STORAGE DEVELOPER CONFERENCE

SDC 21

BY Developers FOR Developers

Virtual Conference
September 28-29, 2021

A SNIA Event

SPDK Schedulers

Realizing Power Savings in Polled Mode Applications

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Introductions

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SPDK Overview

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SPDK Overview

- Storage Performance Development Kit
  - Framework for building high-performance storage applications
  - Set of drivers and libraries
  - Includes fully functional storage target applications
  - Userspace, polled-mode programming model
  - Open-source community
  - BSD licensed
  - https://spdk.io

Block Storage Protocols

Networking: NVMe-oF (RDMA, TCP, FC), iSCSI

Virtualization: vhost-scsi, vhost-blk, NVMe vfio-user

Block Storage Services

Partitioning: Logical Volumes, GPT

Caching: OCF

Host FTL: ZNS

Pooling: RAID-0

Transforms: Crypto, Compression

Block Storage Providers

NVMe, io_uring, Linux AIO, virtio, iSCSI, Ceph RBD

Drivers

NVMe (PCIe, RDMA, TCP), **virtio** (scsi, blk), **idxd**, ioat

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SPDK Threading Model

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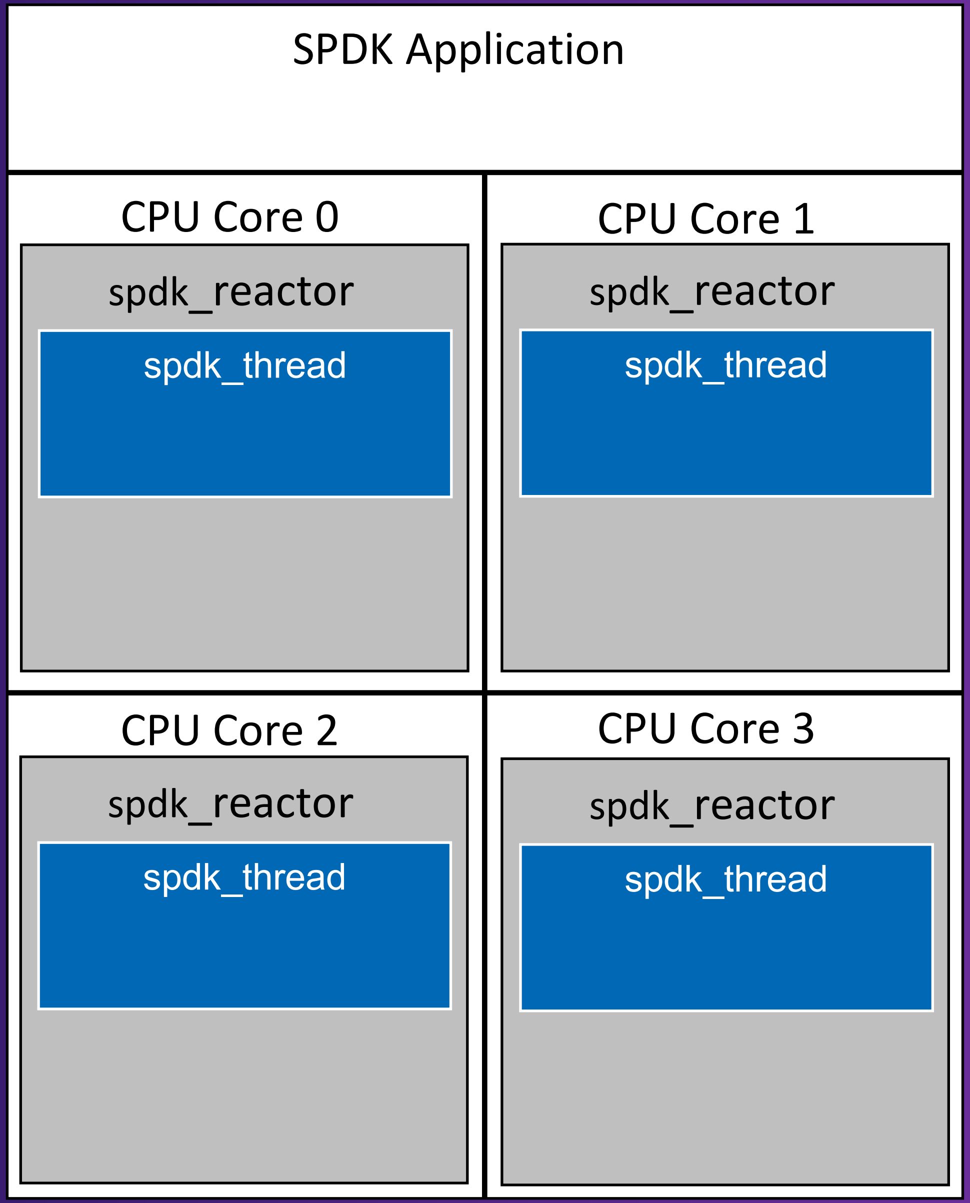
SPDK Threading Model

