NETRONOME

BPF Hardware Offload Deep Dive

Jakub Kicinski

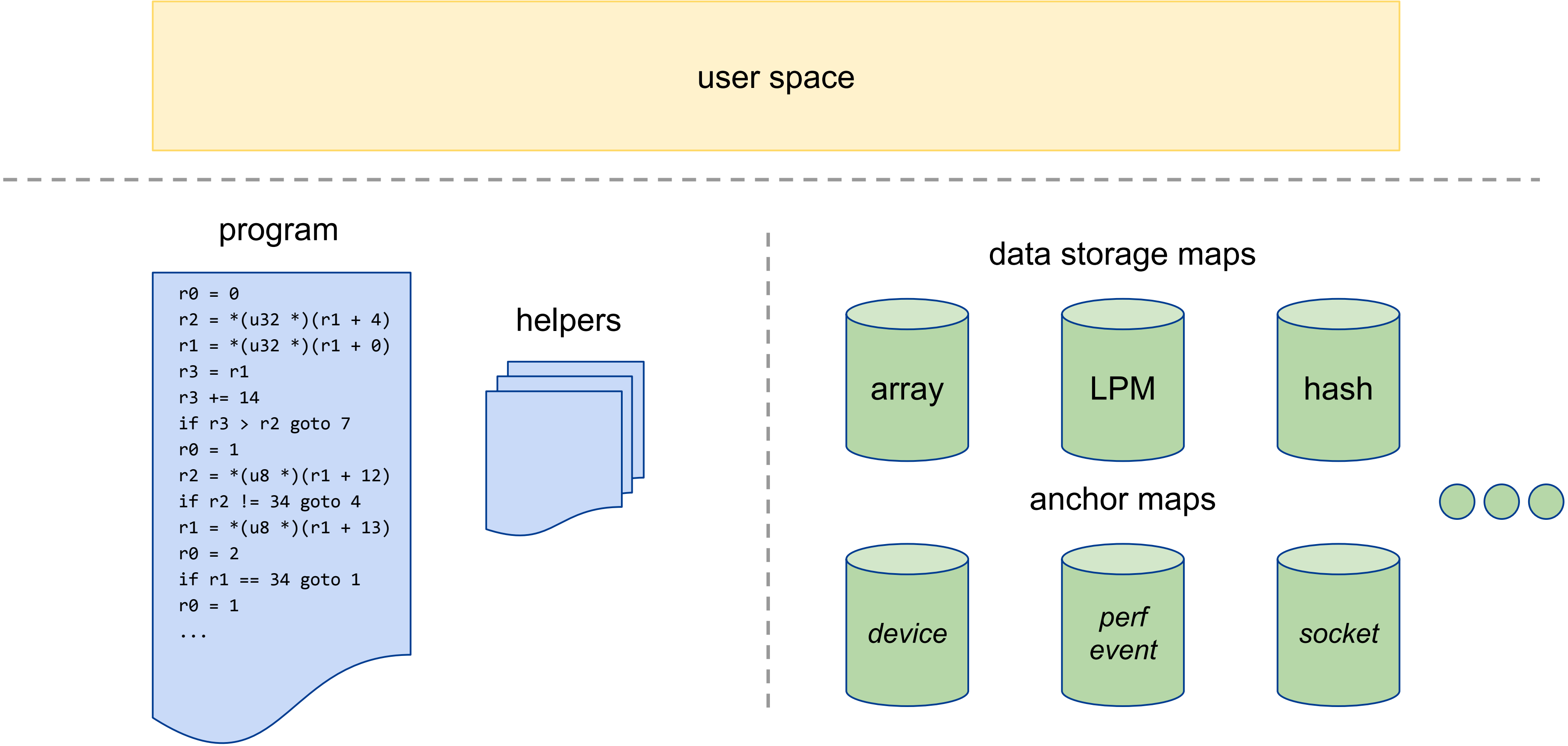
BPF Sandbox

- As a goal of BPF IR JITing of BPF IR to most RISC cores should be very easy
- BPF VM provides a simple and well understood execution environment
- Designed by Linux kernel-minded architects making sure there are no implementation details leaking into the definition of the VM and ABIs
- Unlike higher level languages BPF is a intermediate representation (IR) which provides binary compatibility, it is a mechanism
- BPF is extensible through helpers and maps allowing us to make use of special HW features (when gain justifies the effort)

BPF Ecosystem

- Kernel infrastructure improves, including verifier/analyzer, JIT compilers for all common host architectures and some common embedded architectures like ARM or x86
- Linux kernel community is very active in extending performance and improving BPF feature set, with AF_XDP being a most recent example
- Android APF targets smaller processors in mobile handsets for filtering wake ups from remote processors (most likely network interfaces) to improve battery life

