



Flash Induced Latency at Scale

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Focusing on a real problem...

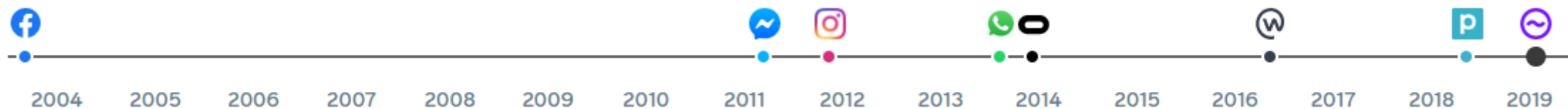


Latency stall – A single I/O event taking more than the expected time to complete



Family MAP : 3.59B

Globally, there are more than 3.59B people using Facebook, WhatsApp, Instagram or Messenger each month.



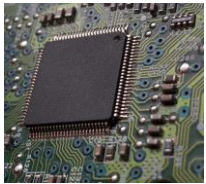
 Meta

*MAP - Monthly Active People

Source: Meta Platforms Inc. Q4 2021

1 Read/Write/Trim > 1 second

Latency Stalls in SSD



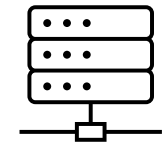
Firmware or
ASIC bugs



Hard to
detect



Extremely difficult
and long debug

















Significant impact
to services

Odds per Day

Greater than 1 second - I/O stalls per day

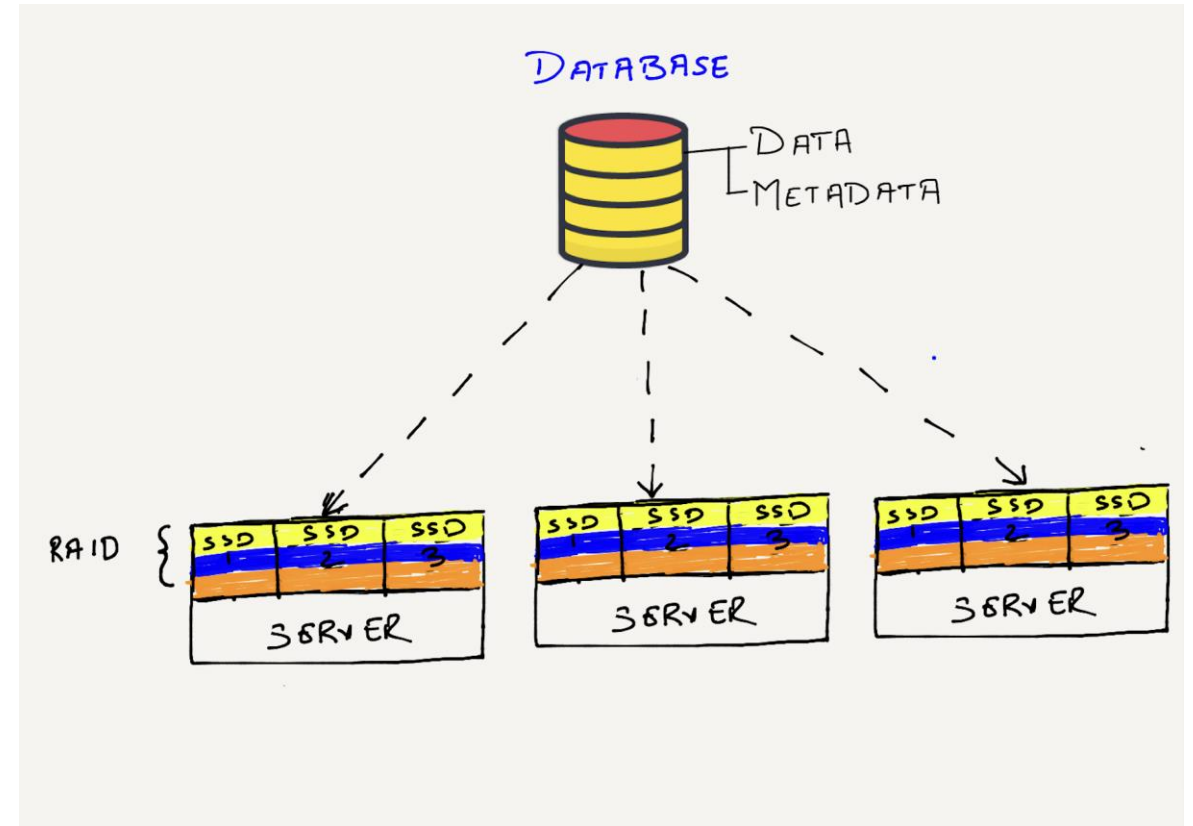
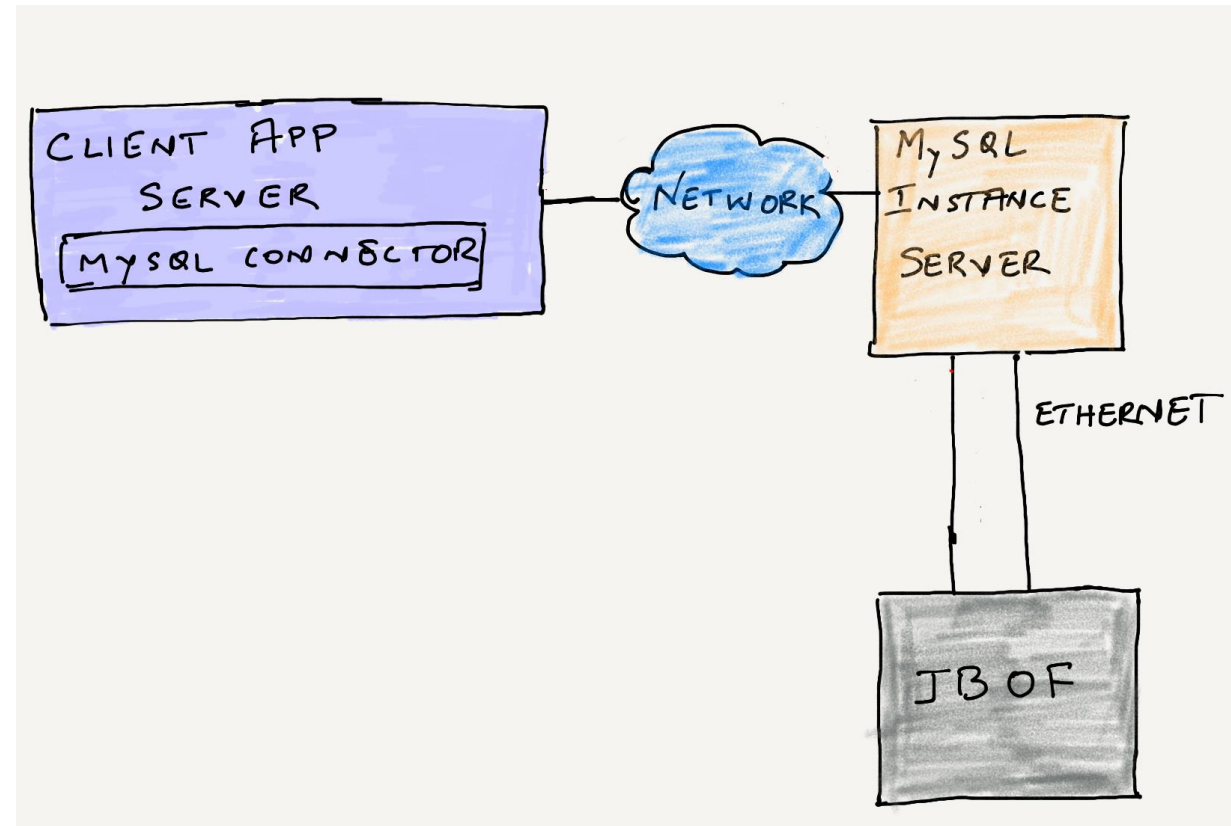
