RDMATracer: Lessons from scaling BPF to detect RDMA Device Drivers Bugs in real time

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Training Infrastructure at Meta

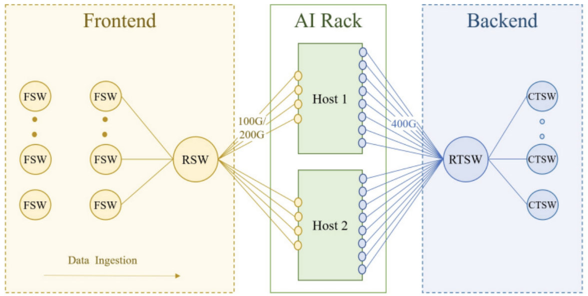


Figure 5: Frontend and Backend networks

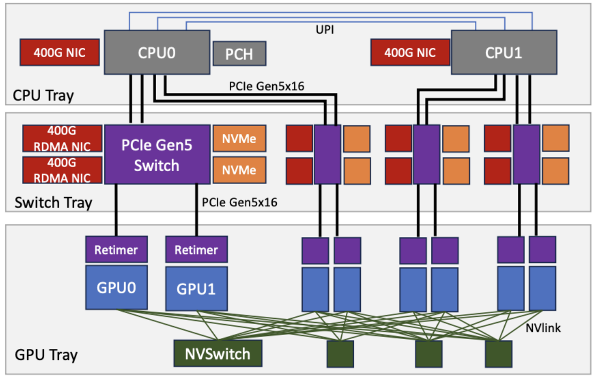
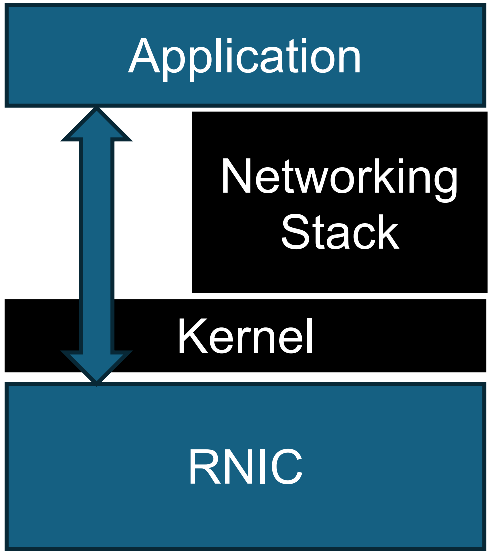


Figure 4: Grand Teton platform



RDMA is used extensively for GPU-based training for proven performance benefits

- Avoids network stack
- Allows direct transfers to memory

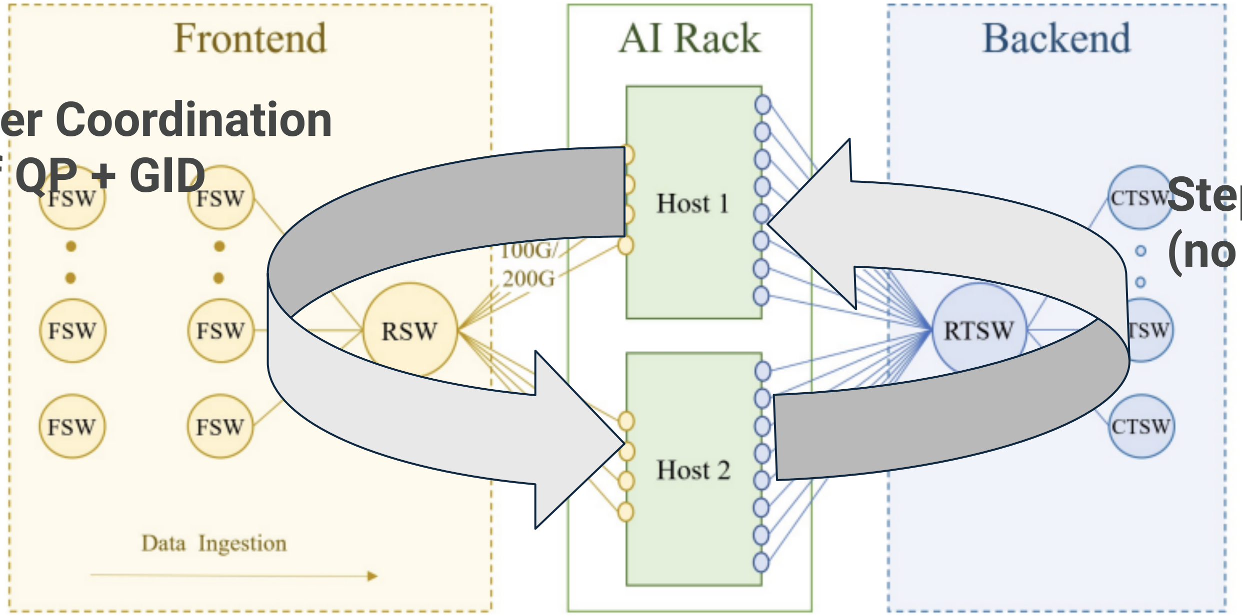
http://engineering.fb.com/wp-content/uploads/2024/08/sigcomm24-final246.pdf