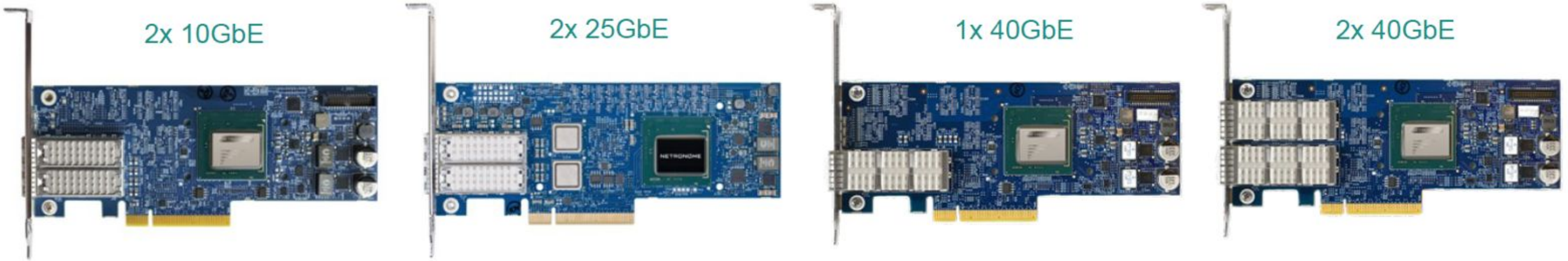
BPF Universe



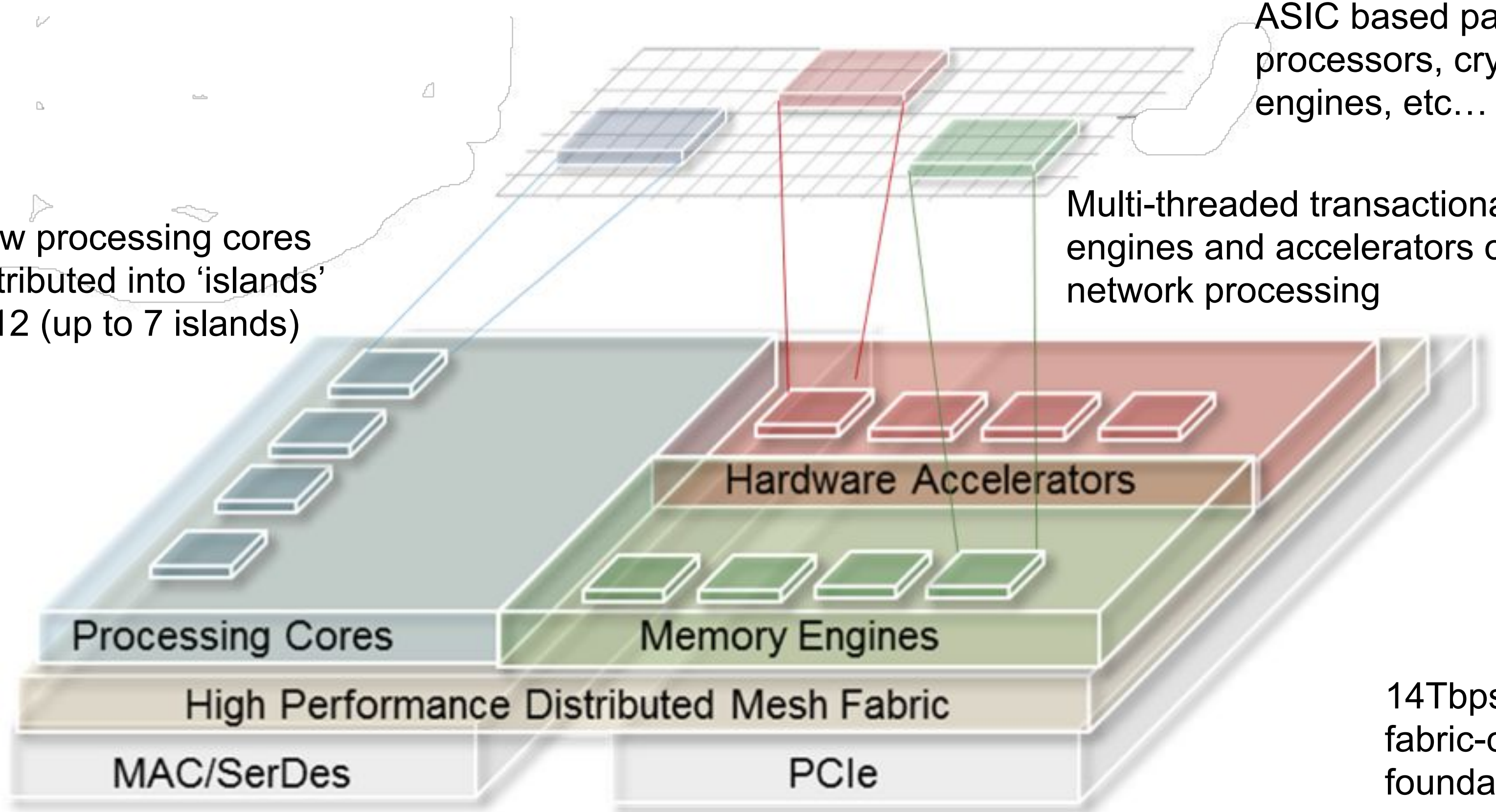
BPF Universe

- Translate the program code into device's native machine code
  - Use advanced instructions
  - Optimize instruction scheduling
  - Optimize I/O
- Provide device-specific implementation of the helpers
- Use hardware accelerators for maps
  - Use of richer memory architectures
  - Algorithmic lookup engines
  - TCAMs
- Filter packets directly in the NIC
- Handle advanced switching/routing
- Application-specific packet reception policies

- Optimized for standard server based cloud data centers
- Based on the Netronome Network Flow Processor 4xxx line
- Low profile, half length PCIe form factor for all versions
- Memory: 2GB DRAM
- <25W Power, typical 15-20W



SoC Architecture-Conceptual Components



ASIC based packet processors, crypto engines, etc…

Flow processing cores distributed into 'islands' of 12 (up to 7 islands)

Multi-threaded transactional memory engines and accelerators optimized for network processing

14Tbps distributed fabric-crucial foundation for many core architectures

Up to 100 Gbps

4x PCIe Gen 3x8

NFP SoC Architecture

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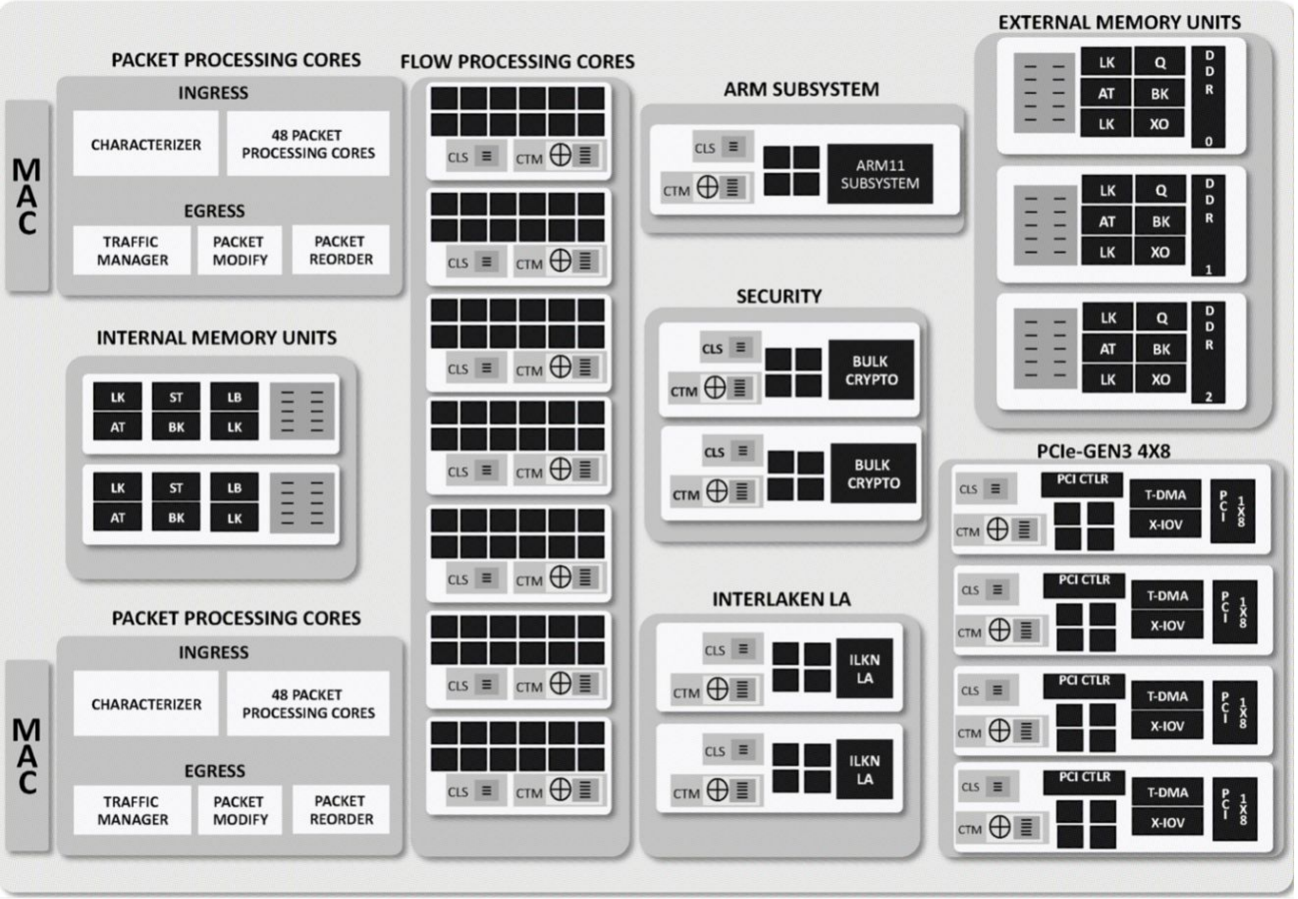