40 distinct SSD stalls in a thousand devices

Equivalent Odds

ELO WITH TOP QB	1-WEEK CHANGE	CURRENT QB ADJ.	TEAM	DIVISION	PLAYOFF CHANCES			
					MAKE DIV. ROUND	MAKE CONF. CHAMP	MAKE SUPER BOWL	WIN SUPER BOWL
1680			 Packers 13-4	NFC North	✓	77%	50%	27%
1689	+11		 Chiefs 12-5	AFC West	86%	60%	38%	21%
1654	+13		 Buccaneers 13-4	NFC South	80%	52%	24%	13%
1590	+17		 Titans 12-5	AFC South	✓	67%	31%	12%
1637	+5		 Bills 11-6	AFC East	70%	27%	16%	8%
1636	+41		 Cowboys 12-5	NFC East	69%	30%	13%	7%
1591	-25		 Rams 12-5	NFC West	70%	20%	7%	4%
1570			 Bengals 10-7	AFC North	74%	24%	8%	3%
1571	-23		 Patriots 10-7	AFC East	30%	12%	4%	2%
1580	+19		 49ers 10-7	NFC West	31%	9%	3%	2%
1523	-36		 Cardinals 11-6	NFC West	30%	7%	2%	0.8%
1480	+10		 Raiders 10-7	AFC West	26%	6%	1%	0.4%
1508	-28		 Eagles 9-8	NFC East	20%	3%	1%	0.4%
1486	+15		 Steelers 8-7-1	AFC North	14%	4%	1%	0.3%