High level steps for Training

Step 2: Server Configuration
(kernel programs NIC and allocate memory)

Step 1: Server Coordination
exchange of QP + GID

Step 3: Data Exchange
(no kernel)



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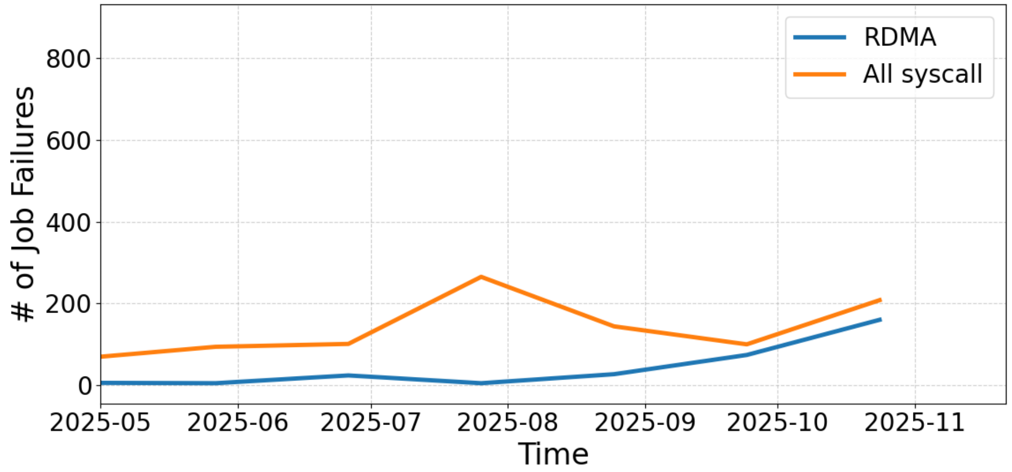
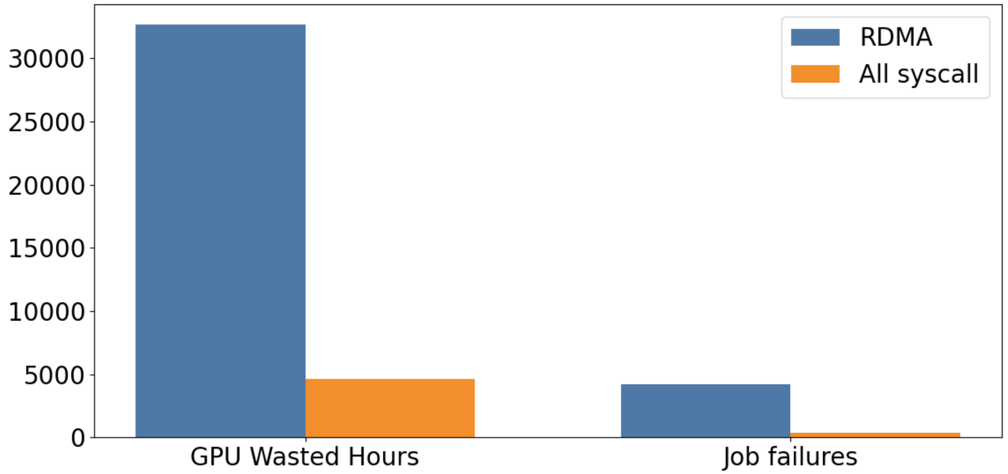
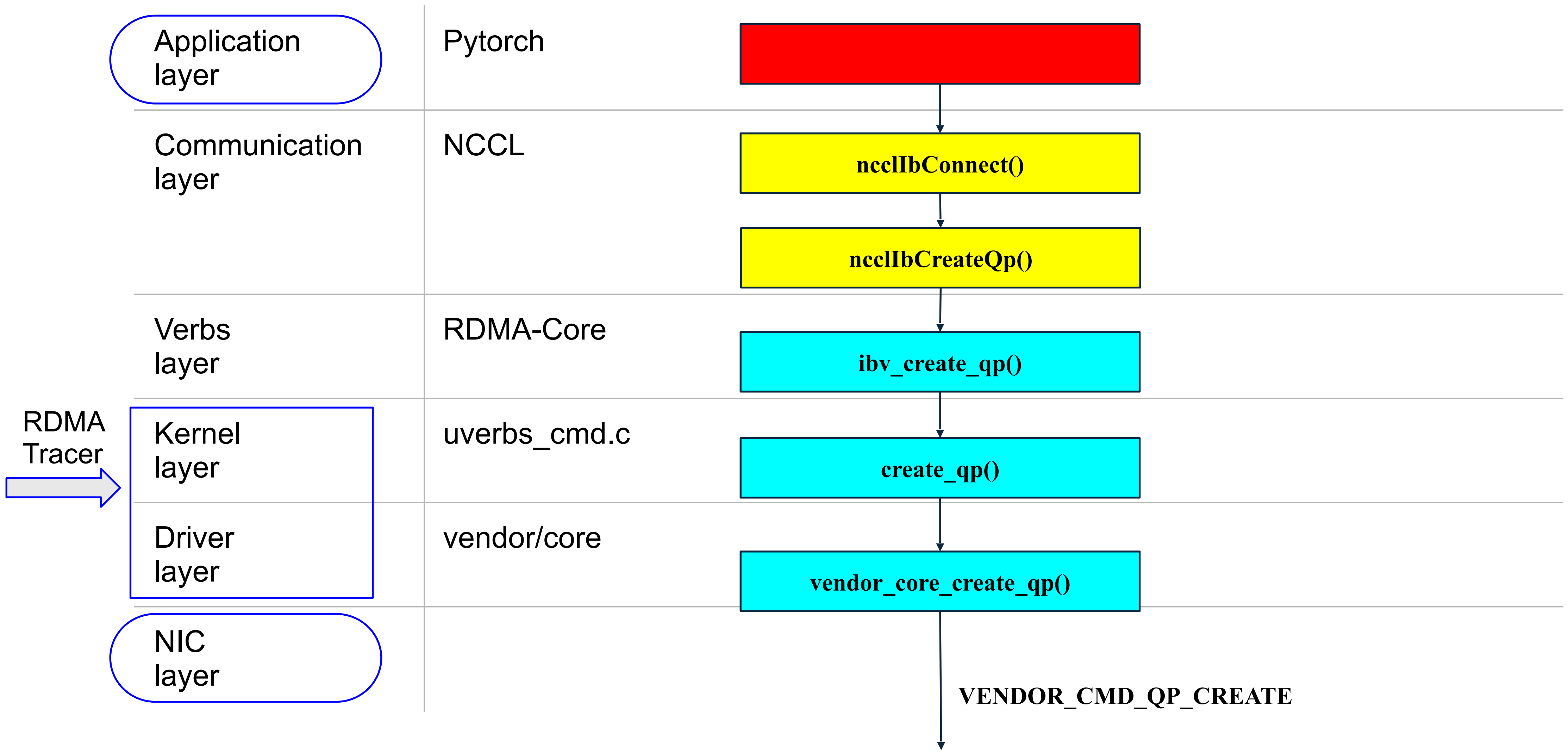
Case Study: Impact of Syscall Errors at Meta Scale