NFP SoC Architecture

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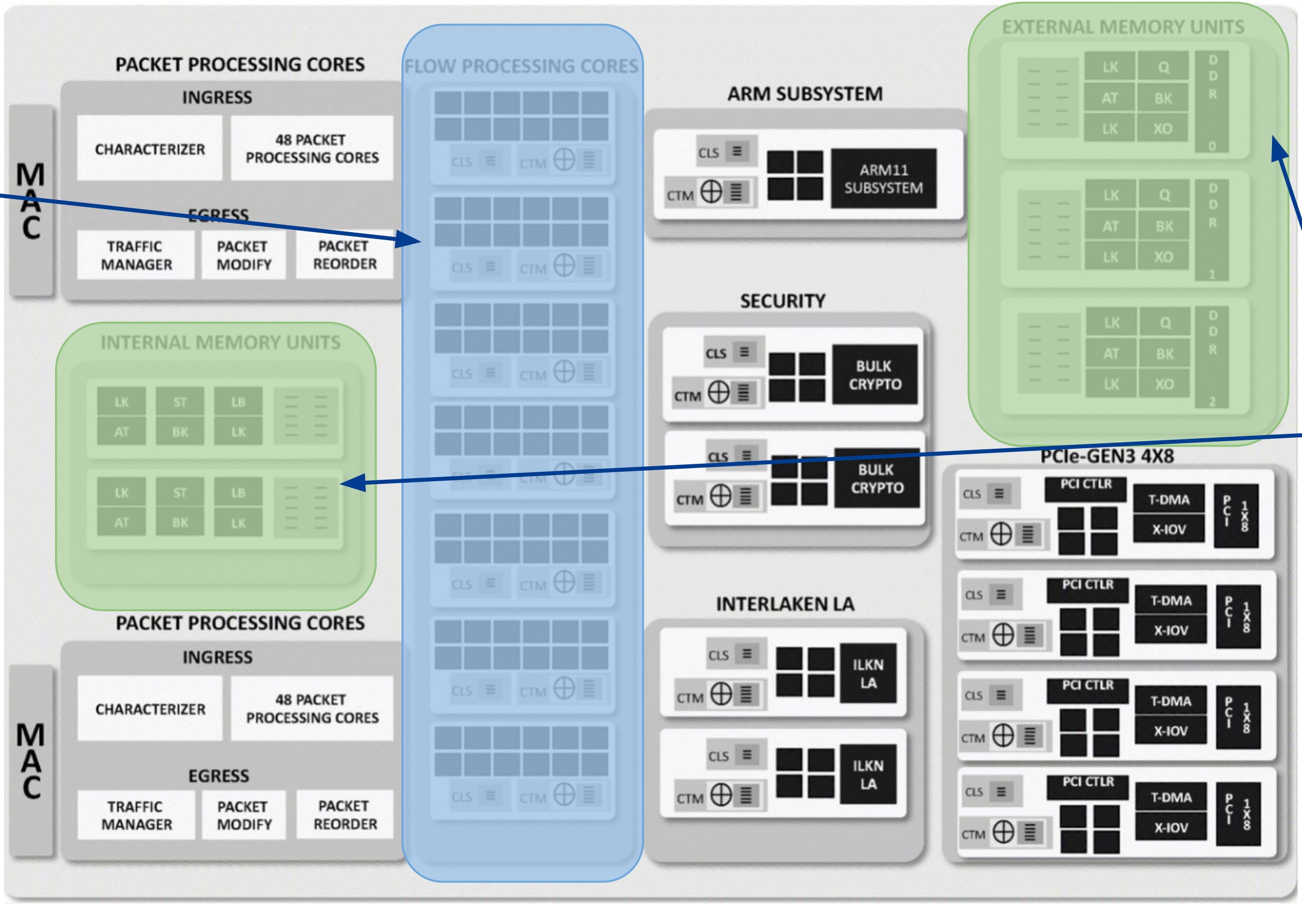
BPF programs



