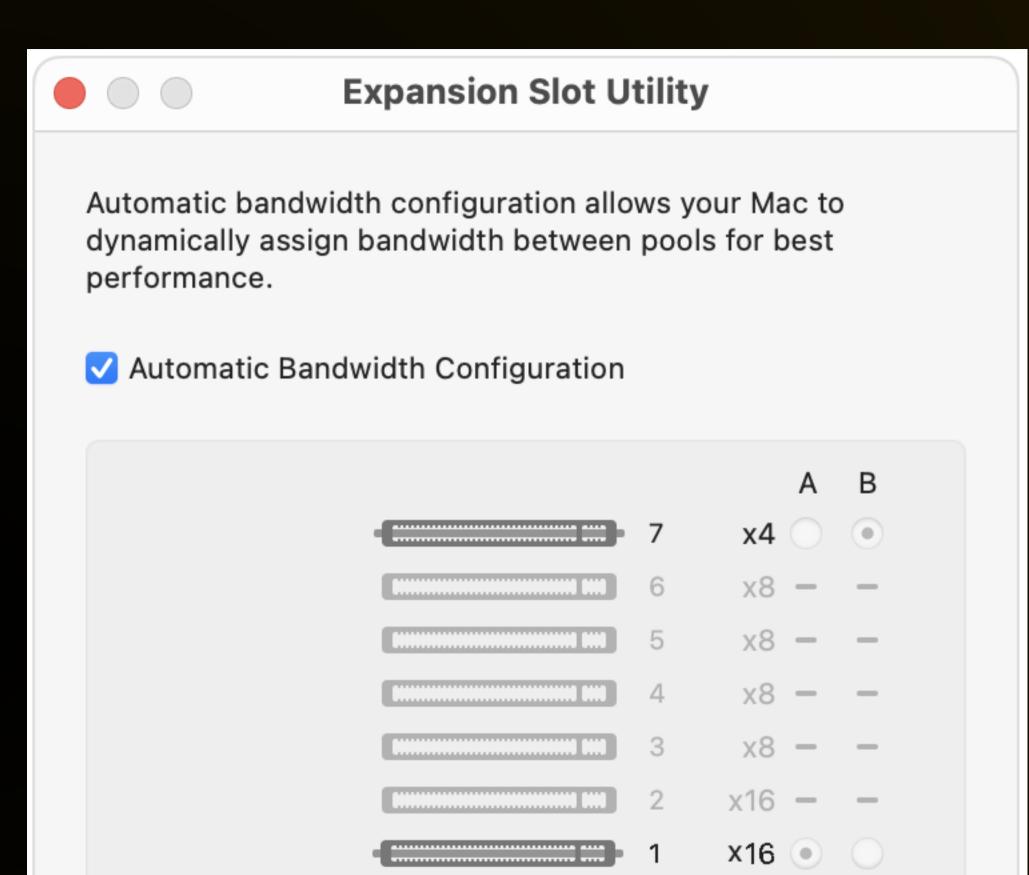
# Double speed of PCI Gen 3 •2 GB/sec/lane More power & more heat

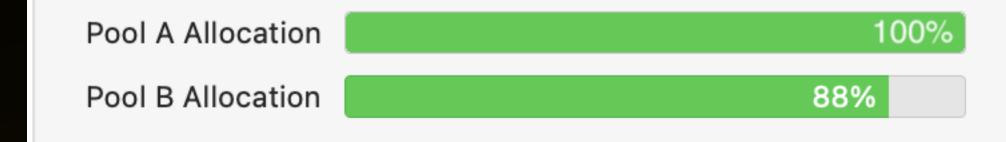
## PCI Gen 4



## 2023 Mac Pro PCIe Lanes

2 Pools: -16 lanes -8 Lanes









## Thunderbolt 5

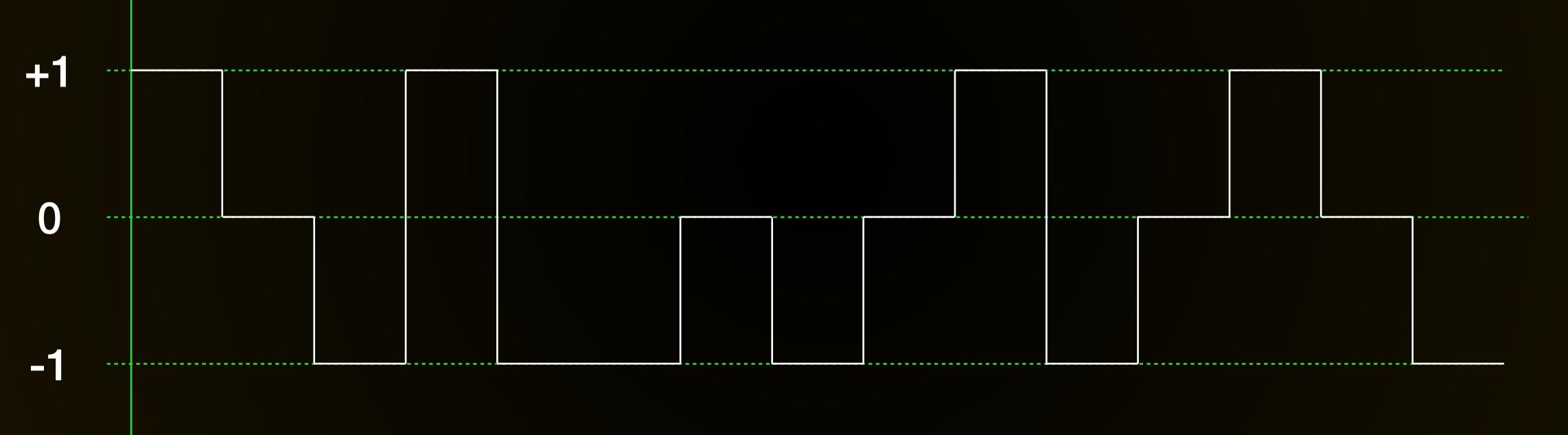


## Thunderbolt

Thunderbolt Version	1	2	3	4	5
Gb/s	10 Gb/s	20 Gb/s	40 Gb/s	40 Gb/s	80 Gb/s
Data Rate GB/s	0.7 GB/s	1.4GB/s	2.8 GB/s	2.8 GB/s	5.6 GB/s
PCIe	Gen 2 2 Ianes	Gen 2 4 Ianes	Gen 3 4 Ianes	Gen 3 4 Ianes	Gen 4 4 Ianes