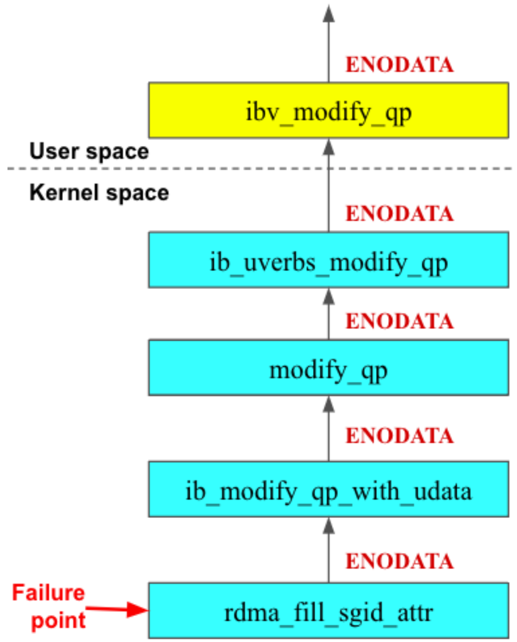


- On average, 10-20% of AI job crashes per day, are associated with RDMA (not network-related)
- For the last 6 month, 32k+ GPU Hours wasted, 5k+ for RDMA subsys
- Multiple blocking issues for flagship AI model trainings in the past, distracting 10+ people for weeks to root-cause and mitigate.

RDMA stack - Control Path



Syscall Errors in RDMA Network

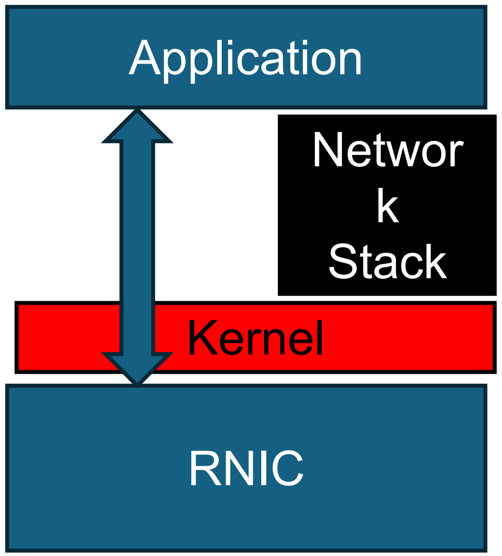


- Syscall/Async errors impact 29% of job
- Manual diagnosis with ftrace
  - Ftrace does not expose call return values
  - Required trace comparison: bad trace is shorter!
- Issue motivated the need for a system
  - Process all NCCL failures in production
  - Dynamically compare traces
  - Localize cause of differences to state differences

Why build our RDMATracer with eBPF?