BPF maps

NFP SoC Packet Flow

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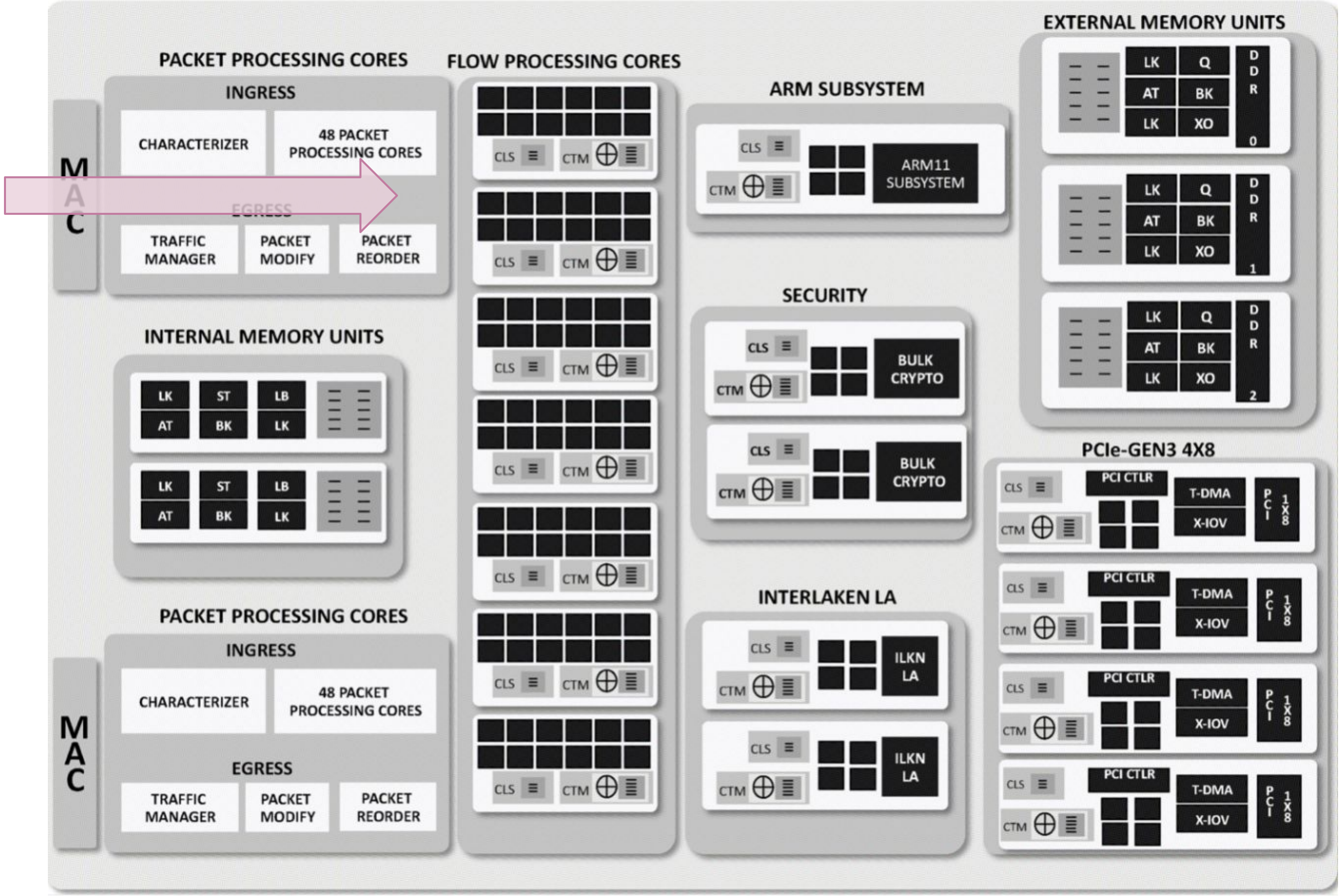
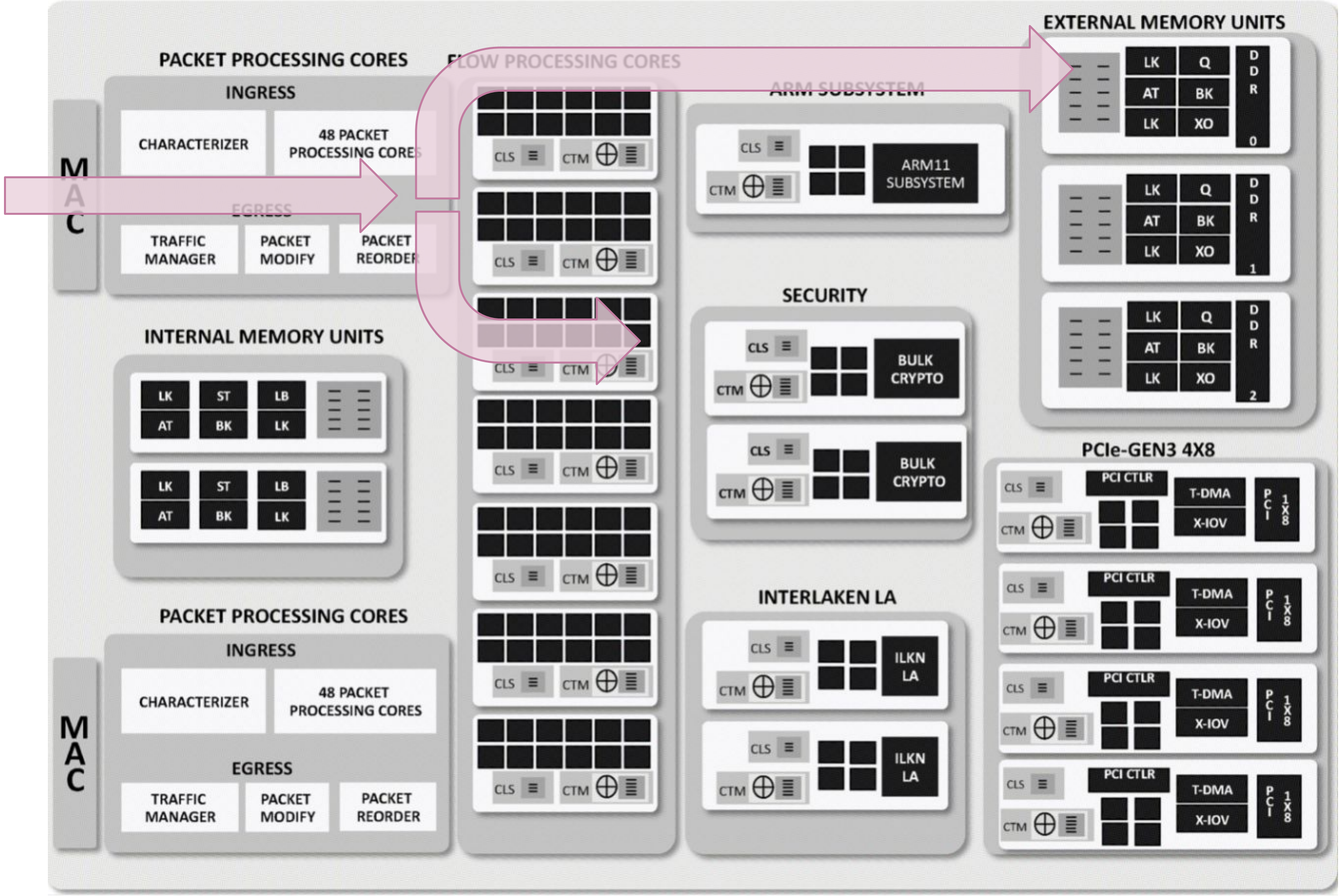