- spdk_reactor
  - One spdk_reactor per CPU core
  - Pinned POSIX thread
  - Created by SPDK application framework
- spdk_thread
  - Lightweight "thread" abstraction
  - By default, one spdk_thread per CPU core
    - Created by top-level block storage protocol library (nvmf, vhost, iscsi)
  - spdk_thread_poll() used by application framework to "run" an spdk_thread



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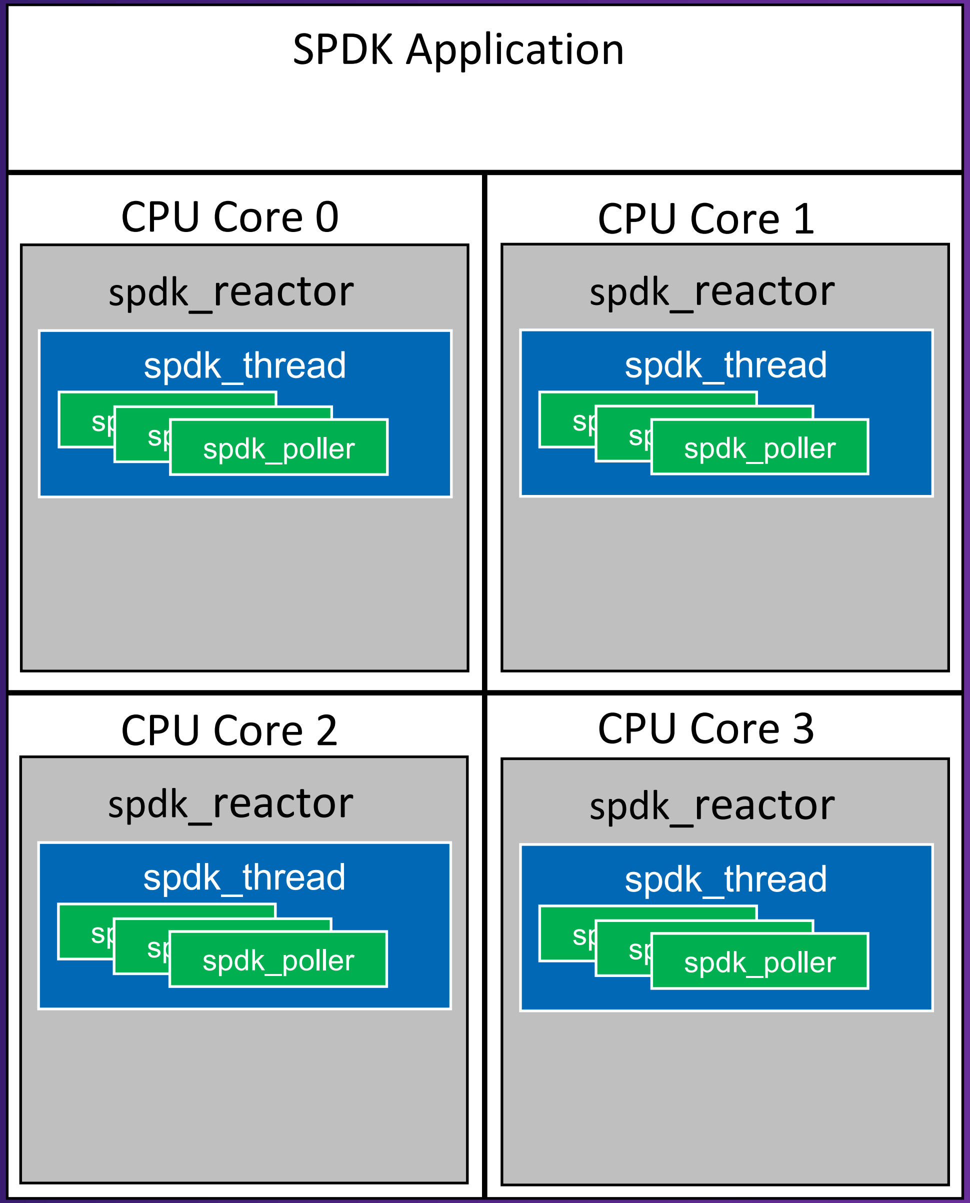
spdk_thread_poll()

- spdk_poller
  - Libraries register spdk_pollers to poll on something
    - NVMe qpair
    - epoll fd (group of TCP sockets or rbd eventfds)
    - RDMA completion queue
  - One call to spdk_thread_poll() runs every spdk_poller once
    - Except for timed pollers
- spdk_thread_send_msg()
  - Used for inter-thread communication



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Saving Power When Idle

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All of this polling!