- Linux is still crucial in RDMA systems
  - Performs control and resource accounting
  - Processes all ibverbs ioctls - rdma core (no retries)

- Building eBPF provides
  - Flexibility: monitor and extract additional data from internal variables
  - Complexity: implement complex aggregation logic
  - Interoperability: no need to modify kernel or runtime

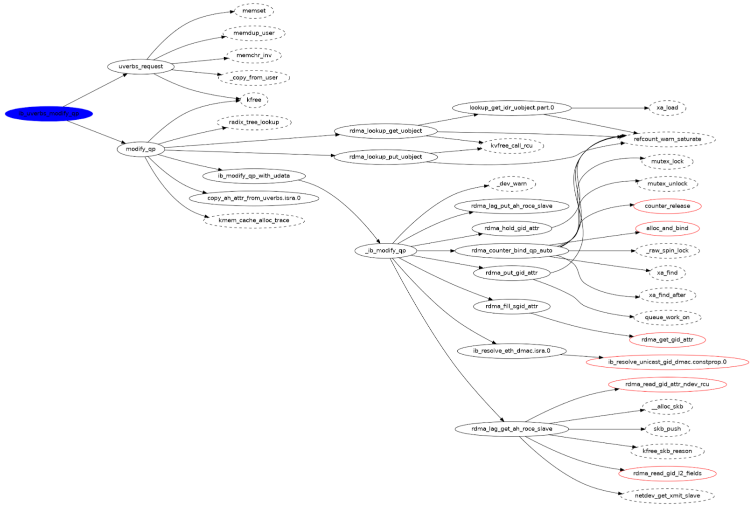


Challenges Tracing Syscalls

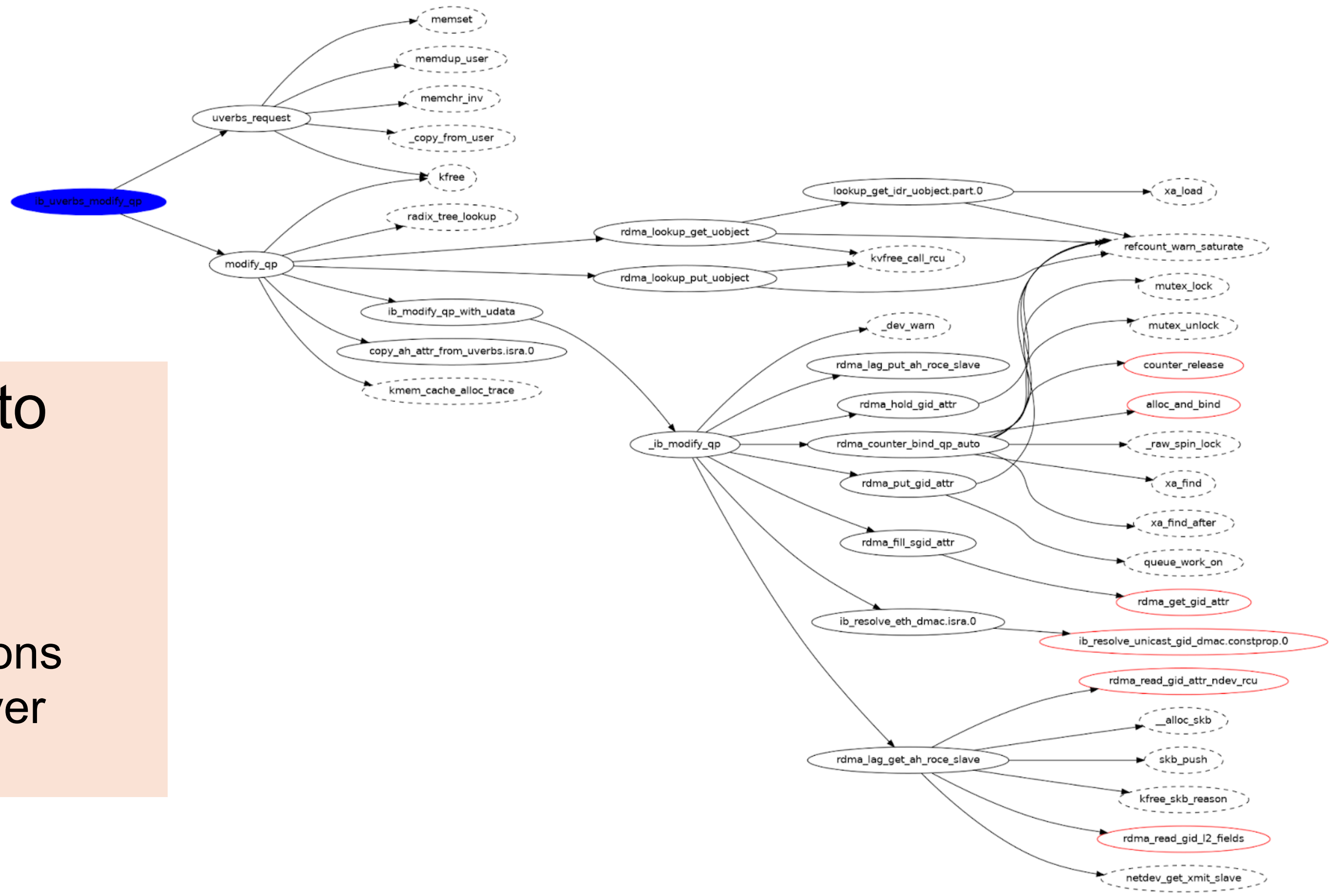
- All RDMA interactions maps to one Syscall
  - Many different paths → significant tracing overheads
  - Heuristic: focus on paths which translate state
    - RDMA hardware state → Software state (Kernel Data structures)

- BPF provides many options for creating probes
  - Selecting optimal is non trivial

- Always on probe is expensive
  - Reactive approach to data collection



Scaling Syscall Tracing for RDMA Backend



Used static analysis to create rules to prune call path.