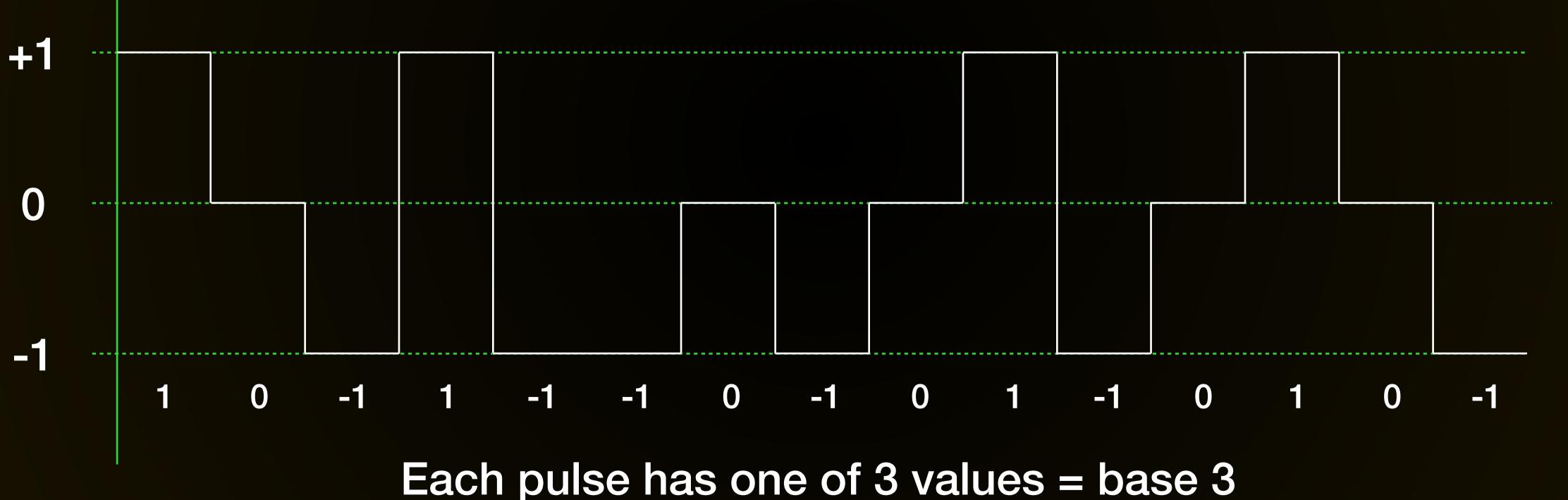
# Thunderbolt 5 Signalling PAN-3



**Pulse Amplitude Modulation** 3 Levels





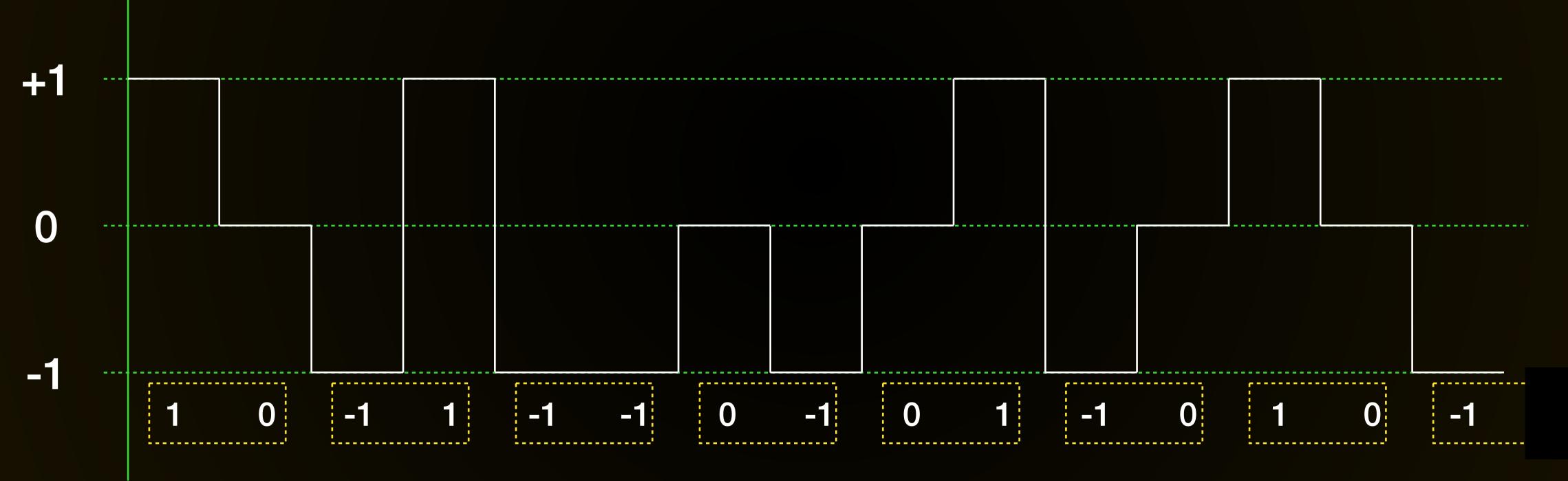


## Thunderbolt 5 Signalling PAN-3

2 pulses =  $3^2$  possible values



# Thunderbolt 5 Signalling PAM-3



2 pulses used to encode 3 binary bits



Thunderbolt Passive



USB





#### Works for Thunderbolt 3 - 5

#### Thunderbolt 3 Active

#### Thunderbolt 4 Active

#### Thunderbolt 5 Active







#### Don't Use

#### Use for Thunderbolt 3 & 4

#### Use for **Thunderbolt 5**



USB



•Slower Less Reliable Not Certified

Don't Use

Might work for Thunderbolt



#### Thunderbolt Passive



# Works for all Thunderbolt levels Avoid 2 m cables ( = Thunderbolt 2 speed)

Works for Thunderbolt 3 - 5



#### **Thunderbolt 3** Active





USB devices run at USB 2.0 speed (40 MB/sec)





 Protecting the System Volume Are kexts going to disappear? •What is Bit-Rot History of Volume Loss An Example of Volume Loss