Los Angeles Rams winning Superbowl
(2021 Playoff odds by FiveThirtyEight)

High Level Storage Architecture



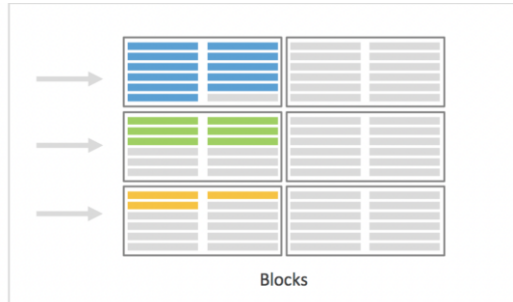
A single I/O stall can lead to multiple application requests stalled



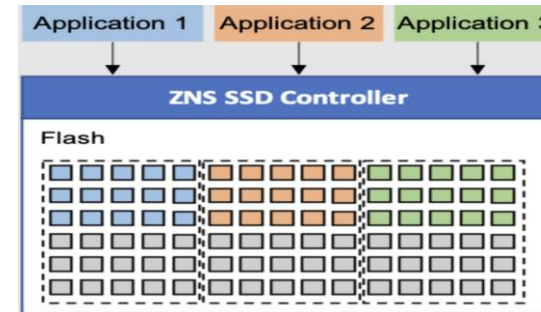
Stream 1
Sequential

Stream 2
Sequential

Stream 3
Random



Streams



ZNS

Evolution of flash drives into complex storage system

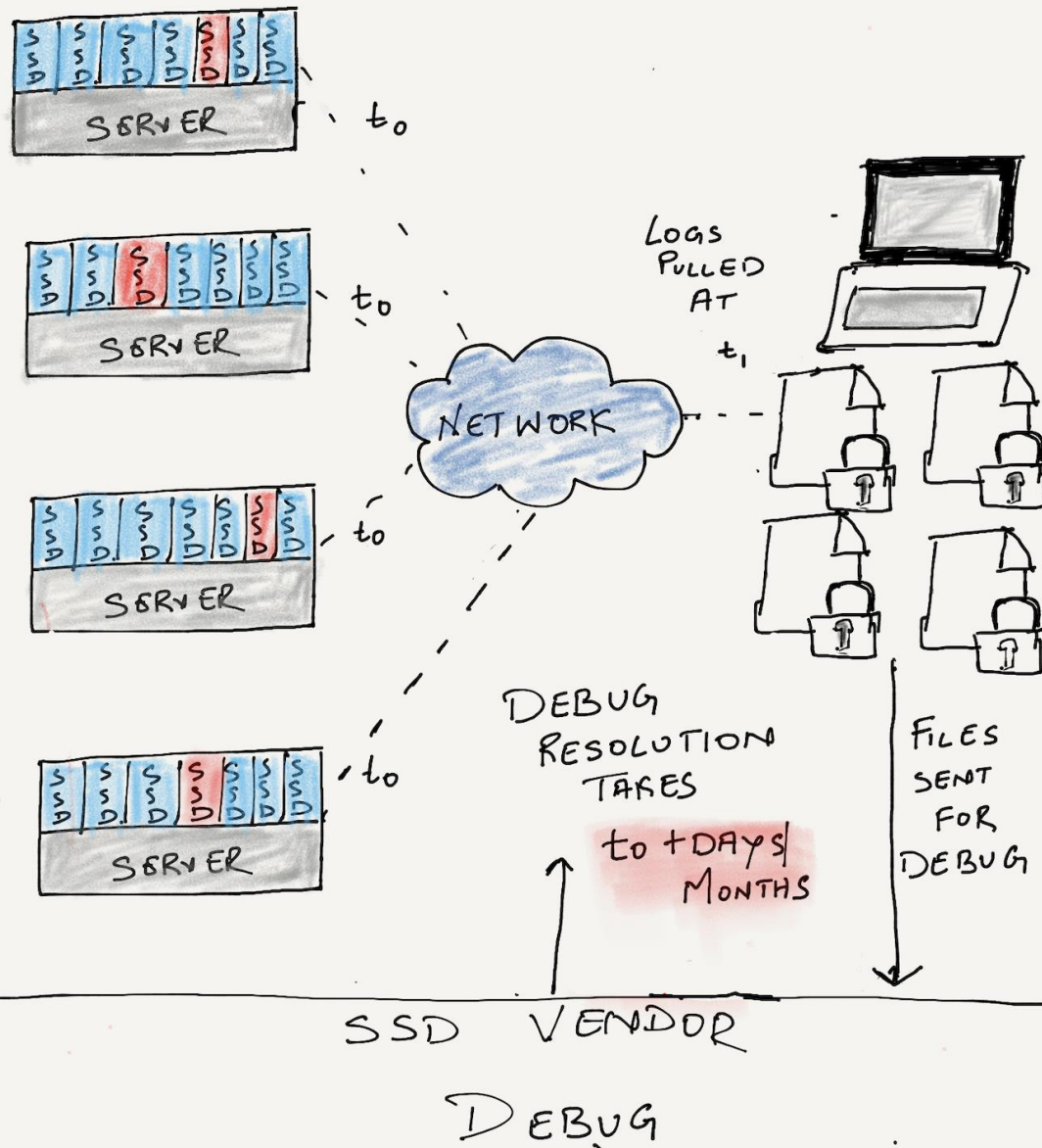
Telemetry and SMART can help debug all problems....



```
$ sudo nvme smart-log /dev/nvme0n1
Smart Log for NVME device:nvme0n1 namespace-id:ffffff
critical_warning : 0
temperature : 21 C
available_spare : 100%
available_spare_threshold : 10%
percentage_used : 2%
endurance group critical warning summary: 0
data_units_read : 5,749,452
data_units_written : 10,602,948
host_read_commands : 77,809,121
host_write_commands : 153,405,213
controller_busy_time : 756
power_cycles : 1,719
power_on_hours : 1,311
unsafe_shutdowns : 129
media_errors : 0
num_err_log_entries : 1,243
Warning Temperature Time : 0
Critical Composite Temperature Time : 0
Temperature Sensor 1 : 21 C
Temperature Sensor 2 : 22 C
Thermal Management T1 Trans Count : 0
Thermal Management T2 Trans Count : 0
Thermal Management T1 Total Time : 0
Thermal Management T2 Total Time : 0
```