- Polled mode ideal for best performance and efficiency when CPU cores are busy
- But how can we save CPU cycles when we are not as busy?

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Interrupt Mode

- SPDK does have some limited interrupt mode support
  - Restricted to very small subset of SPDK libraries (not including nvme driver or nvmf target)
  - Supporting libraries register fds with spdk_thread
  - spdk_reactor waits on epoll fd containing fds from all spdk_threads on that reactor
- Overly complex to implement efficiently
  - Avoid nested epoll fd groups
  - *Every* library must be modified to support interrupts

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umonitor/umwait

- Newer x86 instructions to allow unprivileged monitor/mwait
- umwait – enables CPU to enter low-power state
  - Exits low-power state on observed write to memory range specified by umonitor
- Works well for one thread polling one HW queue
  - i.e. DPDK packet processing and userspace Ethernet PMDs
- Not suitable when polling many HW queues from one thread
  - Or when polling kernel TCP sockets!

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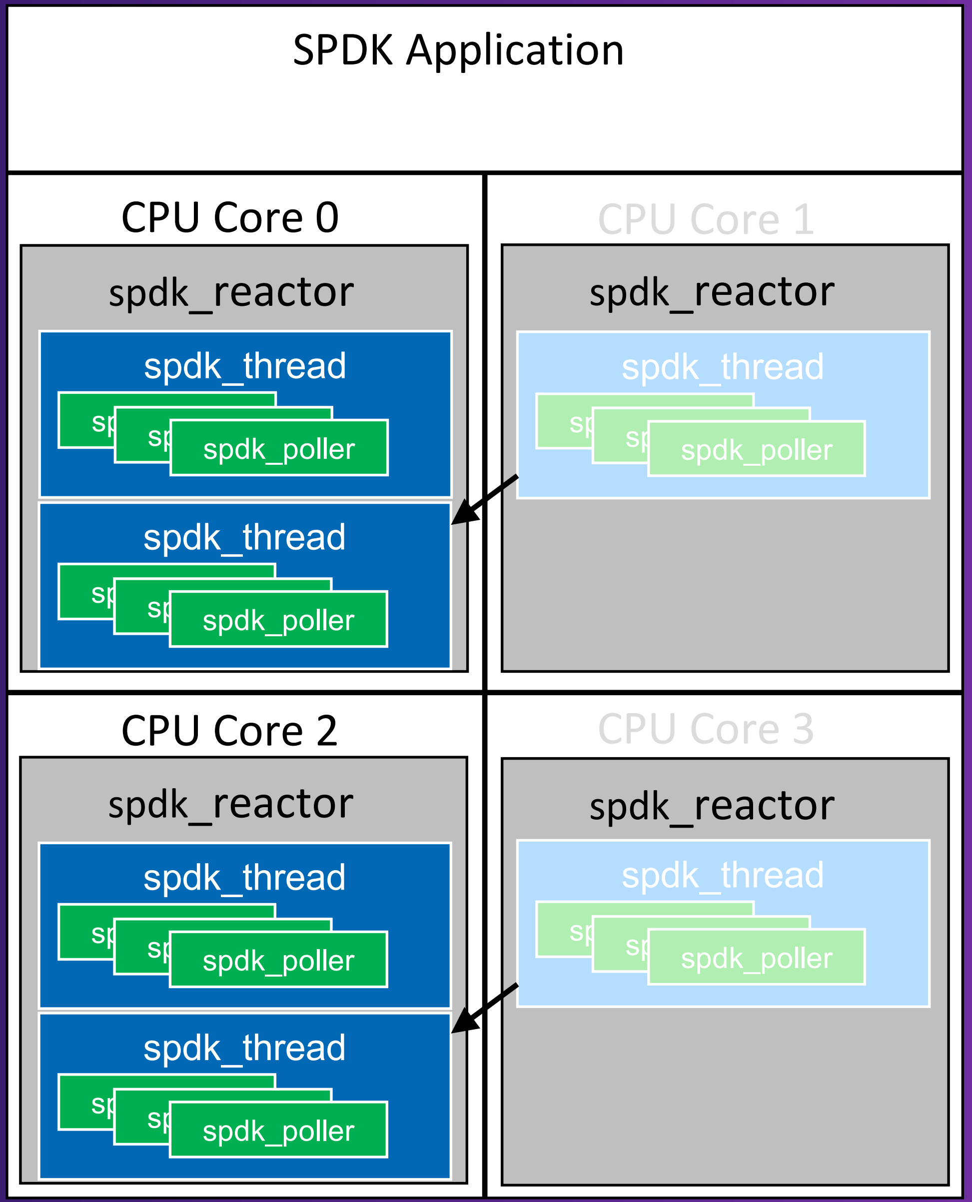
Move spdk_threads?