- Reliability



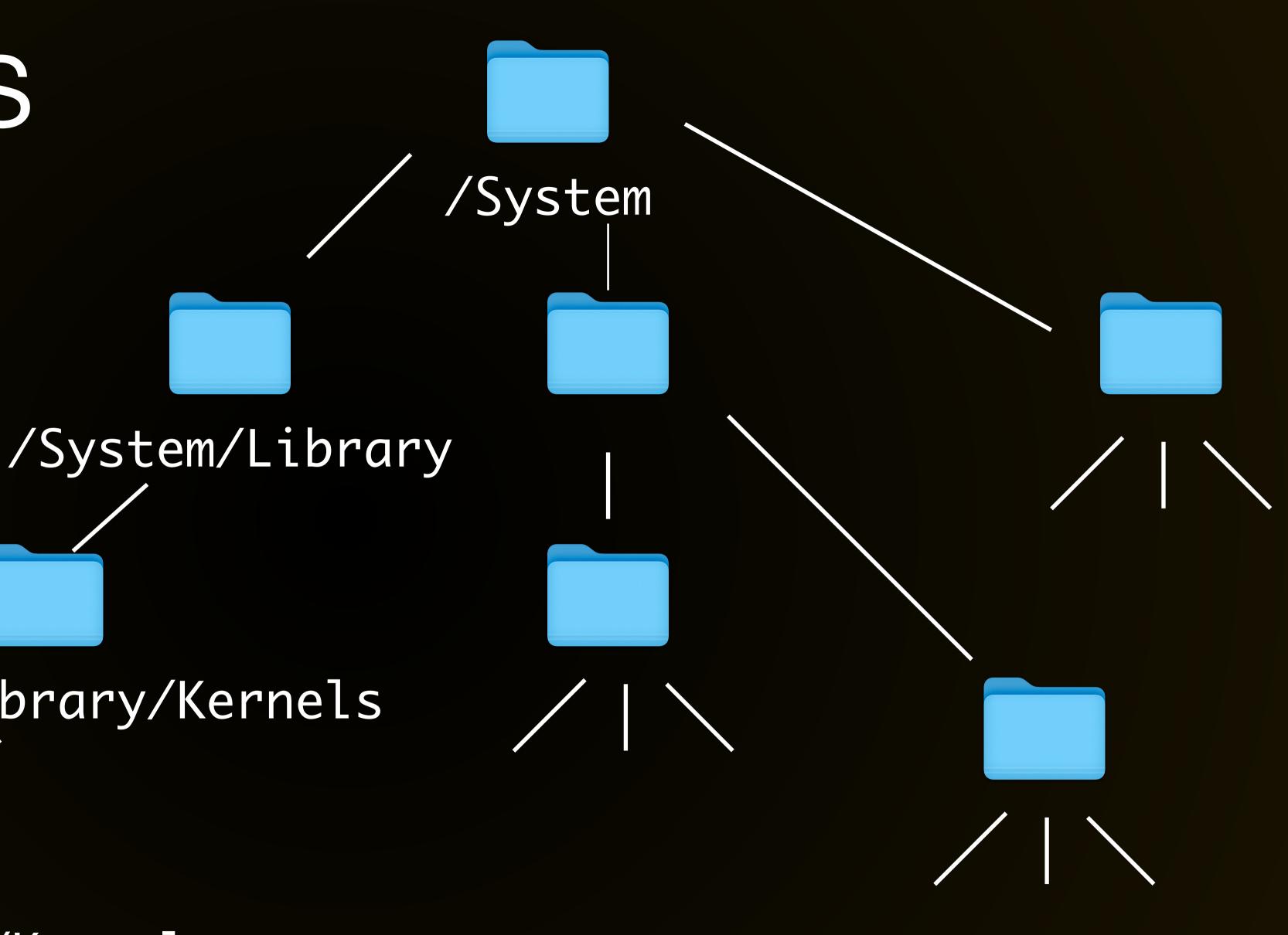
# **Protecting the System Volume**





#### /System/Library/Kernels

/System/Library/Kernel



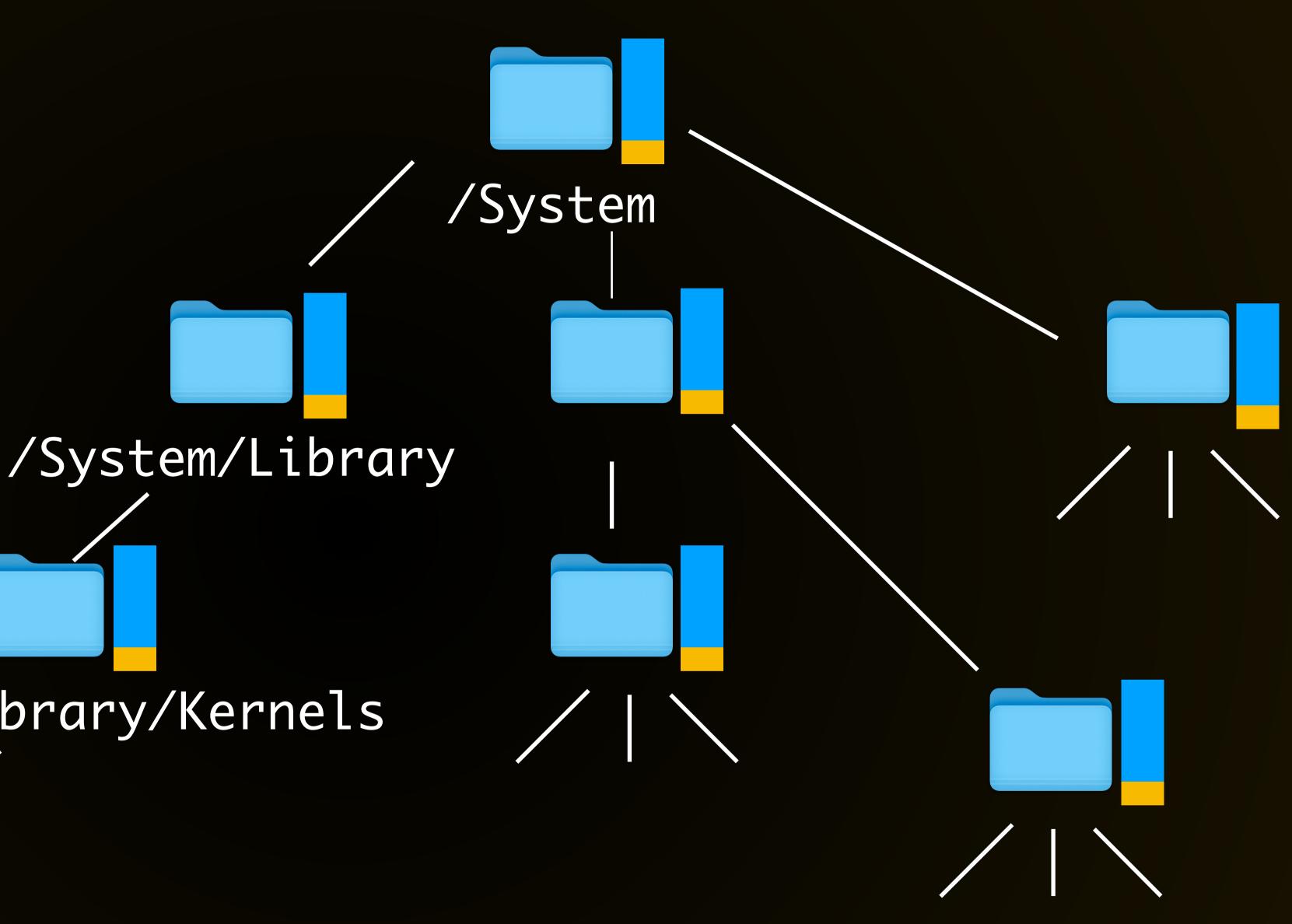


#### = metadata

= checksum

#### /System/Library/Kernels

/System/Library/Kernel





# Signed System Volumes

•••	Disk Uf
Internal	
✓	
✓	
∽ 😂 Cortado volumes	
🗸 🗁 Cortado	
😑 Cortado snapshot	
😑 Cortado - Data	<b>Used</b> 9.17 GB
	Mount Point (
	Capacity:
	Available:
	Used:
	Snapshot Nan

Utility + │ — ♡ Volume First		<del>ය</del> ි ර irase Restore	⊜ Unmount	(j) Info
<b>Cortado</b> APFS Startup Snapshot • APFS (E macOS 13.6 (22G120)	Encrypted)	5	1 TB Shared by 8 volumes	
Other Volume 348.5 GB	Free 642.57 GB			
t (Read-Only): /	Туре:	APF	S Startup Snapshot	
1 TB	Owners:		Disabled	
644.07 GB (1.49 GB purgeable)	Connection:		PCI-Express	
9.17 GB	Device:		disk1s2s1	
ame: com.apple.os.update-192FEF8	Snapshot UUID:	992601F4-8E	73-4D0F-9F46-A	



#### System Volume

																	5	S
stano 																		
	Co:																	
	AP Si Ca Ca	FS ze pa	ci		nt ap y	a a I	in ci n	t U	r y s	e l	Re Ce	ef ei Sy	e 1	re in Vo	en ng	ic( ) .ur	e :	:
	 +																25	\$2
	   			PF:			hy	s	i	c	a]		s	to	or	e	0	Di
-	 +-: 	>	Vo	)1	um	ie	d	li	s	k:	15	:1		96	99	53	33	32
	     		Na Mo Ca Se	PF amo apa apa apa	e: nt ac le	i	Po ty :	i,	n C	t	:							Le
(	+-:	>	Vo	1	um	ie	d	li	s	k:	15	52		1/	٩E	в	36	34
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	     		Sr Sr	naj naj naj	o s	h h	ot ot		M	01	ur	۱t			<b>j</b> i	.n <sup>-</sup>	t:	

```
standing — -zsh — 77×38
                                            \blacksquare
list disk1
2C05-4EA1-B78F-CEED3C791B7D
_____
    disk1
   1000240963584 B (1.0 TB)
: 357651013632 B (357.7 GB) (35.8% used)
    642589949952 B (642.6 GB) (64.2% free)
 E8F4A4ED-AEE8-444E-AE04-276585F07163
.sk: disk0s2
     1000240963584 B (1.0 TB)
22-8CE8-4CC3-8252-31D47B320E31
_____
e): disk1s1 (Data)
    Cortado - Data (Case-insensitive)
    /System/Volumes/Data
    169620041728 B (169.6 GB)
    No
    Yes (Unlocked)
4-DE4C-49CB-BB61-DD6822E31F56
_____
e): disk1s2 (System)
    Cortado (Case-insensitive)
    Not Mounted
    9167335424 B (9.2 GB)
    Yes
    Yes (Unlocked)
    No
    992601F4-8E73-4D0F-9F46-A3073FE99140
    disk1s2s1
     Yes
```



### Snapshot of System Volume

		់ ទ
 + Cont	g@Yu ~ % diskutil a ainer disk1 6EF020	48-2
APFS Size Capa	Container Referen Container Referen Capacity Ceiling Acity In Use By Vol Acity Not Allocated	ce: ): umes
+-<	Physical Store dis	k0s2
	APFS Physical Stor Size:	e Di
+->	Volume disk1s1 909	5332
	APFS Volume Disk ( Name: Mount Point: Capacity Consumed: Sealed: FileVault:	
 +->	Volume disk1s2 1AE	B3E4
	APFS Volume Disk ( Name: Mount Point: Capacity Consumed: Sealed: FileVault: Encrypted:	
	Snapshot: Snapshot Disk: Snapshot Mount Poi Snapshot Sealed:	nt:

standing — -zsh —	77×38	
list disk1		
2C05-4EA1-B78F-CE		
disk1		
100024096358	4 B (1.0 TB) B (357.7 GB) (35.8% used)	
	B (642.6 GB) (64.2% free)	
2 E8F4A4ED-AEE8-4	44E-AE04-276585F07163	I
isk: disk0s2		
1000240963	584 B (1.0 TB)	
22-8CE8-4CC3-8252	-31D47B320E31	I
.e): disk1s1 (Da	 ta)	
	ata (Case-insensitive)	
/System/Vol 16962004172	umes/Data 8 B (169.6 GB)	
No	(	
Yes (Unlock	ed)	
44-DE4C-49CB-BB61	-DD6822E31F56	
.e): disk1s2 (Sy	stem)	
	se-insensitive)	
Not Mounted 9167335424		
Yes		
Yes (Unlock	ed)	
No		
992601F4-8E	73-4D0F-9F46-A3073FE99140	
disk1s2s1		
/ Yes		



### Data Volume

• • •	S
standing@Yu ~ % diskutil apf 	s
+ Container disk1 6EF02048	
그는 것은 것을 했다.	
APFS Container Reference	
Size (Capacity Ceiling):	
Capacity In Use By Volum Capacity Not Allocated:	es
l	
 +-< Physical Store disk0	s2
	<u> </u>
APFS Physical Store	DI
Size:	
+-> Volume disk1s1 90953	32
APFS Volume Disk (Ro	10
Name:	те
Mount Point:	
Capacity Consumed:	
Sealed:	
FileVault:	
+-> Volume disk1s2 1AEB3	E4
APFS Volume Disk (Ro	le
Name:	
Mount Point:	
Capacity Consumed:	
Sealed:	
FileVault:	
Encrypted:	
Snapshot:	
Snapshot Disk:	
Snapshot Mount Point	:
Snapshot Sealed:	

```
standing — -zsh — 77×38
                                           list disk1
2C05-4EA1-B78F-CEED3C791B7D
_____
    disk1
   1000240963584 B (1.0 TB)
: 357651013632 B (357.7 GB) (35.8% used)
   642589949952 B (642.6 GB) (64.2% free)
 E8F4A4ED-AEE8-444E-AE04-276585F07163
.sk: disk0s2
     1000240963584 B (1.0 TB)
22-8CE8-4CC3-8252-31D47B320E31
_____
e): disk1s1 (Data)
    Cortado - Data (Case-insensitive)
    /System/Volumes/Data
    169620041728 B (169.6 GB)
    No
    Yes (Unlocked)
4-DE4C-49CB-BB61-DD6822E31F56
_____
e): disk1s2 (System)
    Cortado (Case-insensitive)
    Not Mounted
    9167335424 B (9.2 GB)
    Yes
    Yes (Unlocked)
    No
    992601F4-8E73-4D0F-9F46-A3073FE99140
    disk1s2s1
    Yes
```