NFP SoC Packet Flow



NFP SoC Packet Flow

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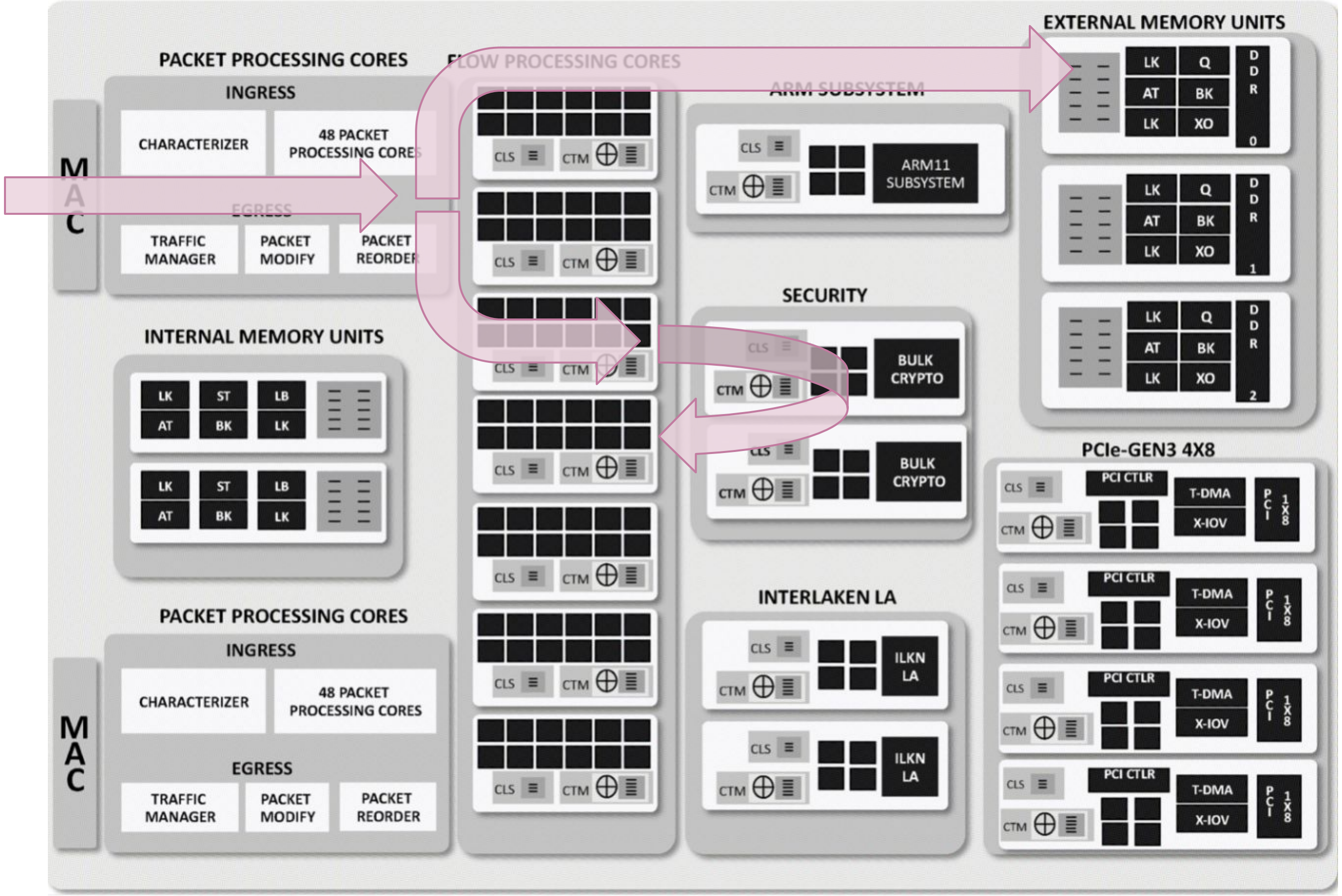
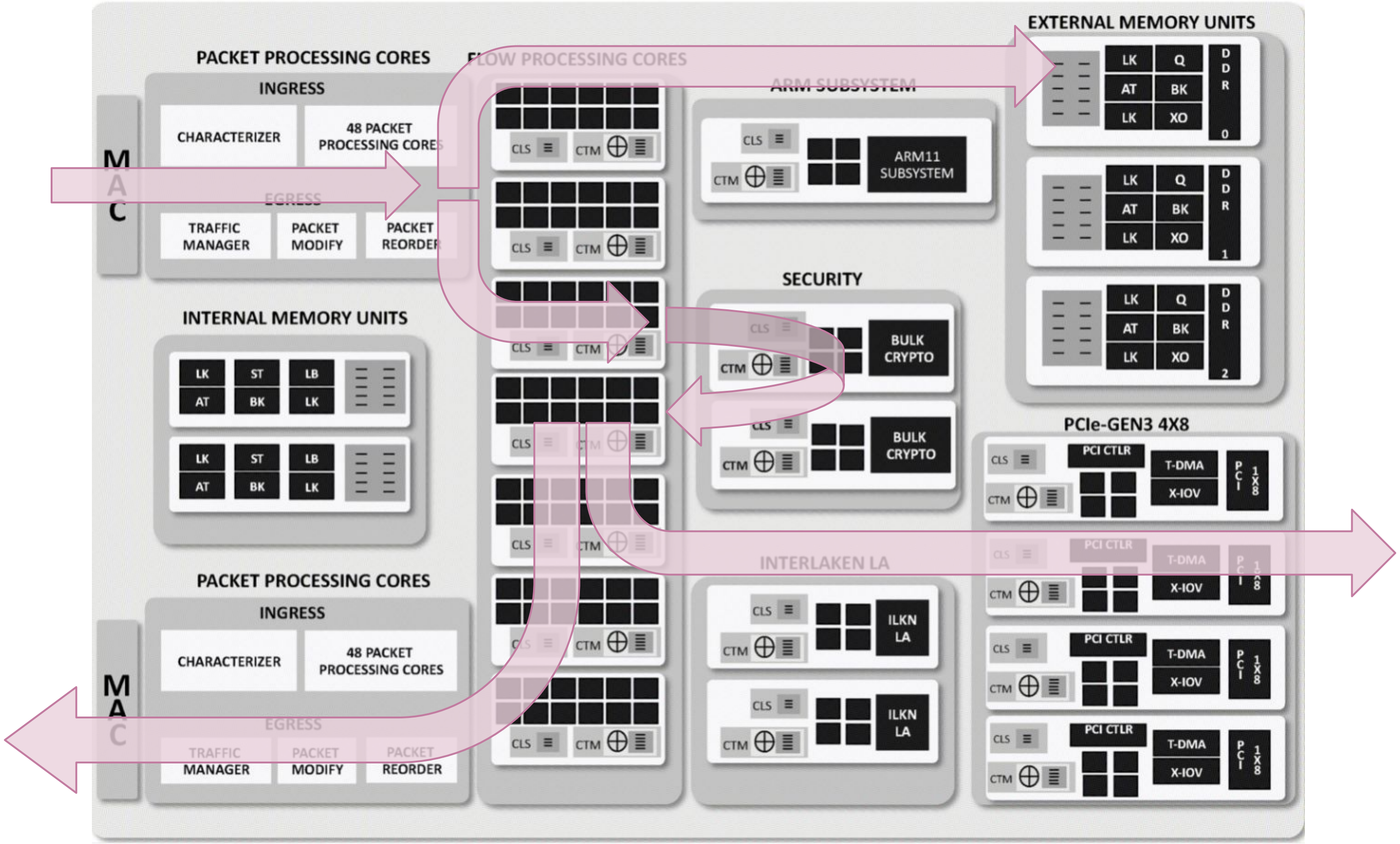
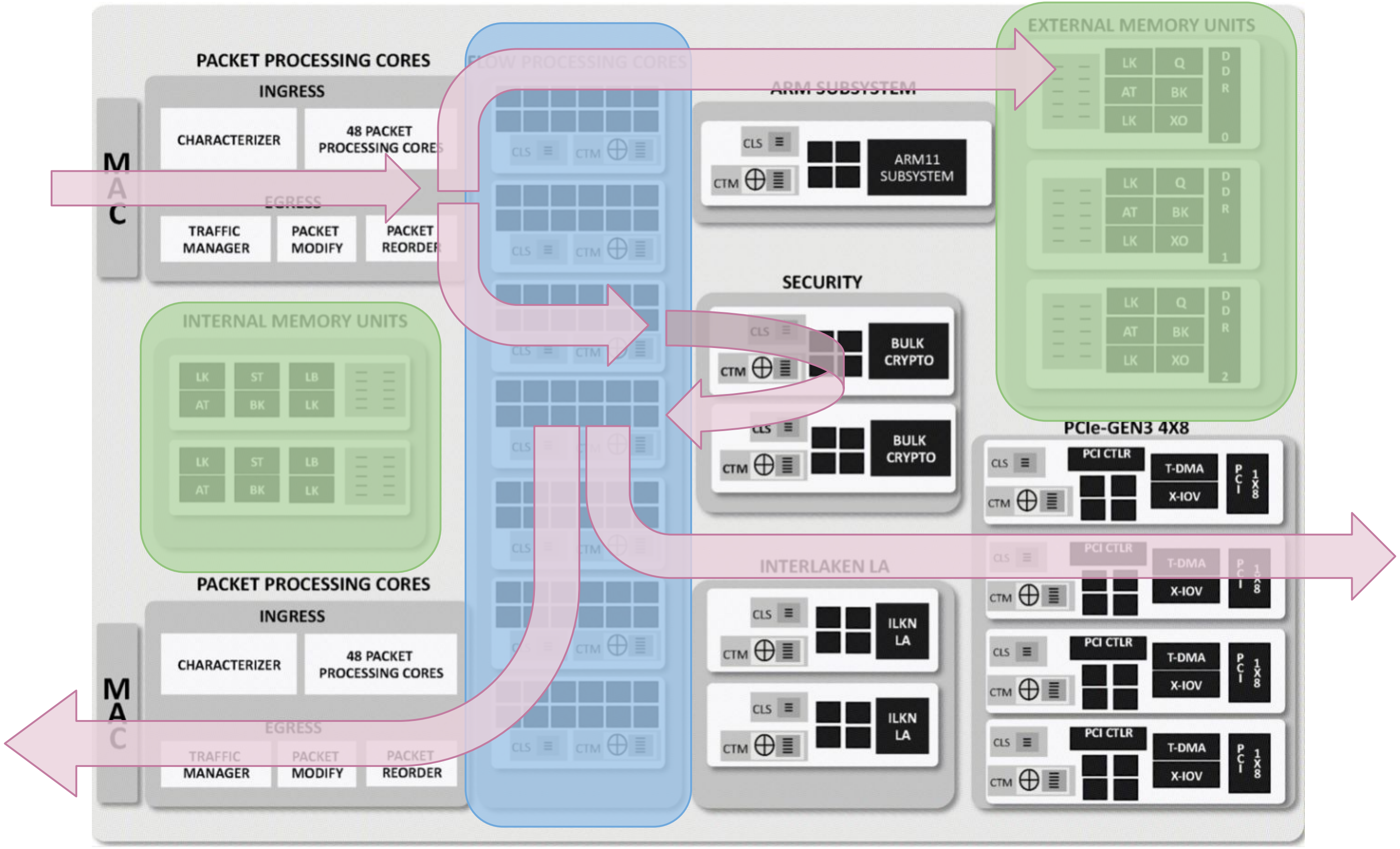