- Would allow putting a CPU core to sleep!
  - While still ensuring the spdk_thread is continually polled (just on a new core)
- Supported by SPDK threading model
  - Since all resources allocated by an spdk_poller are spdk_thread local



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SPDK Scheduler Framework

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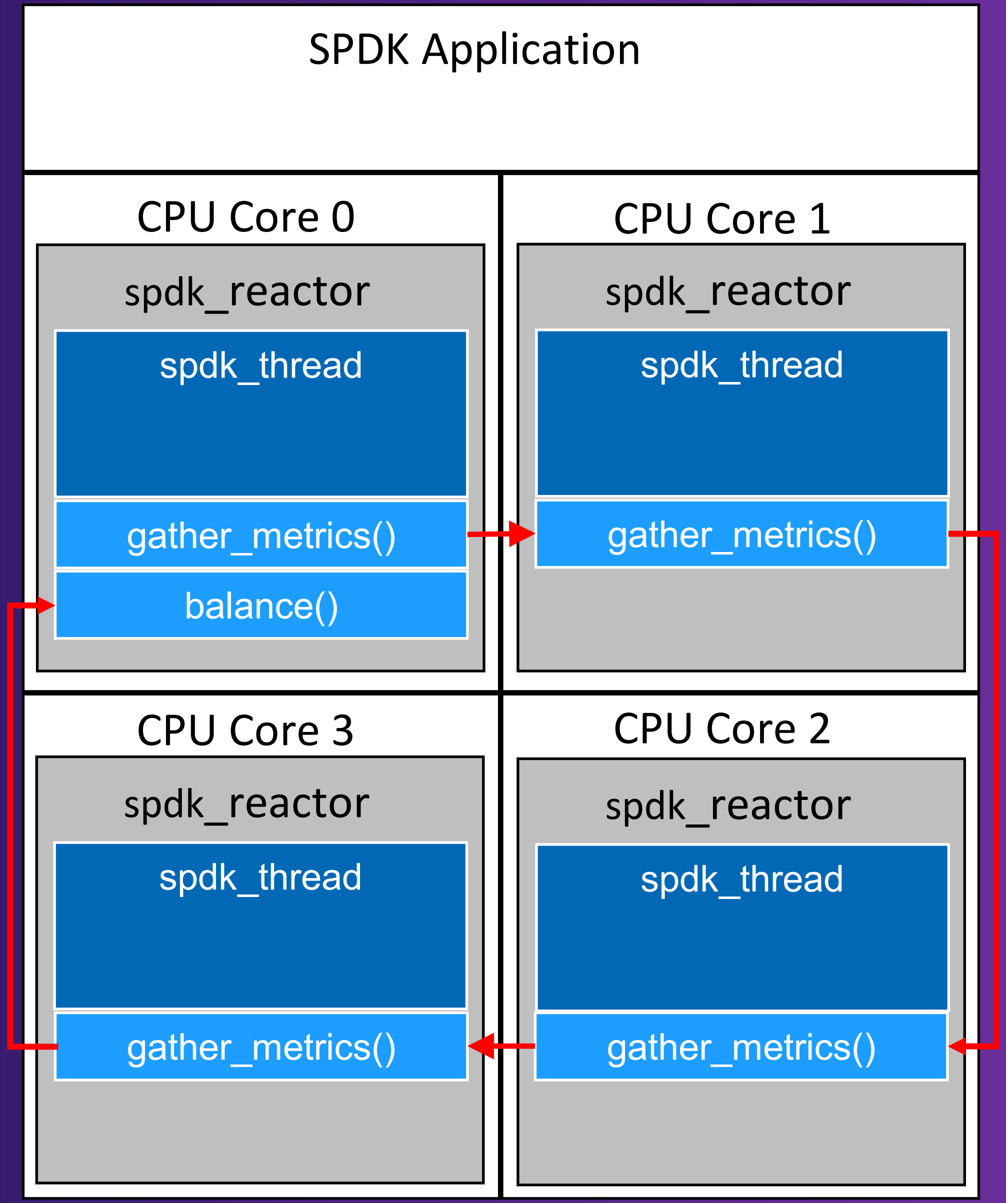
Scheduling Phases