#### Cortado

# Data volume mounted at: /System/Volumes/Data

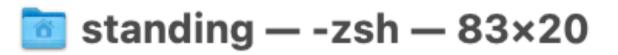


Cortado - Data

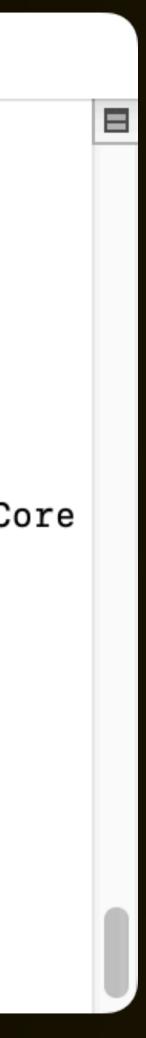


# - Irm Links

standing@Yu ~ % cat /usr/share/firmlinks /AppleInternal AppleInternal /Applications Applications /Library Library /System/Library/Caches System/Library/Caches /System/Library/Assets System/Library/Assets /System/Library/PreinstalledAssets System/Library/PreinstalledAssets /System/Library/AssetsV2 System/Library/AssetsV2 /System/Library/PreinstalledAssetsV2 System/Library/PreinstalledAssetsV2 /System/Library/CoreServices/CoreTypes.bundle/Contents/Library System/Library/Core Services/CoreTypes.bundle/Contents/Library /System/Library/Speech System/Library/Speech /Users Users /Volumes Volumes /cores cores /opt opt private /private /usr/local usr/local /usr/libexec/cups usr/libexec/cups /usr/share/snmp usr/share/snmp



#### /usr/share/firmlinks





### Where are your applications?

			l	o st	andi	ng ·	– -zsh	— 78×24	
[standing@Yu total 0	~ 9	% ls -	-l /Syst	em/Ap	opli	cati	ions		] 🗖
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	App Store.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Automator.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Books.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Calculator.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Calendar.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Chess.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Clock.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Contacts.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Dictionary.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	FaceTime.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	FindMy.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Font Book.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Freeform.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Home.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Image Capture.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Launchpad.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Mail.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Maps.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Messages.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Mission Control.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	Music.app	
drwxr-xr-x	3	root	wheel	96	Sep	16	09:48	News.app	

### /System/Applications

#### .

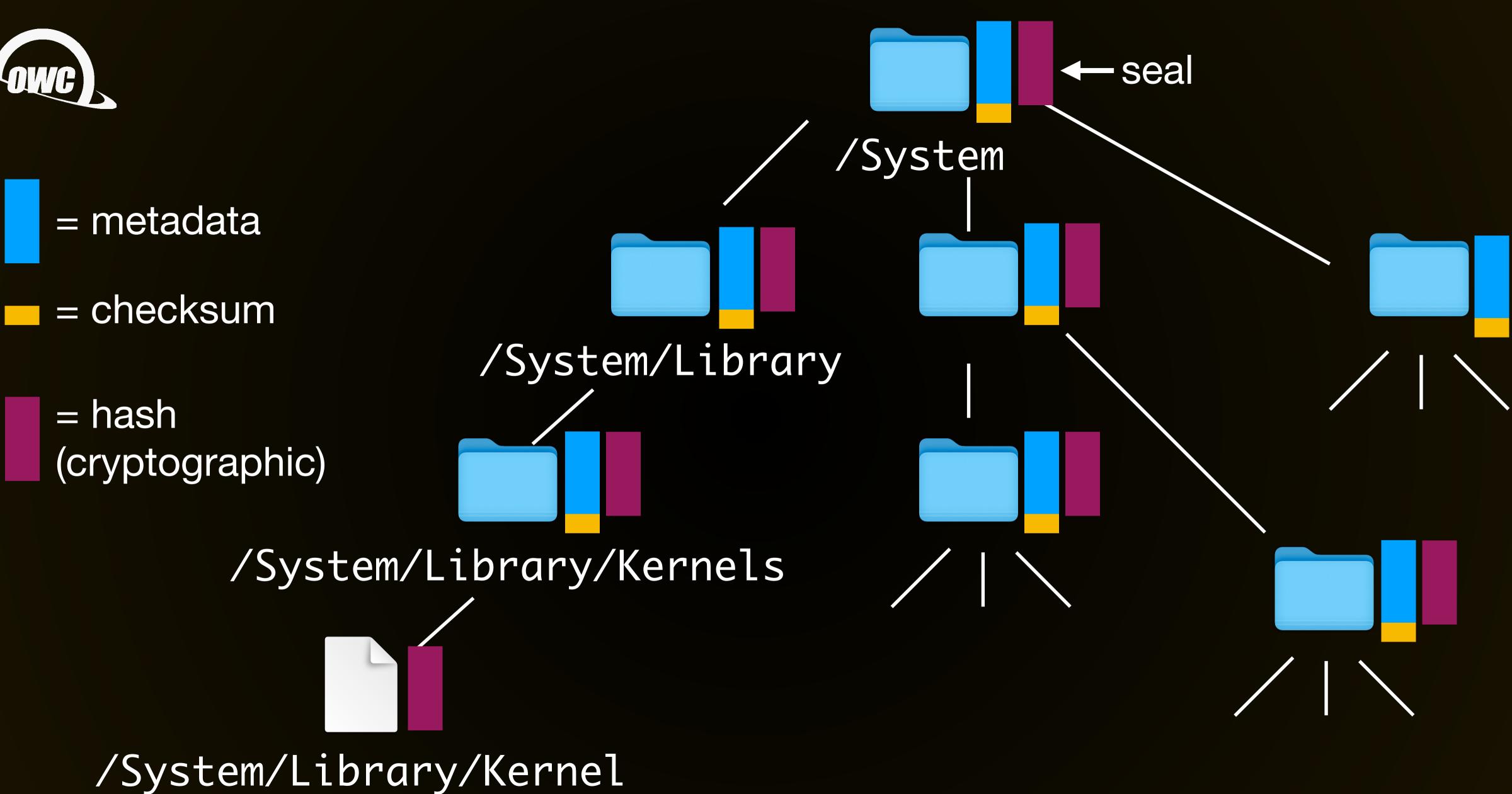
standing — -zsh — 78×24

[standing@Yu total 0	~	% ls -l /	System/\	/olu	umes/	/Dat	ta/App]	lications
drwxr-xr-x@	3	standing	staff	96	Sep	13	20:17	1Password.app
drwx0		-		96	Sep	27	2022	AJA System Test 16.2.25.app
drwxr-xr-x@	3	root	wheel	96	Mar	29	2023	AJA System Test Lite.app
drwxr-xr-x@	3	root	wheel	96	Jan	10	2023	Apple Configurator.app
drwxr-xr-x0	3	standing	staff	96	May	24	23:08	Carbon Copy Cloner.app
drwxrwxr-x	3	standing	staff	96	Mar	25	2022	Cisco Webex Meetings.app
drwxr-xr-x0	3	standing	staff	96	Jul	10	18:44	Copy That.app
drwxr-xr-x0	3	standing	admin	96	Sep	30	2020	DataVault Password Manager.app
drwxr-xr-x0	3	root	wheel	96	Jun	5	18:09	Developer.app
drwxr-xr-x0	3	root	wheel	96	Jun	9	21:34	Focusrite Control.app
drwxr-xr-x	3	root	wheel	96	Sep	26	20:48	Install macOS Sonoma.app
drwxr-xr-x0	3	standing	staff	96	Feb	8	2022	Kaleidoscope.app
drwxr-xr-x0	3	root	wheel	96	Sep	26	20:24	Keynote.app
drwxr-xr-x0	3	standing	admin	96	May	8	11:42	LastPass.app
drwxr-xr-x0	3	root	wheel	96	Sep	13	19:53	Microsoft Teams.app
drwxr-xr-x0	3	root	wheel	96	Sep	26	20:31	Numbers.app
drwxr-xr-x0	3	root	wheel	96	Sep	26	20:30	OmniFocus.app
drwxr-xr-x0	3	standing	admin	96	Sep	20	06:48	OmniOutliner.app
drwxr-xr-x0			wheel					PDFScanner.app
drwxr-xr-x@			wheel					Pages.app
drwxr-xr-x@			wheel		•			Pixen.app
drwxr-xr-x@	3	standing	admin	96	Nov	28	2022	Qobuz.app

/System/Volumes/Data/Applications









# Creating a bootable volume **1.Install or update files** 2. Calculate cryptographic hash for all files and directories using file data and directory metadata **3.**Save B-tree in volume metadata 4. Compare hash of root with value from Apple 5. Take snapshot of volume