- Avoid reads calls
- Avoid internals of “pure kernel” functions
- Avoid “cleanup” or “reference counter” functions
- Depending on HW vendor, focus on their driver system calls

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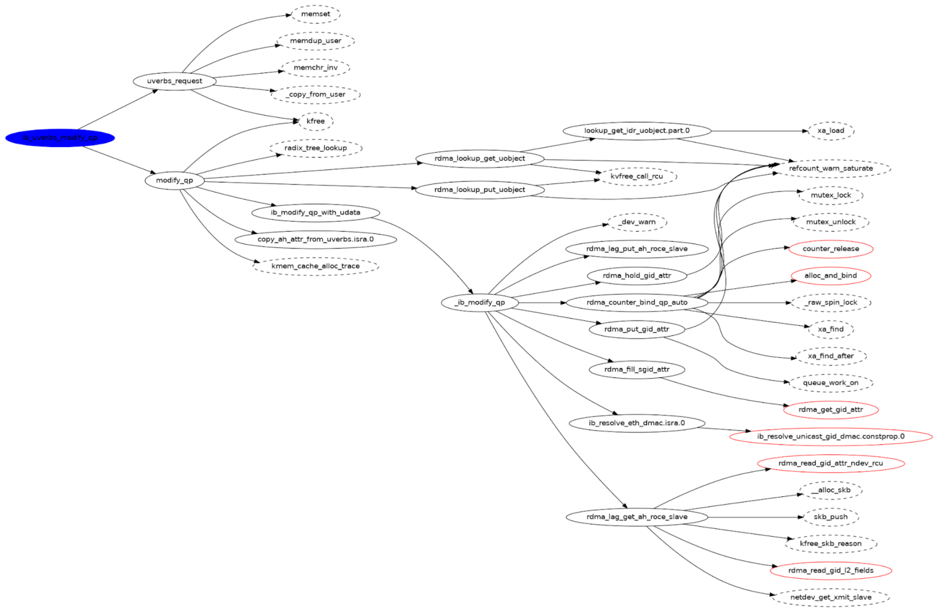

Traced functions for ib_uverbs_modify_qp

- modify_qp,
- rdma_lookup_get_uobject,
- _ib_modify_qp,
- ib_resolve_eth_dmac.isra.0,
- rdma_lag_get_ah_roce_slave,
- rdma_get_gid_attr,
- alloc_and_bind,
- rdma_counter_bind_qp_auto.

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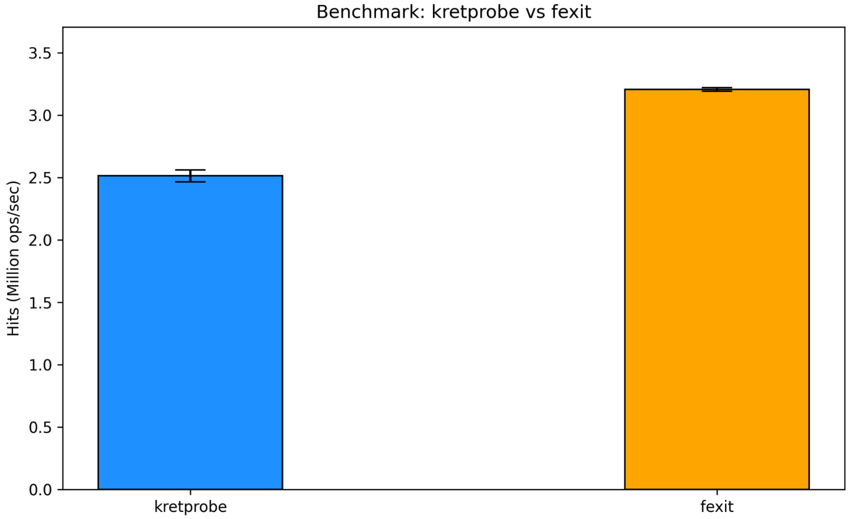
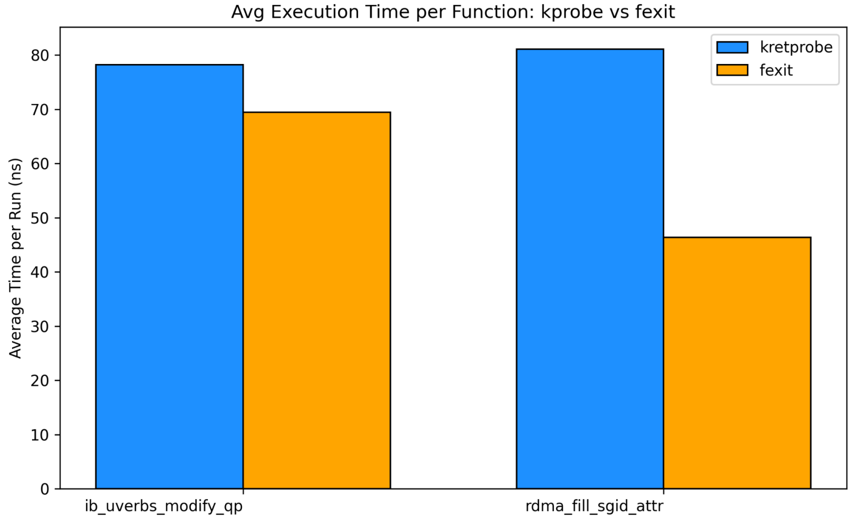
Monitoring Solution Design: Kprobe V Kfunc