- Reactors are never halted
- 1) gather_metrics() collects info on core and threads status

```
struct spdk_scheduler_core_info {
        /* stats over a lifetime of a core */
        uint64_t total_idle_tsc;
        uint64_t total_busy_tsc;
        /* stats during the last scheduling period */
        uint64_t current_idle_tsc;
        uint64_t current_busy_tsc;

        uint32_t lcore;
        uint32_t threads_count;
        bool interrupt_mode;
        struct spdk_scheduler_thread_info *thread_infos;
};
```

```
struct spdk_scheduler_thread_info {
        uint32_t lcore;
        uint64_t thread_id;
        /* stats over a lifetime of a thread */
        struct spdk_thread_stats total_stats;
        /* stats during the last scheduling period */
        struct spdk_thread_stats current_stats;
};
```



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Balancing Threads

- 2) balance()
  - Change thread's core assignment
  - Put a core to sleep
  - Modify core frequency via governor

- Plug your own !

```
SPDK_SCHEDULER_REGISTER(scheduler_dynamic);
```

```
$ ./scripts/rpc.py framework_set_scheduler dynamic -p 1000000
```

```
struct spdk_scheduler {
	const char *name;

	/**
	* This function is called to initialize a scheduler.
	*
	* \return 0 on success or non-zero on failure.
	*/
	int (*init)(void);

	/**
	* This function is called to deinitialize a scheduler.
	*/
	void (*deinit)(void);

	/**
	* Function to balance threads across cores by modifying
	* the value of their lcore field.
	*
	* \param core_info Structure describing cores and threads on them.
	* \param count Size of the core_info array.
	*/
	void (*balance)(struct spdk_scheduler_core_info *core_info, uint32_t count);

	TAILQ_ENTRY(spdk_scheduler) link;
};
```

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SPDK Governors

- Use of governors by scheduler is optional
- Dynamic scheduler uses dpdk_governor
  - rte_power library
- Plug your own !

```
SPDK_GOVERNOR_REGISTER(dpdk_governor);
```

```
rc = spdk_governor_set("dpdk_governor");
```

```
struct spdk_governor {
	const char *name;
	uint32_t (*get_core_curr_freq)(uint32_t lcore_id);
	int (*core_freq_up)(uint32_t lcore_id);
	int (*core_freq_down)(uint32_t lcore_id);
	int (*set_core_freq_max)(uint32_t lcore_id);
	int (*set_core_freq_min)(uint32_t lcore_id);
	int (*get_core_capabilities)(uint32_t lcore_id, struct spdk_governor_capabilities *capabilities);
	int (*init)(void);
	void (*deinit)(void);

	TAILQ_ENTRY(spdk_governor) link;
};
```

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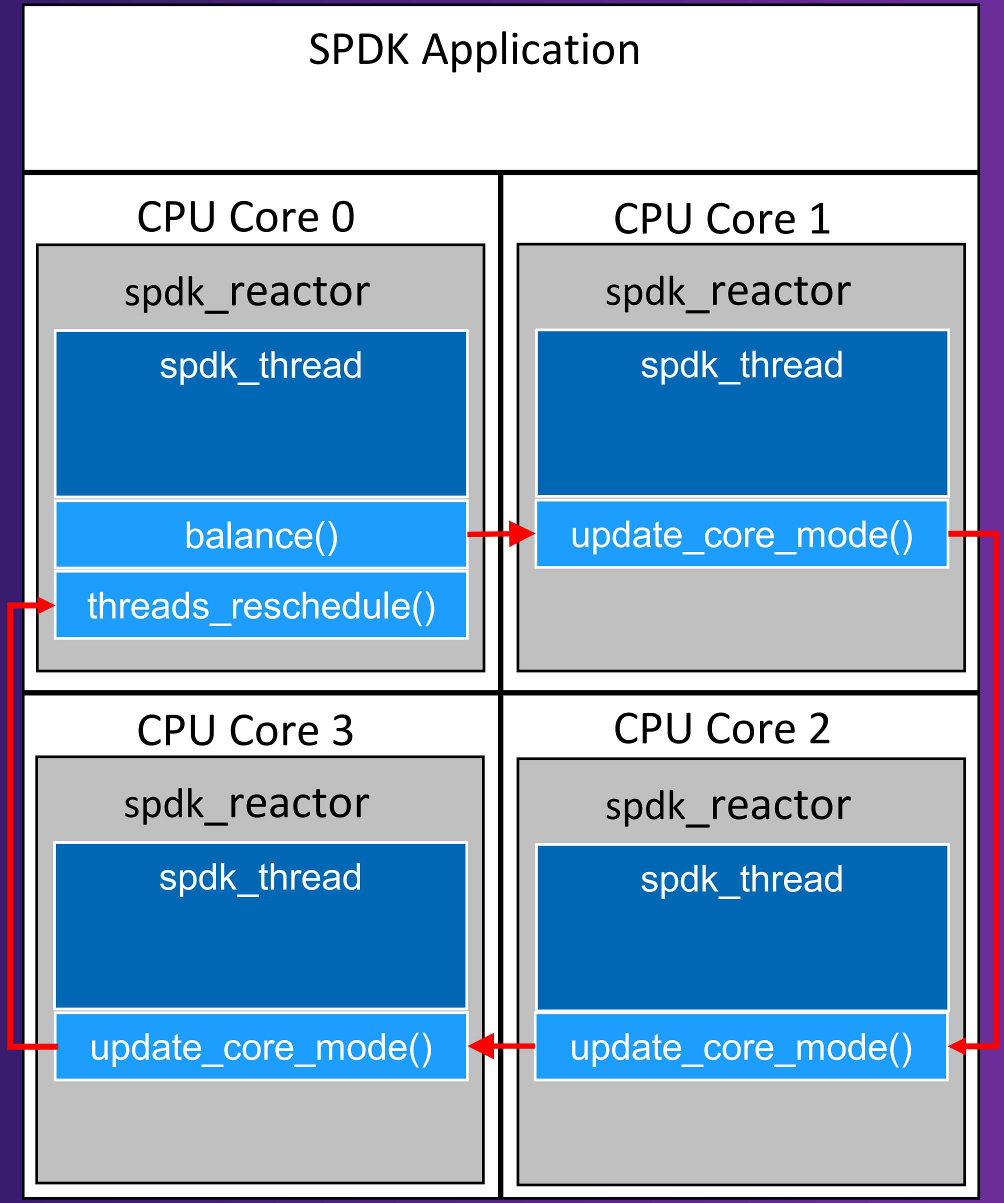
Scheduler Actions