# During startup

## 1. Verify that seal is a valid value before mounting system volume

### 2.Verify cryptographic hash for every file as it is read





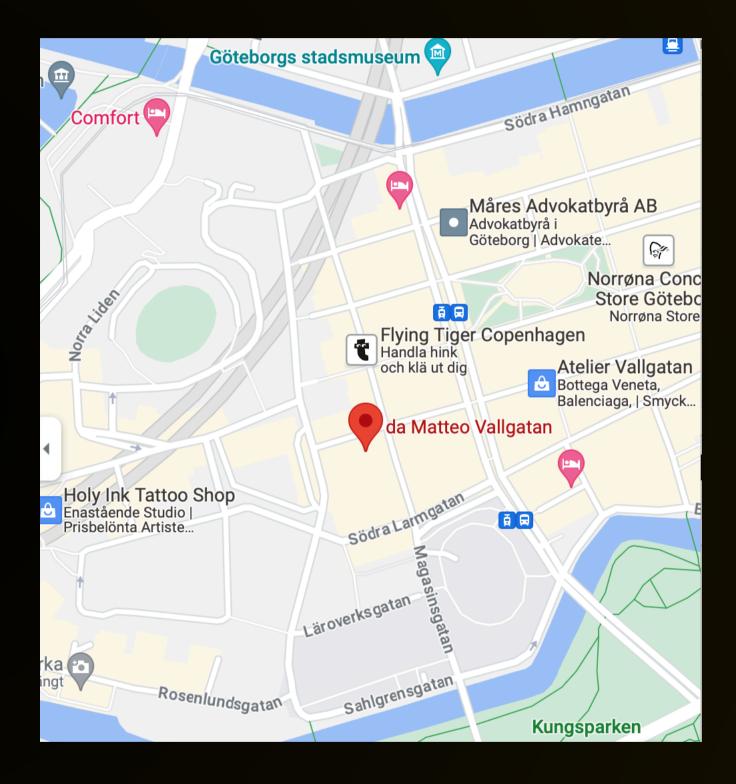
# Places to Visit in Göteborg







### Da Matteo Valgatan 5 Göteborg

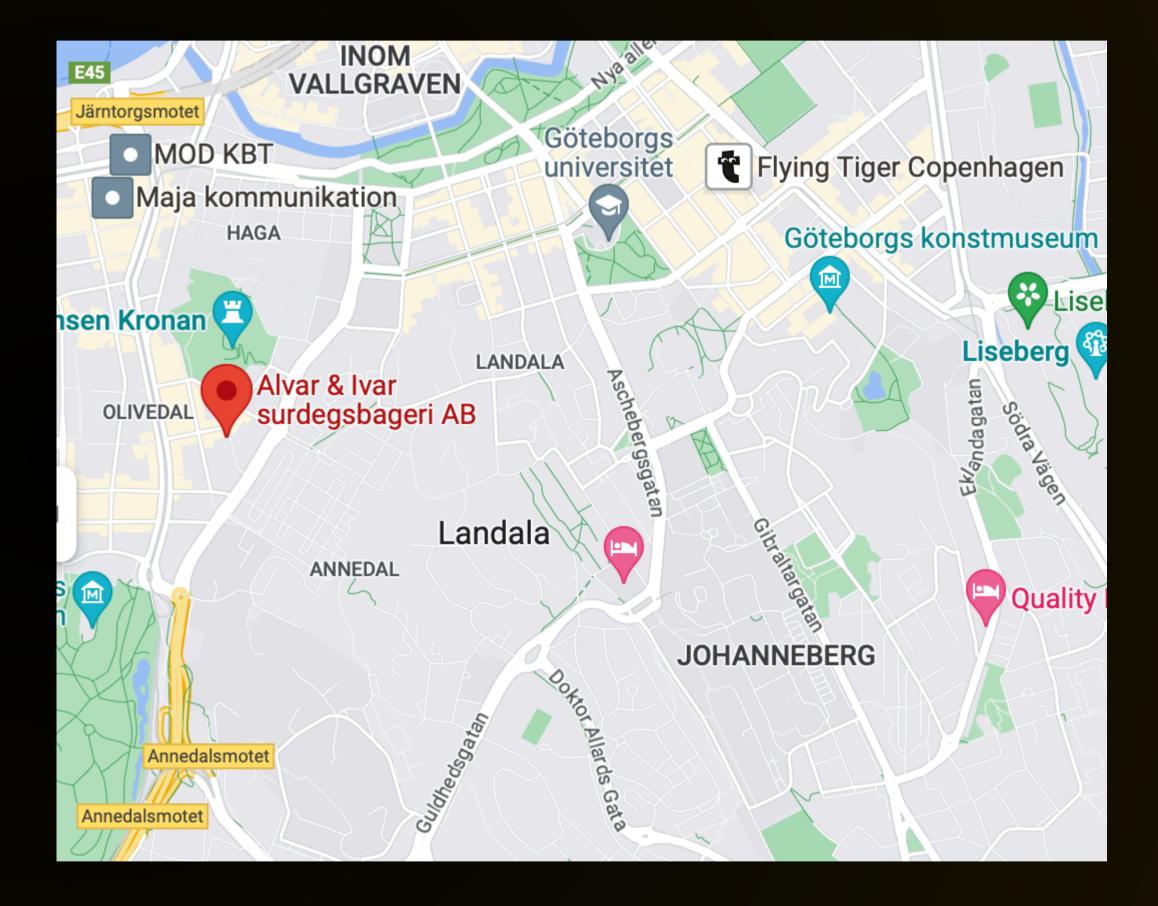








### Alvar & Ivar Kastellgatan 11 Göteborg









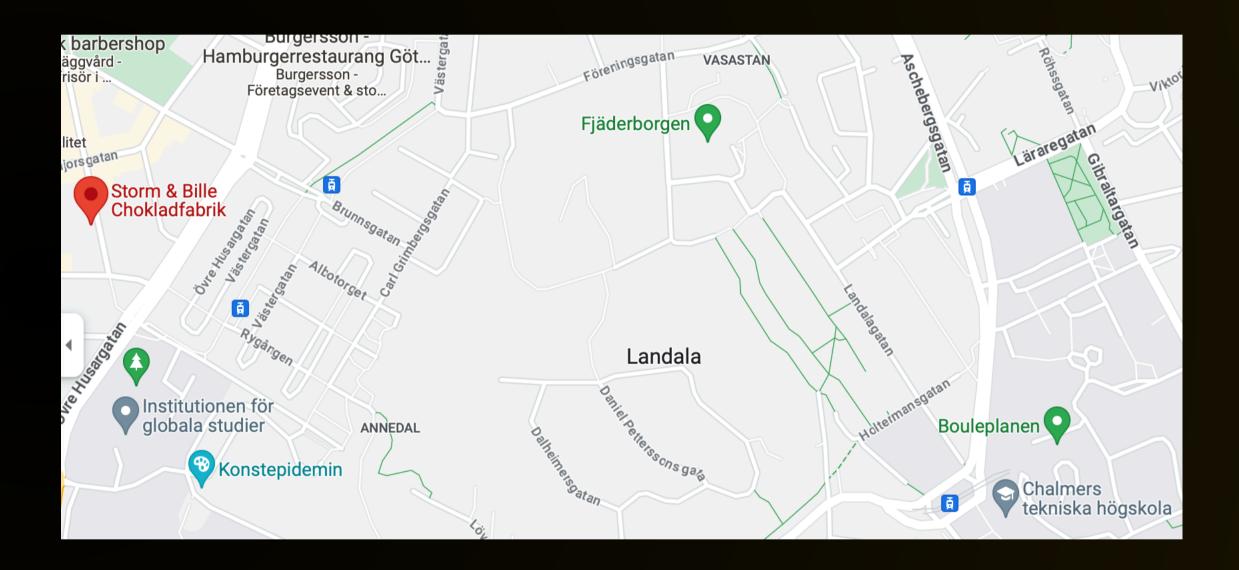






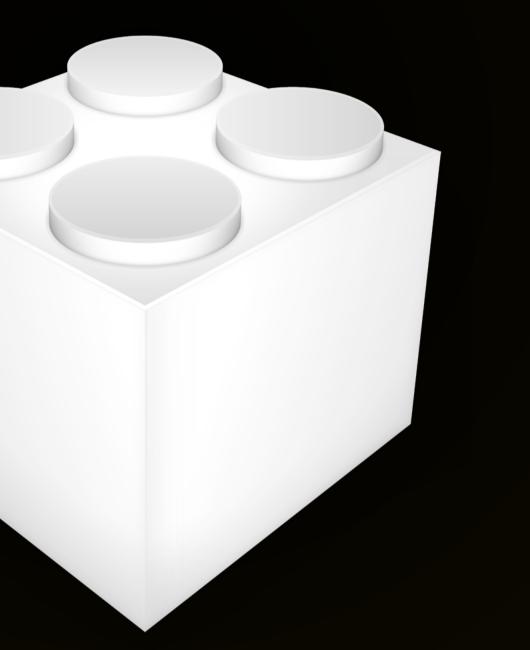


## Da Storm & Bille Chokladfabrik Sveagatan 19 Göteborg



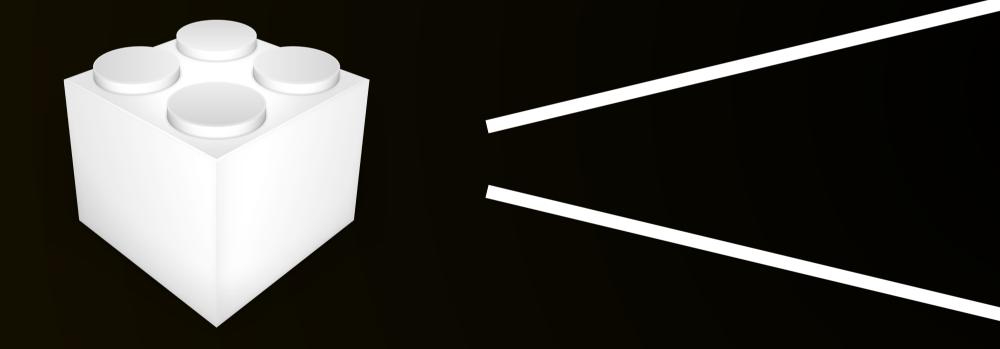


# Are kexts going to disappear?



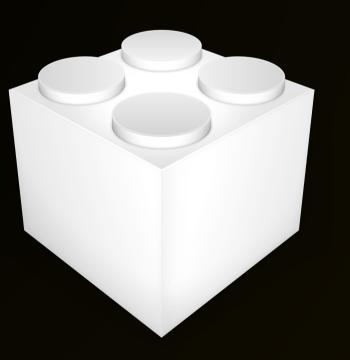


# The Future of Kexts



/Library/Extensions

#### /System/Library/Extensions



/System/Library/DriverExtensions





### /System/Library/Extensions

### Protected by SSV **Requires Reduced Security Requires Admin Approval** User Loadable **Codes Signed** Notarized



- Yes
- No
- No
- No
- NO
- No
- No

### /Library/Extensions

- - Yes



## SoftRAID kext

### Before macOS 13.3

#### /Library/Extensions/SoftRAID.kext

### **Requires Reduced Security**

**Requires Admin Approval** 

**Requires New Driver Install** on Apple silicon

### macOS 13.3 and later

#### /System/Library/Extensions/SoftRAID.kext

### No Reduced Security

**No Admin Approval** 

**No Driver Install Possible** 







### <u>macOS 13.3 - 13.6</u>

### SoftRAID kext version 7.5

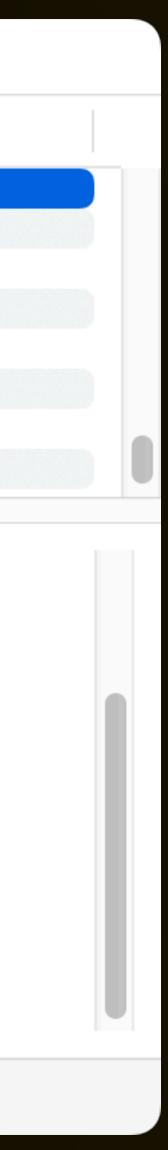
## SoftRAID kext

### macOS 14.0 and later

SoftRAID kext version 7.6

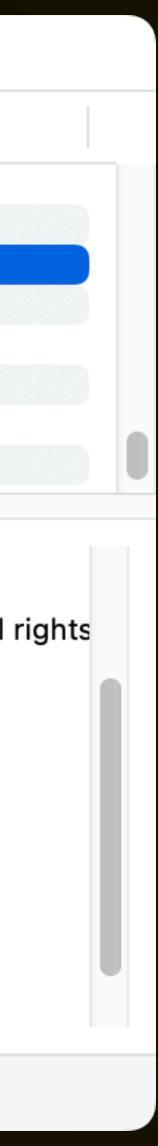


	MacBook Pro							
Firewall	Extension N ^	Version	Last Modified	Notarized	Loaded	Obtained from		
Locations Volumes WWAN Wi-Fi Software Accessibility Applications Developer	smbfs SMCMotionSensor SoftRAID SonyXDCAMDriver StorageLynx System tmpfs	5.0 3.0.4 7.5 554 554 22.6.0 1.0 3.0	9/16/23, 9:48 AM 9/16/23, 9:48 AM 9/16/23, 9:48 AM 9/16/23, 9:48 AM 9/16/23, 9:48 AM 9/16/23, 9:48 AM 9/16/23, 9:48 AM	Unknown Unknown Unknown Yes Unknown Yes Unknown Unknown	No No No No No No No No	Not Signed Not Signed Not Signed Apple Not Signed Not Signed Not Signed		