- Probe location: KProbe V. kretprobes
  - Kprobes: inserted into any location inside a kernel function.
  - Kretprobes: triggered when a specified function returns.

- Probe type: K{ret}probe V. fentry/fexit
  - Mostly interested in “what happened” along with input and return val
  - Stable Kernel Interface ?
- Goal: Lowest possible overhead
  - Measuring overheads with Kernel benchmark tool
  - Validate with NCCL-test tool

Performance Comparison: Kretprobe v. fexit



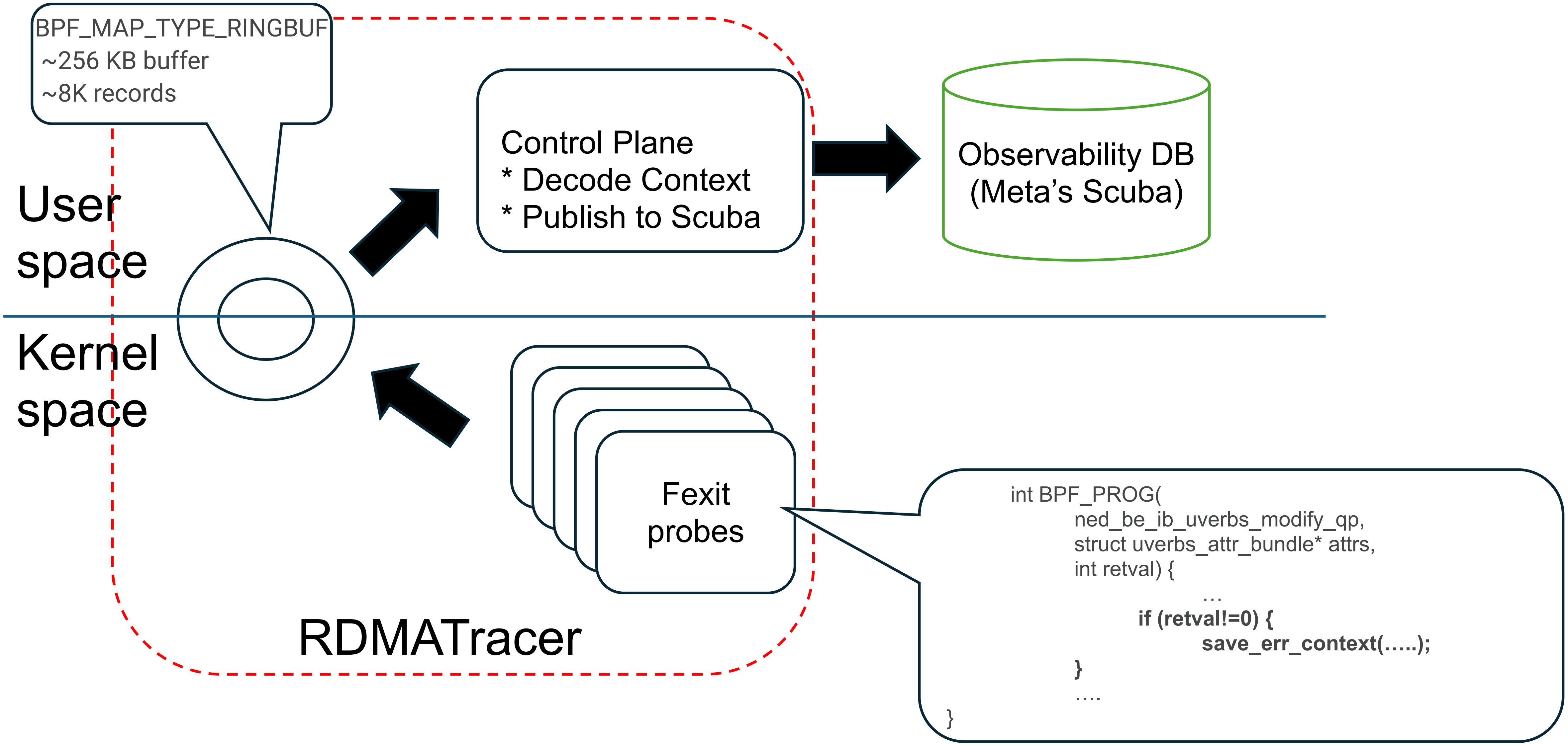


Kernel Benchmark tool

NCCL Benchmark tool

Across all benchmarks: fexit is roughly 72% of kprobe.