- 3a) update_core_mode()
  - Puts a core into sleep
- 3b) threads_reschedule()
  - Marks spdk_thread for move



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Dynamic Scheduler

- Implementation of a scheduler

```
$ ./scripts/rpc.py framework_set_scheduler dynamic -p 1000000
```

- Prioritizes performance over power saving
  - Eager spdk_thread expansion
- Consolidates spdk_threads on minimal set of cores
- Puts unused cores to sleep
- Reduces CPU frequency of the main core on low use

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Performance Data

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Test Setup

- SPDK NVMe-oF TCP Target
  - 30 CPU cores assigned for the whole application
- Two SPDK NVMe-oF TCP Initiators, each:
  - 4 CPU cores
  - 8 NVMe-oF subystems
- FIO 4k block size randread workload
  - Increasing Queue Depth
  - Increasing # of TCP connections with 'numjobs'

Test by Intel as of 9/15/2021.
Target Node: 1-node, 2x Intel® Xeon® Gold 6230 Processor, 20 cores HT On Turbo ON Total Memory 384GB (12 slots/32GB/2933 MHz), BIOS: 3.4 (ucode:0x5003003), Fedora 33, Linux Kernel 5.8.15-300, gcc 9.3.1 compiler, fio 3.19, SPDK 21.07 with 28ab38a, Storage: 16x Intel® SSD DC P4610 1.6TB, Network: 2x 100 GbE Mellanox ConnectX-5.
Host Nodes: 2-nodes, 2x Intel® Xeon® Gold 6252 Processor, 24 cores HT On Turbo ON Total Memory 192GB (6 slots/32GB/2933 MHz), BIOS: 3.4(ucode:0x5003003), Fedora 33, Linux Kernel 5.8.15-300, gcc 9.3.1 compiler, fio 3.19, SPDK 21.07 with 28ab38a, Network: 1x 100 GbE Mellanox ConnectX-5