Disabled Software Extensions Fonts Frameworks Installations Language & Region Legacy Software Logs Managed Client Preference Panes Printer Software Profiles Raw Support SmartCards	triggers       3.0       9/16/23, 9:48 AM       Unknown       No       Not Signed         Bundle ID:       com.apple.Tilesystems.smbts       Obtaining       Unknown       Loaded:       Unknown         Loaded:       No       Not Signed       Location:       /System/Library/Extensions/smbfs.kext         Kext Version:       5.0       Solution       Loadable:       No         Validity Errors:       Validation Failures:       Kext has a CFBundleExecutable property but the executable can't pe found:       smbfs         Signature Validation Errors:       Not Signed       Dependencies:       Incomplete         Signed by:       Not Signed       Not Signed       Not Signed							
Startup Items Sync Services	💻 Yu > Software >	Extensior	ns > smbfs					





	MacBook Pro							
Firewall	Extension N	Version	Last Modified	Notarized	Loaded	Obtained from		
Locations Volumes WWAN Wi-Fi Software Accessibility Applications Developer Disabled Software Extensions Fonts Frameworks Installations Language & Region Legacy Software Logs Managed Client Preference Panes Printer Software Profiles Raw Support	smbfs SMCMotionSensor SoftRAID SonyXDCAMDriver StorageLynx System tmpfs triggers Bundle ID: Notarized: Loaded: Get Info String: Obtained from: Location: Kext Version: Loadable: Validity Errors: Validation Failures	5.0 3.0.4 7.5 554 554 554 22.6.0 1.0 3.0 Con Unk No Sof rese Not /Sys 7.5 Not	9/16/23, 9:48 AM 9/16/23, 9:48 AM 1.apple.oriver.SottRAID frown tRAID version 7.5, Copy erved. Signed stem/Library/Extensions	Unknown Unknown Yes Unknown Unknown Unknown	No No No No No No No 23 Other Worl	Not Signed Not Signed Apple Not Signed Not Signed Not Signed		
SmartCards Startup Items Sync Services	Signed by:		Signed					





## What is Bit-Rot?



- Write 2 GB file to each of 3,000 servers
- Write file and verify every 2 hours
- 360 TB total transferred in 5 weeks
- 500 data corruption events observed

"Data Integrity" **Panzer-Steindel - CERN** 2007



## OWC

### Testing for Data Corruption on Disk





## Testing for Data Corruption on Disk

- 2 RAID 5 volumes, each with 15 disks
- First volume is active, constant reads and writes
- Second volume is passive, contains data, no reads or writes
- Every 10 days, verified that the parity information is correct
- Repeat for 18 months (54 parity verify operations)