Solution Design



Solution Design

- Shared Maps for all fexit progs
  - Ring Buffer to store err_ctx
  - counter map (per-CPU) tracks how many times a syscall has been invoked.

There are three types of counters:

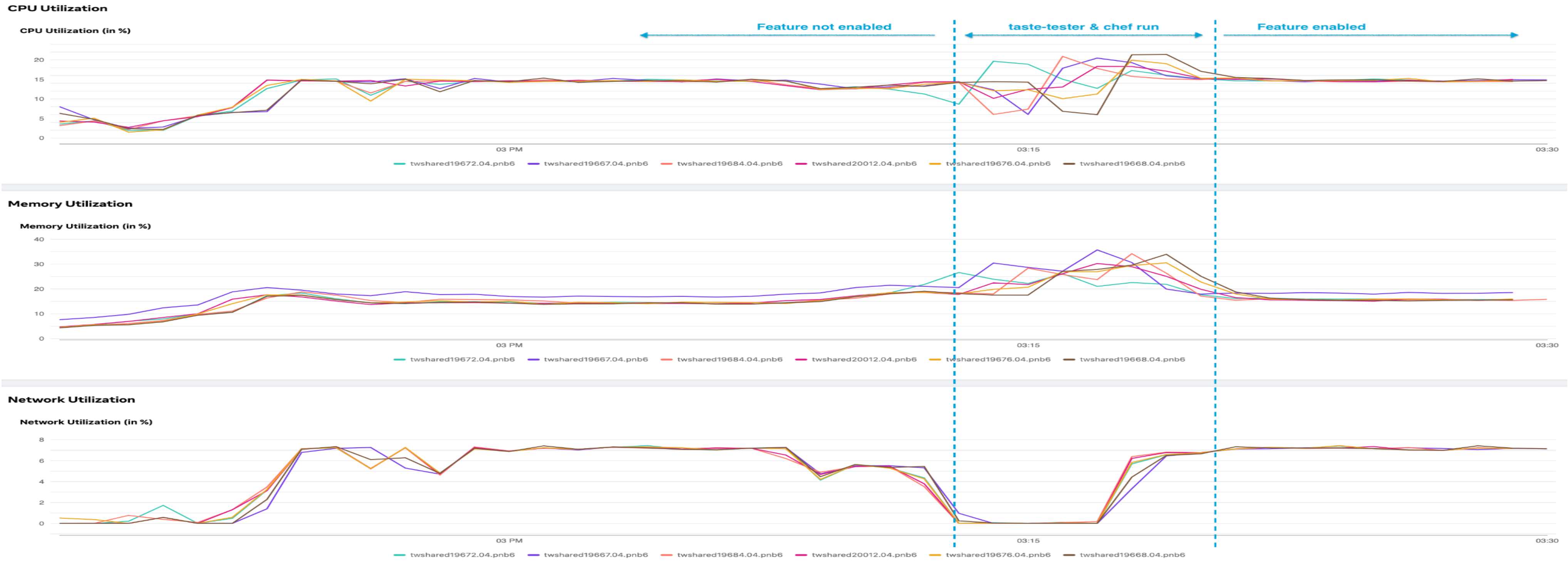
- Type 1: Read as <syscall>, track how many times a syscall has been invoked.
- Type 2: Read as <syscall>_err, track how many times a syscall has been failed.
- Type 3: Read as <syscall>_errno, track the errno returned by a syscall upon its failure.

Sun, Nov 30, 2025 12:19:48 AM (PST)	1	580.82.07	6.13.2-0_fbk7_0_gbc14455e13aa	0	[{"syscall":"mlx5_ib_post_send","errmsg":"Input/output error","errno":5,"process":"nvlsm","timestamp":"11/30/25 00:19:45 ...
Wed, Nov 26, 2025 06:21:04 AM (PST)	1	570.124.06	6.9.0-0_fbk10_0_gc5fa564d33e3	9	[{"syscall":"ib_peer_umem_get","errmsg":"Cannot allocate memory","errno":12,"process":"rdmaC_mlx5_2","timestamp":"11/26/ ...

Again Performance Comparison: With and without BPF

Observations:

- No major change on host metrics before and after feature enabled.
  - bpf_tax - p50 (88.7% less), p99 (98.9% less)
- Workflow QPS not impacted by enabling this feature.



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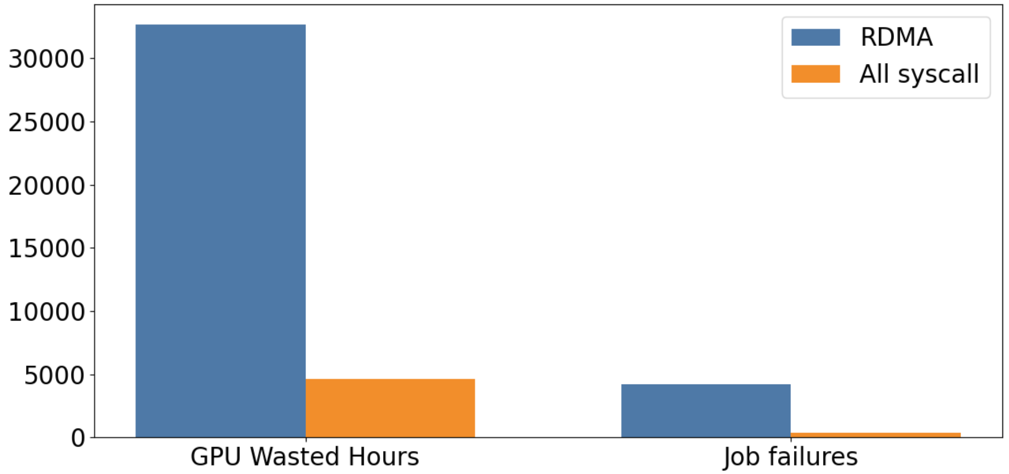
Auditing System Workflow