https://ci.spdk.io/download/performance-reports/SPDK_tcp_perf_report_2104.pdf

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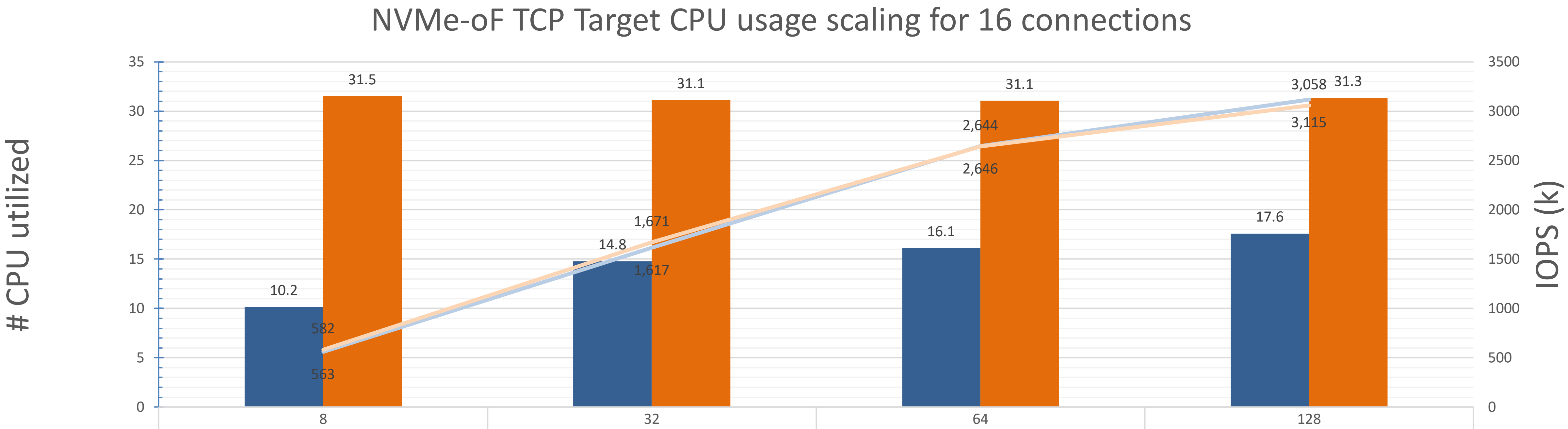
Dynamic vs Static Scheduler



	8	32	64	128
# CPU Dynamic	10.2	14.8	16.1	17.6
# CPU Static	31.5	31.1	31.1	31.3
IOPS (k) Dynamic	562.6	1617.3	2646.1	3115.3
IOPS (k) Static	582.3	1671.2	2644.2	3058.1

- 16 NVMe-oF subsystems
- 1 connection each

See configuration details – slide 20

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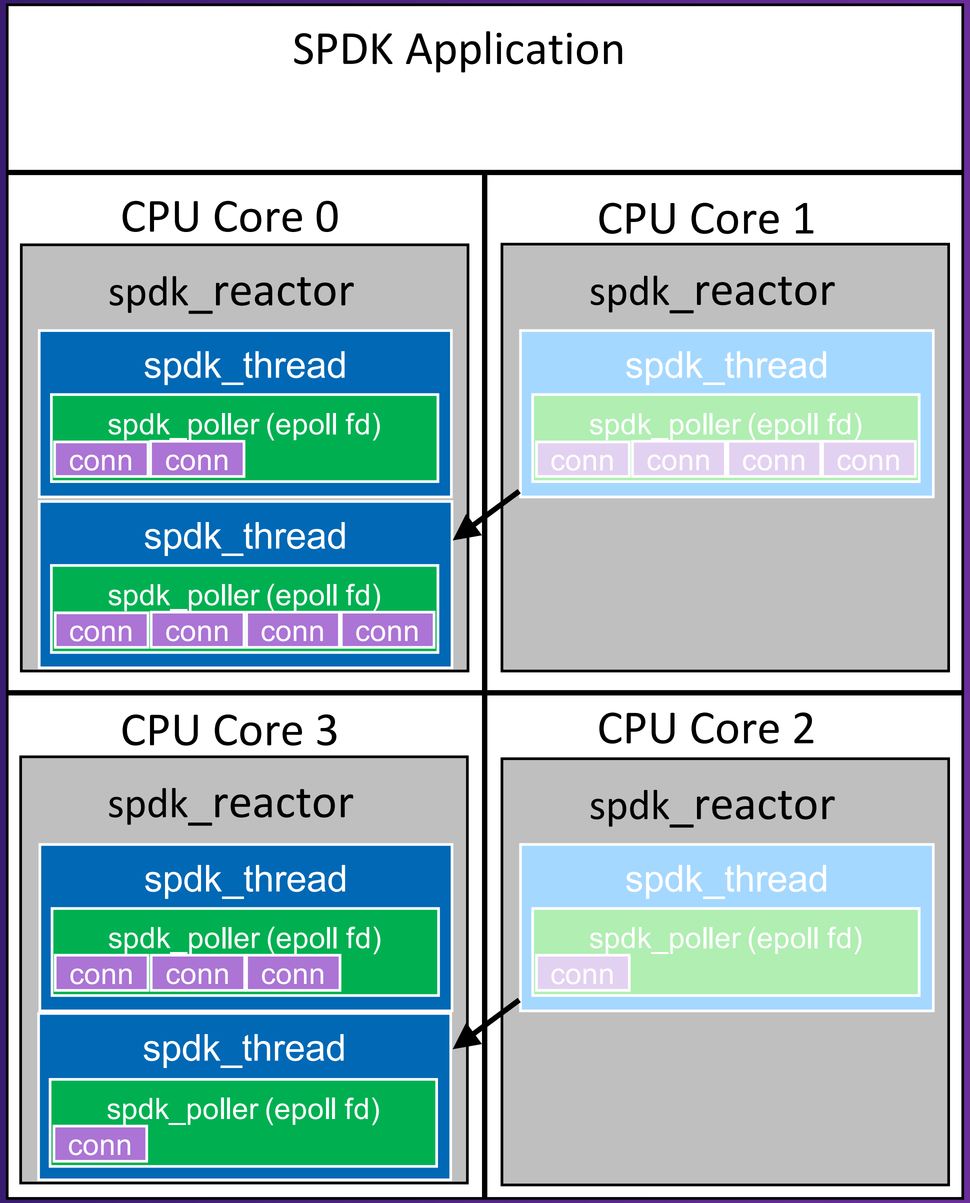
NVMe-oF Poll Group