## **Testing for Data Corruption** on Disk

### • 21 PB transferred, 3 billion i/os

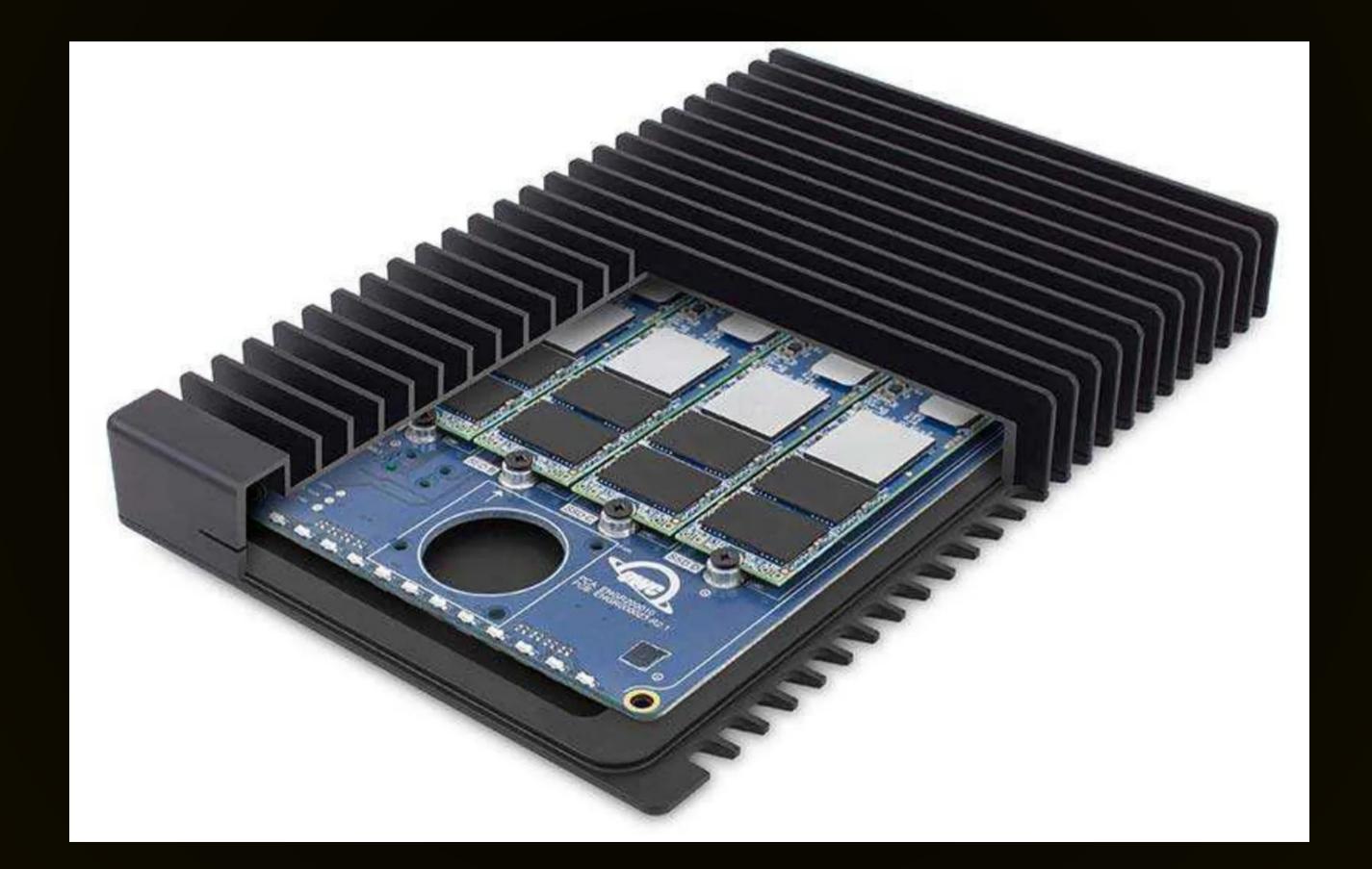
power loss while writing to the volume

Only incorrect parity was on active volume and was result of





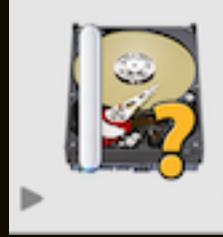
### Bit-Rot Observed





### **Detecting Bit-Rot**

### 1) SoftRAID Certify Function



SATA bus 0, ID 0, LUN 0 (Thunderbolt) size: 18 TB · available: 0 bytes model: ST18000NM000J-2TV103 certifying, pass 1 of 3 - writing pattern • 0 errors current offset: 171,798,691,840 · time remaining: 106:21:01

# 2) Copy and verify 200 GB file cp ~/Desktop/200GB.zip /Volumes/TestVolume/

- cmp -l ~/Desktop/200GB.zip /Volumes/TestVolume/200GB.zip



# History of Volume Loss



## Volume Failure Rates **During the year 2008**

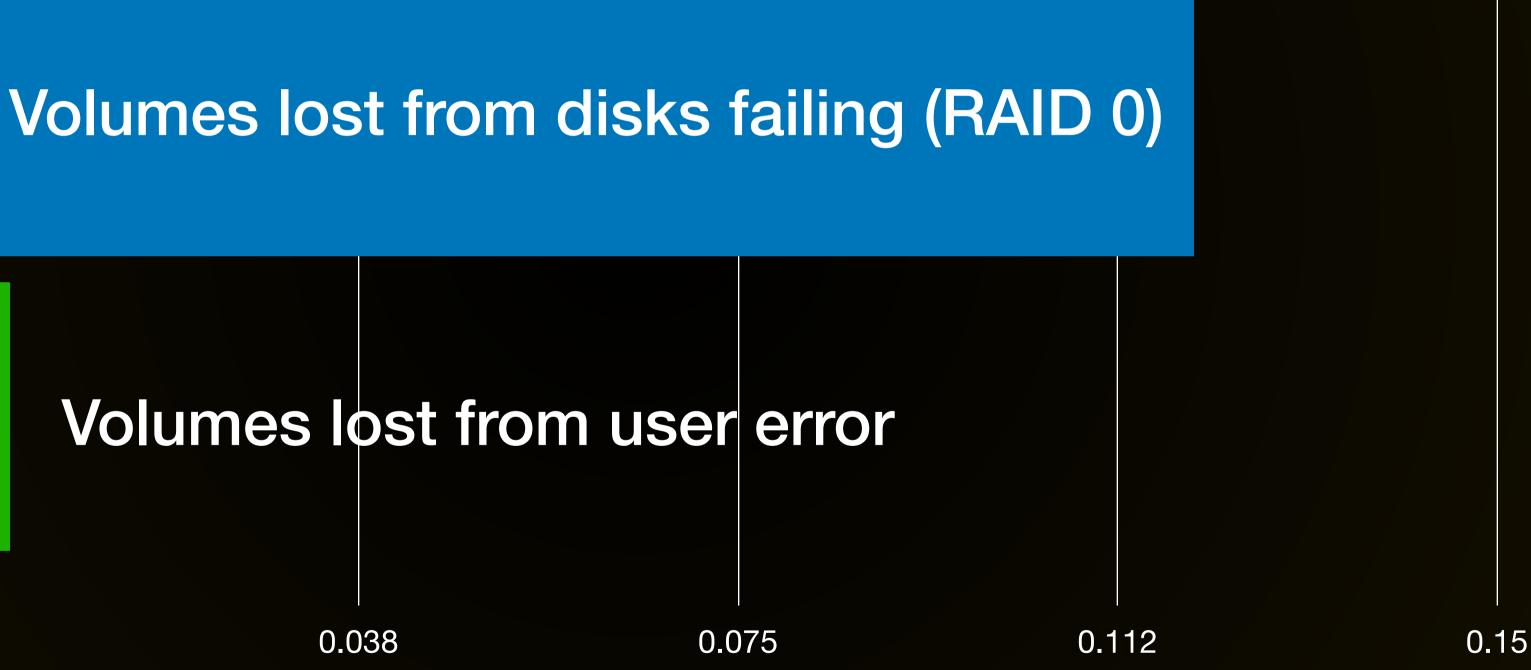
#### 1 out 100 per month

1 out 3,000 per month

0

### Volumes lost from user error

0.038



#### **Annual Failure Rates**

(all numbers approximate)