But can they????

SSD FAILURE



Debugging flash Issues in hyperscale environment is inefficient

Efficient Debugging

-Latency Monitor/C3 Log Page Data-			
Controller : nvme0n1			
Feature Status 0x1			
Active Bucket Timer 6025 min			
Active Bucket Timer Threshold 0 min			
Active Threshold A 5 ms			
Active Threshold B 50 ms			
Active Threshold C 500 ms			
Active Threshold D 1000 ms			
Active Latency Minimum Window 0 ms			
Active Latency Stamp Units 1230			
Static Latency Stamp Units 0			
Debug Log Trigger Enable 1			
	Read	Write	Deallocate/Trim
Active Latency Mode: Bucket 0	0	0	0
Active Latency Mode: Bucket 1	0	0	0
Active Latency Mode: Bucket 2	0	0	0
Active Latency Mode: Bucket 3	0	0	0
Active Bucket Counter: Bucket 0	33	7	147
Active Bucket Counter: Bucket 1	0	0	9
Active Bucket Counter: Bucket 2	5	0	0
Active Bucket Counter: Bucket 3	35	0	0
Active Measured Latency: Bucket 0	0 ms	0 ms	0 ms
Active Measured Latency: Bucket 1	0 ms	0 ms	0 ms
Active Measured Latency: Bucket 2	0 ms	0 ms	0 ms
Active Measured Latency: Bucket 3	0 ms	0 ms	0 ms
Active Latency Time Stamp: Bucket 0	2022-05-14 18:29:04.784 GMT	2022-05-14 13:25:54.224 GMT	2022-05-14 13:25:53.289 GMT
Active Latency Time Stamp: Bucket 1	N/A	N/A	2022-05-14 13:25:53.281 GMT
Active Latency Time Stamp: Bucket 2	2022-05-14 22:01:26.034 GMT	N/A	N/A
Active Latency Time Stamp: Bucket 3	2022-05-14 13:25:53.209 GMT	N/A	N/A
Static Bucket Counter: Bucket 0	0	0	0
Static Bucket Counter: Bucket 1	0	0	0
Static Bucket Counter: Bucket 2	0	0	0
Static Bucket Counter: Bucket 3	0	0	0
Static Measured Latency: Bucket 0	0 ms	0 ms	0 ms
Static Measured Latency: Bucket 1	0 ms	0 ms	0 ms
Static Measured Latency: Bucket 2	0 ms	0 ms	0 ms
Static Measured Latency: Bucket 3	0 ms	0 ms	0 ms
Static Latency Time Stamp: Bucket 0	N/A	N/A	N/A
Static Latency Time Stamp: Bucket 1	N/A	N/A	N/A
Static Latency Time Stamp: Bucket 2	N/A	N/A	N/A
Static Latency Time Stamp: Bucket 3	N/A	N/A	N/A