- Periodically capture and store “good” traces:
  - Zero / success as return code
  - “Quick” syscall completion (not greater than 50ms)
  - Challenge: there are also cases when syscall returns “non-critical” error code as expected - e.g. ENOENT for disabled functionality.

- Compare those traces with good ones and help narrow down the issue
  - Looking for bifurcation point to determine which exact spot is failing and producing syscall error.

- Dynamically trigger for a new syscall (or parameters)

RDMATracer in Production Today



- Significantly reduces diagnosis time from 10+ mins to seconds
  - Enables issue auto classification and accounting
  - Eliminates the need to retrieve and process gigabytes of logs
  - Provides a precise timelines for issues and provides dmesgs to aide correlations
  - Helps identifies driver bugs in vendor locked drivers (black box drivers)

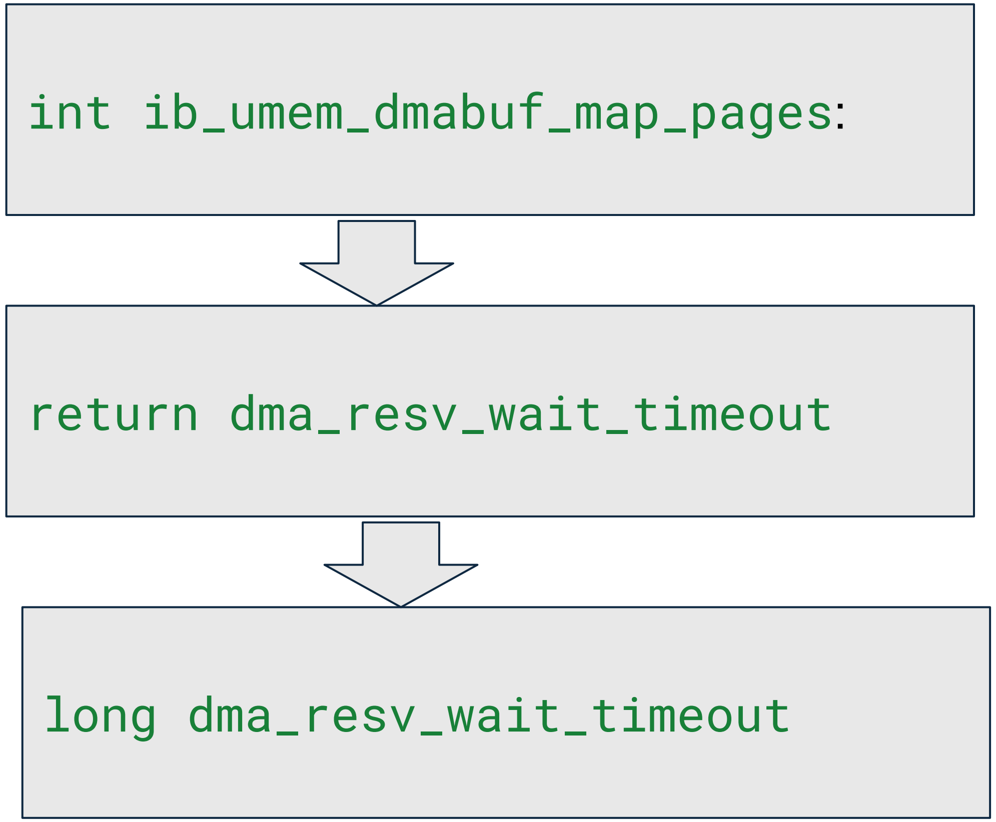
Usecase: Triaging blackbox vendor drivers

AI jobs failed on a newly deployed vendor NIC driver (fb v5.19 kernel)

```
NCCL WARN Call to ibv_reg_dmabuf_mr failed
with error Operation not permitted
```

RDMATracer exported syscall traces which helped identify:

- A chain of syscalls which returned the error
- A mismatch in the return values for these syscalls
- Triaged error to overflow problem



Summary

- RDMA syscall errors have a significant impact at scale
  - 10-20% of Meta's AI job crashes, wasting GPU hours.
- RDMATracer: eBPF-based tool that proactively detects RDMA device driver bugs in real-time.
  - Scalability from Design Choices: minimize # of probes via Static analysis and strategic selection of trace points.
  - Scalability from eBPF Primitive Selected: fexit over Kretprobes.
- RDMATracer streamlines diagnosis and auto-classifies issues
  - Diagnosis reduced from 10+ minutes to seconds