Volumes lost from user error

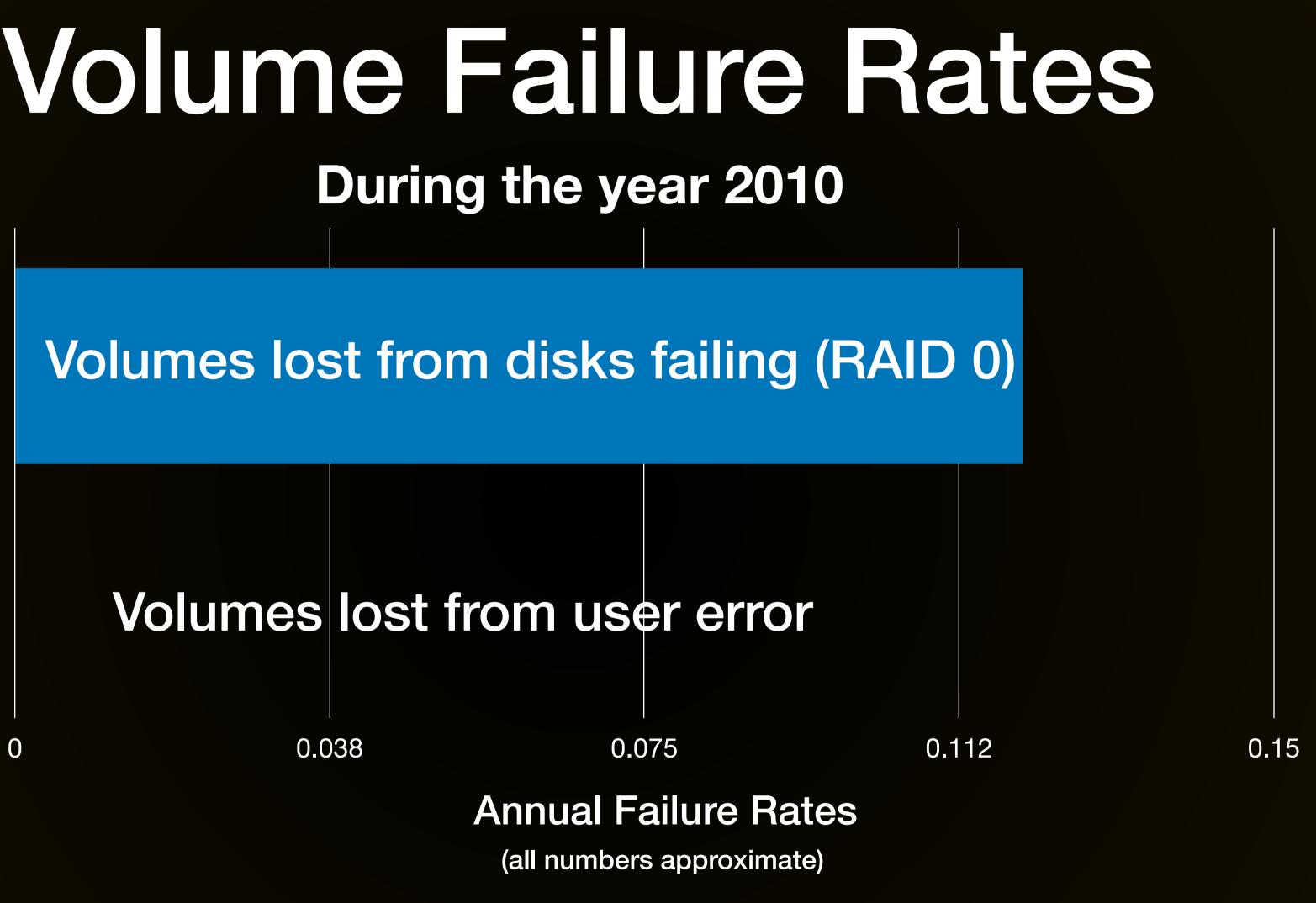
0.038

SoftRAID v.4 added Volume Safeguards = protect from user error

#### 1 out 100 per month

1 out 2,000,000 per month

0



### Volume Failure Rates **During the year 2014** Volumes lost from disks failing (RAID 5) Volumes lost from user error Volumes lost from all disks disappearing Volumes lost from disks changing positions Volumes lost from system software update 0.038 0.075 0.112



 $\mathbf{O}$ 

0.15

- **Annual Failure Rates** 
  - (all numbers approximate)

#### SoftRAID v. 5 added RAID 4 and 5 volumes

### Volume Failure Rates During the year 2014 Volumes lost from disks failing (RAID 5) Volumes lost from user error Volumes lost from all disks disappearing Volumes lost from disks changing positions Volumes lost from system software update 0.038 0.075 0.112 0



Zoom in 50x

0.15

- **Annual Failure Rates** 
  - (all numbers approximate)



# Volume F

Less than 1 out of 2,000,000 per month

> 1 out 700,000 per month

> > 1 out 500 per month

1 out 4,000 per month

1 out 10,000 per month

0

Volumes lost Volumes lost

Volumes lost

Volumes lost

Volumes lost

0.001

	e Fail	ure Ra	ates						
D	During the year 2014								
ies	lost from d	isks failing (	RAID 5)						
es	lost from u	ser error							
es	lost from a	ll disks disa	ppearing						
es	lost from di	sks changin	g positions						
es	lost from s	ystem softw	are update						
0.00	1 0.0	0.	0.00	03					
	Annual Fa	ailure Rates							

(all numbers approximate)

## Volume Failure Rates **During the year 2017** Volumes lost from disks failing (RAID 5) Volumes lost from user error Volumes lost from all disks disappearing Volumes lost from disks changing positions



0.001

Less than 1 out of 2,000,000 per month

> 1 out 700,000 per month

1 out 20,000 per month

1 out 4,000 per month

1 out 10,000 per month

0

Volumes lost from system software update

0.002 **Annual Failure Rates** 

0.003

(all numbers approximate)

#### Mac OS 10.12.1 fixes kernel bug which causes all disks to disappear

0.002

# Volume Failure Rates



0.001

SoftRAID 5.7 detects disks changing position due to kernel bug

Less than 1 out of 2,000,000 per month

> 1 out 700,000 per month

1 out 20,000 per month

Less than 1 out of 2,000,000 per month

> 1 out 10,000 per month

> > $\mathbf{O}$

### **During the year 2019**

- Volumes lost from disks failing (RAID 5)
- Volumes lost from user error
- Volumes lost from all disks disappearing
- Volumes lost from disks changing positions
- Volumes lost from system software update

0.002 0.002 0.003 **Annual Failure Rates** 

(all numbers approximate)

# Volume Failure Rates



Volumes lost from user

0.001

macOS 12 fixes volume loss on system software update

Less than 1 out of 2,000,000 per month

> 1 out 700,000 per month

1 out 20,000 per month

Less than 1 out of 2,000,000 per month Less than 1 out of 2,000,000 per month

0

- **During the year 2019**
- Volumes lost from disks failing (RAID 5)
- Volumes lost from all disks disappearing
- Volumes lost from disks changing positions
- Volumes lost from system software update

0.002 0.002 0.003 **Annual Failure Rates** 

(all numbers approximate)

### **OWC** Gemini (Hardware RAID 0 - 2 HDDs - 28 TB total storage)





# An Example of Volume Loss



Customer's Mac: M1 MacBook Pro



# Do you ever see this?



**Disk Not Ejected Properly** Eject "Backup" before disconnecting or turning it off.



# Laptop with no power source Prevents work loss when battery goes dead Unmount external volumes

## Why Hibernate?



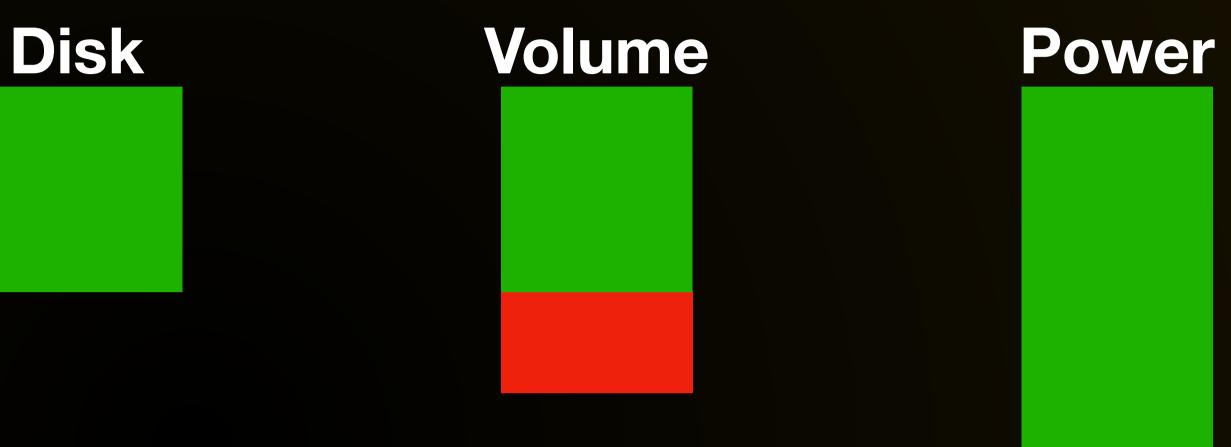
### Hibernate on SATA Volumes

**RAM Image Saved Disks Disappear Volume Unmounted Power Turned Off Power Turned On RAM Image Restored** 

**Disks Reappear** 

**Volume Mounted** 

Time



#### **Mac in Hibernate**



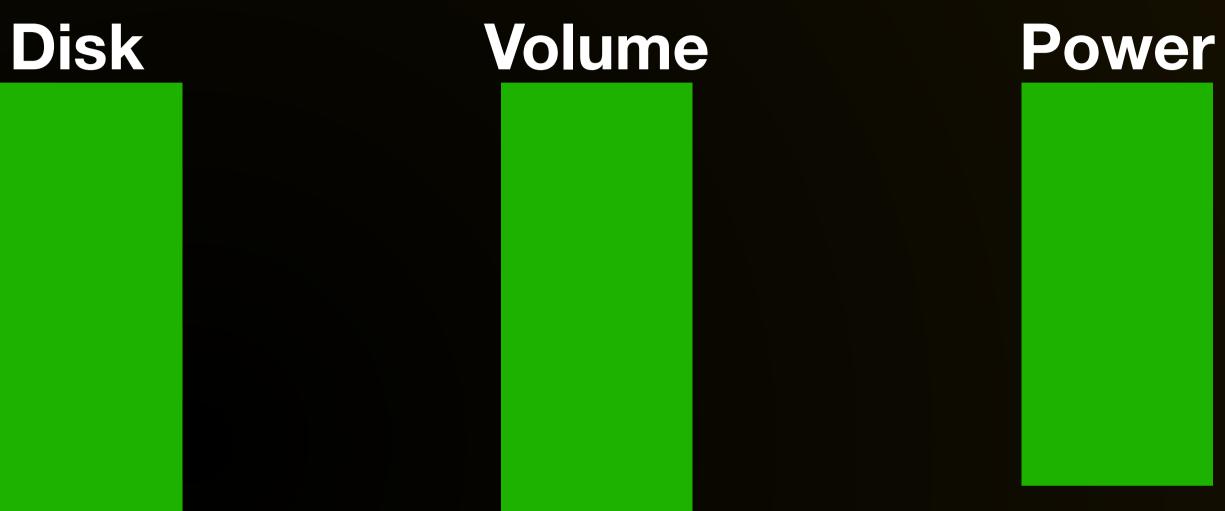
### **Hibernate on NVMe Volumes**

**RAM Image Saved Disks Disappear Volume Unmounted Power Turned Off Power Turned On RAM Image Restored** 

**Disks Reappear** 

**Volume Mounted** 

Time



#### **Mac in Hibernate**