Bucket Structure

Bucket Description

- ❖ Saturating Read Command Counter
 - Measured Latency
 - Latency Stamp
- ❖ Saturating Write Command Counter
 - Measured Latency
 - Latency Stamp
- ❖ Saturating De-allocate/TRIM Command Counter
 - Measured Latency
 - Latency Stamp

Figure 1- Bucket Structure

Latency Monitoring Log

Debug Workflow @ Scale

Kernel stats

App metrics

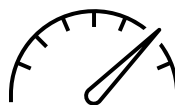
LM Log

SMART
counters

Workload
characteristics



Anomaly
detection / ML



Monitoring

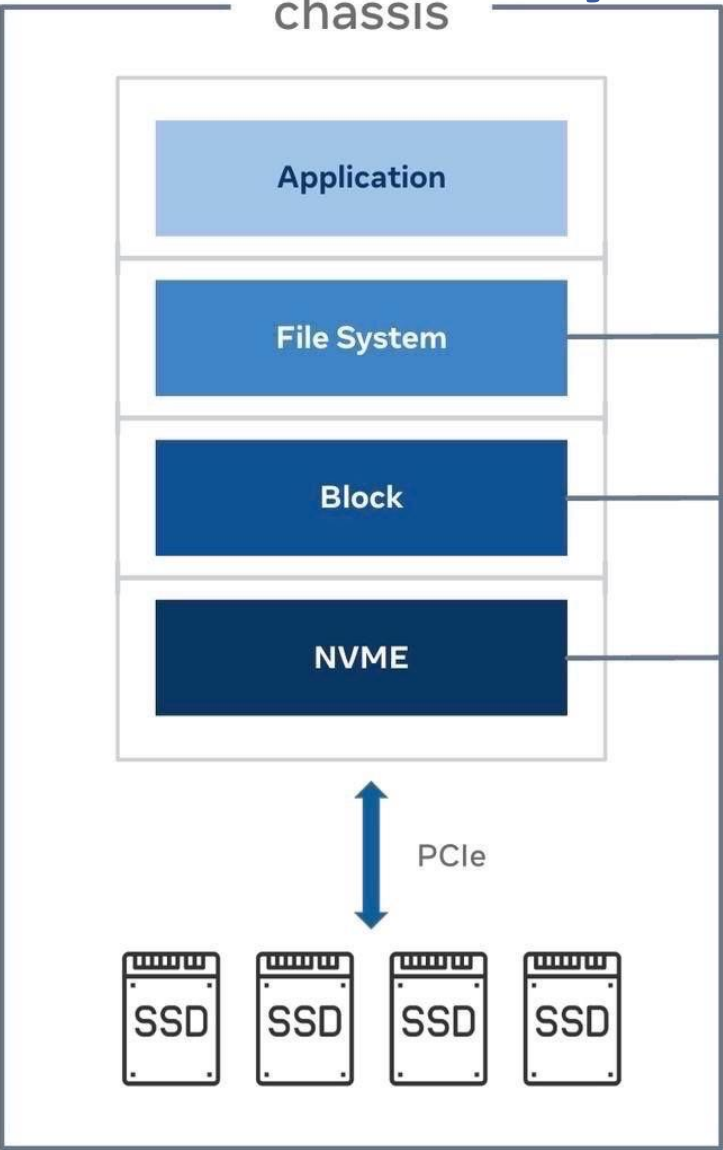


Alerting



Remediation

Observability throughout the I/O lifecycle



A Storage Stack Example

EXT: FILE-OFFSET BLOCK-RANGE AG AG-OFFSET TOTAL FLAGS						
0: [0..409607]: 418328064..418737671 11 (15862528..16272135) 409608 000101						
EVENT	TIME	COMM	TID	CPU	DETAIL	
block_bio_queue	2.75%	mysqld	800131	[009]	9,2 R 125574800 + 16 [mysqld]	
block_bio_remap	0.68%	mysqld	800131	[009]	259,0 R 63051664 + 16 <- (9,2) 125574800	
block_bio_remap	2.75%	mysqld	800131	[009]	259,0 R 418520976 + 16 <- (259,3) 63051664	
block_getrq	1.37%	mysqld	800131	[009]	259,0 R 418520976 + 16 [mysqld]	
nvme_setup_cmd	3.44%	mysqld	800131	[009]	disk=nvme1n1 ctrl_id=1 qid=10 opcode=2 flags=0 fctype=1 cid=294 nsid=1 metadata=0 cdw10=ARRAY[f2, 43, 1e, 03, 00, 00, 00, 00, 01, 00, 00, 00, 00, 00, 00, 00]	
block_rq_issue	88.96%	mysqld	800131	[009]	259,0 R 8192 () 418520976 + 16 [mysqld]	
nvme_complete_rq	0%	swapper	0	[009]	disk=nvme1n1 ctrl_id=1 qid=10 cid=294 result=0 retries=0 flags=0 status=0	

secondary_startup_64_no_verify 60.0%				null 100.0%				[unknown] ([Exited Process]) 20.0%		ret_from_fork 20.0%			
cpu_startup_entry 60.0%								[unknown] ([Exited Process]) 20.0%		kthread 20.0%			
do_idle 60.0%								[unknown] ([Exited Process]) 20.0%		worker_thread 20.0%			
cpuidle_enter 30.0%				schedule_idle 30.0%				[unknown] ([Exited Process]) 20.0%		process_one_work 20.0%			
cpuidle_enter_state 30.0%				__sched_text_start 30.0%				[unknown] ([Exited Process]) 20.0%		blk_mq_run_work_fn 20.0%			