- spdk_poller polls an epoll fd
  - Group multiple TCP sockets
  - Round robin assignment of NVMe-oF qpairs
- No guarantees on balance across spdk_threads
  - Mix of active and idle qpairs
  - Qpairs can disconnect
- Initiator spreads load across qpairs



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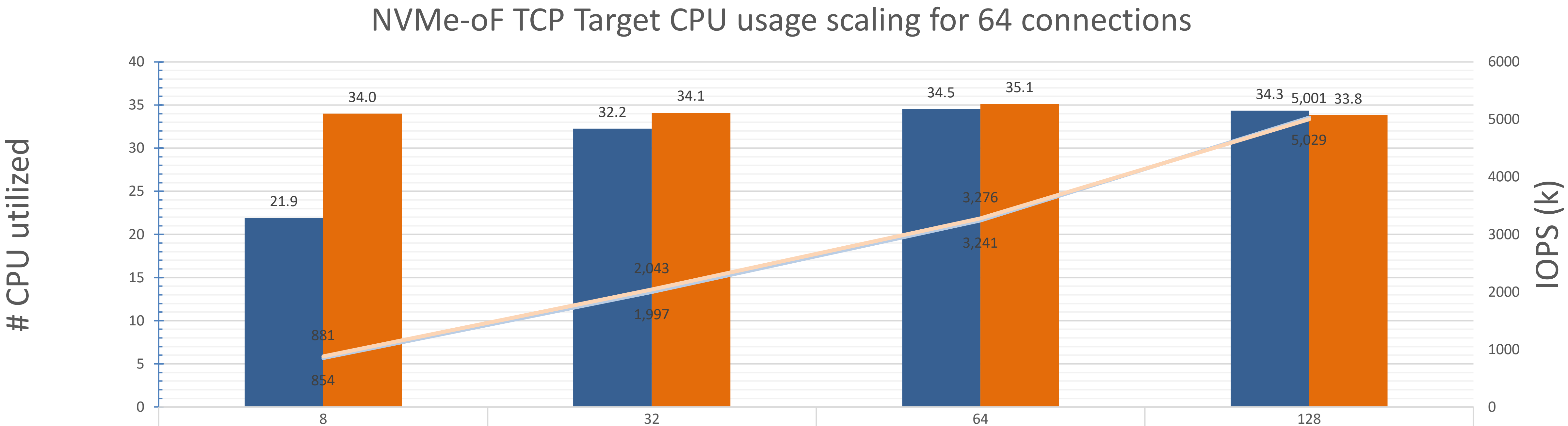
Cost of NVMe-oF TCP Poll Groups



	8	32	64	128
# CPU Dynamic	21.9	32.2	34.5	34.3
# CPU Static	34.0	34.1	35.1	33.8
IOPS (k) Dynamic	854.1	1997.3	3240.7	5029.1
IOPS (k) Static	880.7	2043.3	3276.5	5000.7

Queue depth

- 16 NVMe-oF subsystems
- 4 connections each

See configuration details – slide 20

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Summary and Next Steps

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Summary

- Poll mode applications require special handling to save power and CPU cycles when idle
- SPDK event framework allows moving idle spdk_threads to put cores to sleep thus saving power
- Plugable scheduler framework is provided to define when spdk_threads should be moved
- Dynamic scheduler consolidates spdk_threads on minimal set of cores and puts remaining cores to sleep

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Next steps

- Further improve the logic dynamic scheduler for spdk_thread placement
  - Give tweakable values to the user
- Address the cost of multiple poll groups on single core
- Scale CPU frequency of all cores
- Prioritize cores
  - Based on NUMA, hyperthreading and high frequency cores

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