NFP SoC Packet Flow



NFP SoC Packet Flow



Memory Architecture - Latencies

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GPRS/xfer regs - 1 cycle

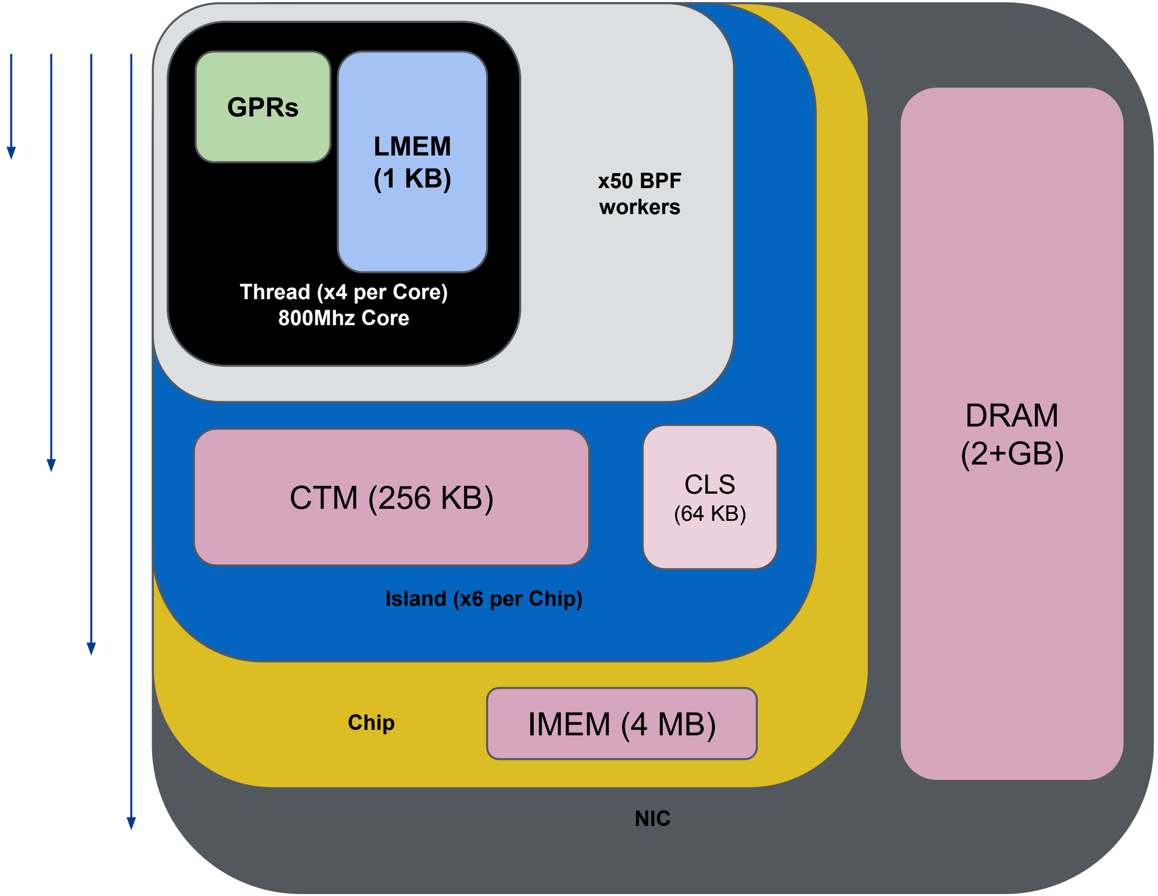
LMEM - 1-3 cycles

CLS - 20-50 cycles

CTM - 50-100 cycles

IMEM - 150-250 cycles

DRAM - 150-500 cycles



Memory Architecture

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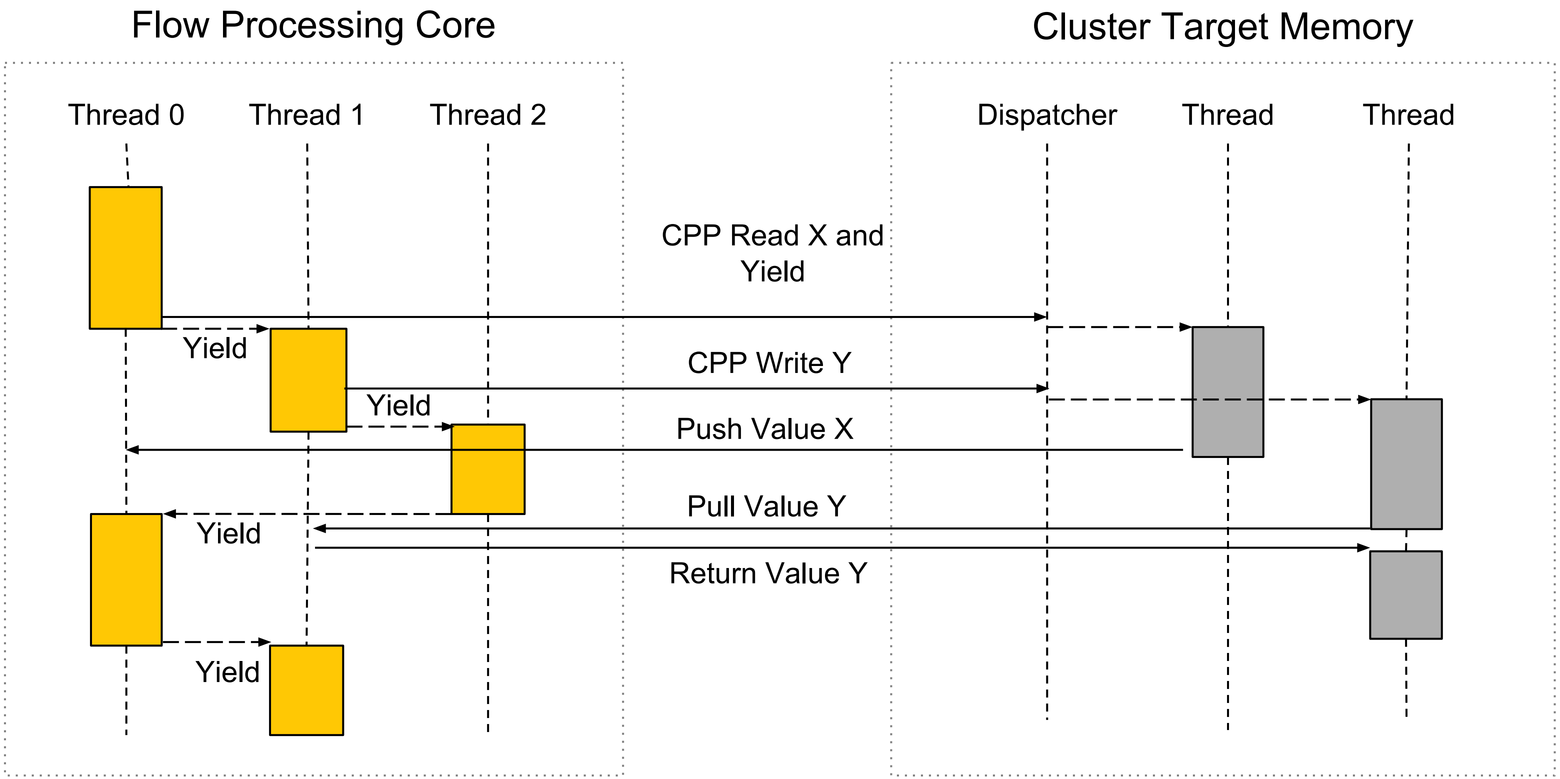
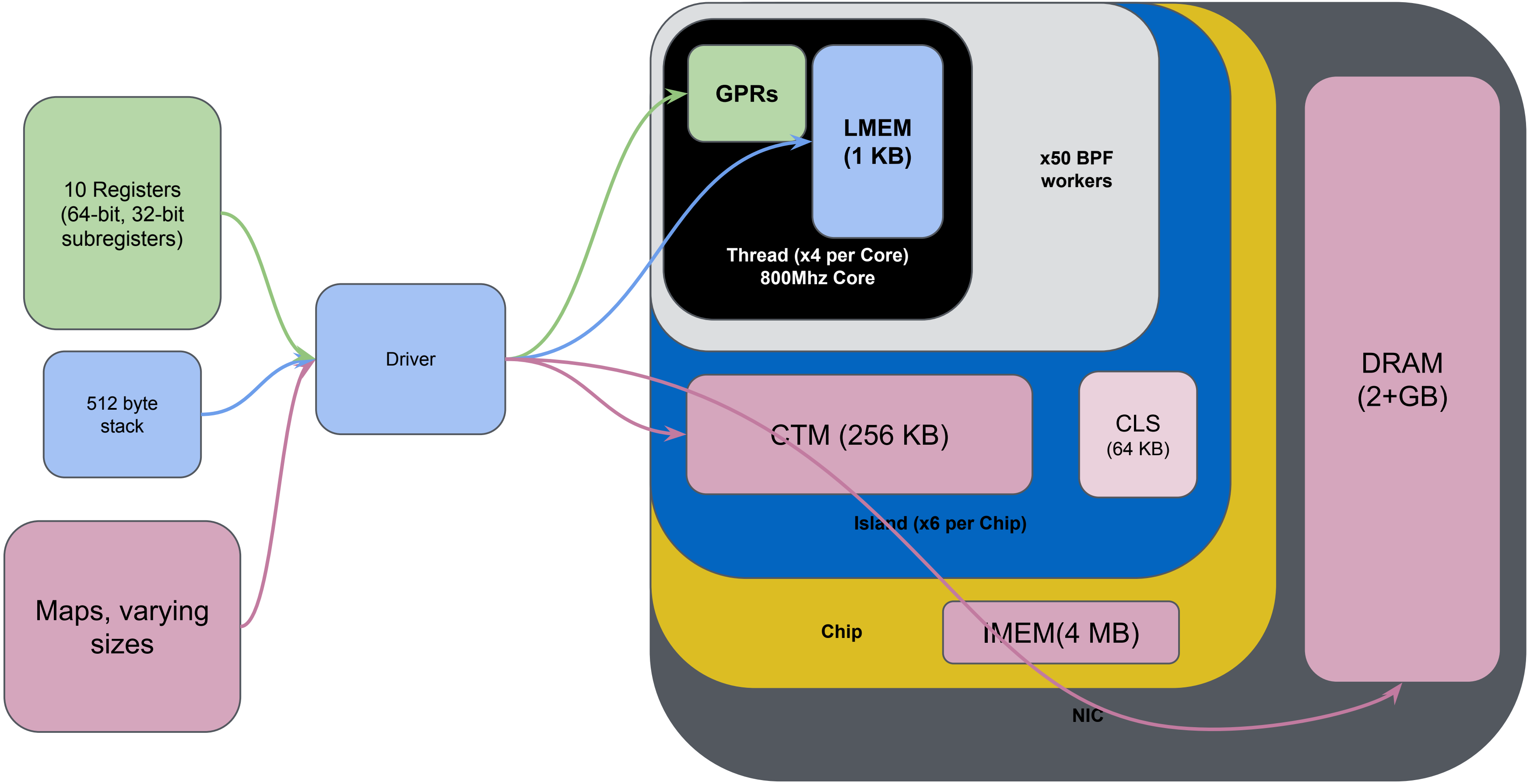