asm_common_interrupt 30.0%				finish_task_switch 30.0%				[unknown] ([Exited Process]) 20.0%		blk_mq_sched_dispatch_requests 20.0%			
common_interrupt 30.0%				asm_common_interrupt 30.0%				entry_SYSCALL_64 20.0%		__blk_mq_sched_dispatch_requests 20.0%			
__common_interrupt 30.0%				common_interrupt 30.0%				do_syscall_64 20.0%		blk_mq_do_dispatch_sched 20.0%			
handle_edge_irq 30.0%				__common_interrupt 30.0%				__x64_sys_execve 20.0%		blk_mq_dispatch_rq_list 20.0%			
handle_irq_event 30.0%				handle_edge_irq 30.0%				do_execveat_common 20.0%		nvme_queue_rq 20.0%			
__handle_irq_event_percpu 30.0%				handle_irq_event 30.0%				bprm_execve 20.0%		blk_mq_start_request 10.0%		nvme_setup_cmd 10.0%	
nvme_irq 30.0%				__handle_irq_event_percpu 30.0%				exec_binprm 20.0%		blk_mq_start_request 10.0%		nvme_setup_cmd 10.0%	
				nvme_irq 30.0%				__kernel_read 20.0%					
blk_mq_end_request 10.0%		nvme_complete_rq 10.0%		nvme_handle_cqe 10.0%		blk_mq_end_request 10.0%		nvme_complete_rq 10.0%		nvme_handle_cqe 10.0%		filemap_read 20.0%	
blk_update_request 10.0%		nvme_complete_rq 10.0%		nvme_handle_cqe 10.0%		blk_update_request 10.0%		nvme_complete_rq 10.0%		nvme_handle_cqe 10.0%		filemap_get_pages 20.0%	
blk_update_request 10.0%						blk_update_request 10.0%						page_cache_ra_unbounded 20.0%	
												read_pages 20.0%	
												blk_finish_plug 20.0%	
												blk_mq_flush_plug_list 20.0%	
												blk_mq_sched_insert_requests 20.0%	
												__blk_mq_delay_run_hw_queue 20.0%	
												blk_mq_sched_dispatch_requests 20.0%	
												__blk_mq_sched_dispatch_requests 20.0%	

Summary

- At scale debug is extremely challenging due to inefficient design of debug logs for use at hyperscale environment
- Let's converge on debug-ability initiatives
 - BPF scripts for triage
 - Latency Monitoring Spec - [Link](#)
 - NVMe-CLI/ plugins / OCP - [Link](#)
- Meta welcomes Industry Partner's ideas on how to improve debug @ Scale

Together we can make debugging SSDs better!