Multithreaded Transactional Memory Architecture Hides Latency

Kernel Offload - BPF Offload Memory Mapping



Programming Model

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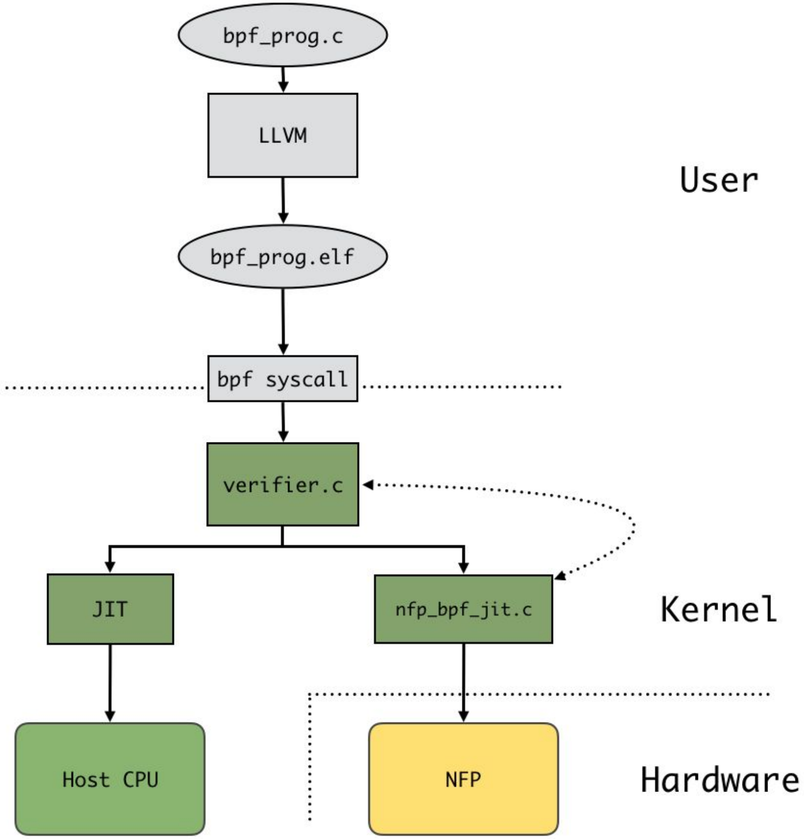
- Program is written in standard manner
- LLVM compiled as normal
- iproute/tc/libbpf loads the program requesting offload
- The nfp_bpf_jit.c converts the BPF bytecode to NFP machine code (and we mean the actual machine code :))
- Translation reuses a significant amount of verifier infrastructure



BPF Object Creation (maps)

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1. Get map file descriptors:
   a. For existing maps - get access to a file descriptor:
      i. from bpffs (pinned map) - open a pseudo file
      ii. by ID - use BPF_MAP_GET_FD_BY_ID bpf syscall command
   b. Create new maps - BPF_MAP_CREATE bpf syscall command:

```
union bpf_attr {
        struct { /* anonymous struct used by BPF_MAP_CREATE command */
                __u32  map_type;    /* one of enum bpf_map_type */
                __u32  key_size;    /* size of key in bytes */
                __u32  value_size;  /* size of value in bytes */
                __u32  max_entries; /* max number of entries in a map */
                __u32  map_flags;   /* BPF_MAP_CREATE related
                                     * flags defined above.
                                     */
                __u32  inner_map_fd;/* fd pointing to the inner map */
                __u32  numa_node;   /* numa node (effective only if
                                     * BPF_F_NUMA_NODE is set).
                                     */
                char   map_name[BPF_OBJ_NAME_LEN];
                __u32  map_ifindex; /* ifindex of netdev to create on */
                __u32  btf_fd;             /* fd pointing to a BTF type data */
                __u32  btf_key_type_id;    /* BTF type_id of the key */
                __u32  btf_value_type_id;  /* BTF type_id of the value */
        };
```

BPF object creation (programs)

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1. Get program instructions;
2. Perform relocations (replace map references with file descriptors IDs);
3. Use BPF_PROG_LOAD to load the program;

```
union bpf_attr {
      struct { /* anonymous struct used by BPF_PROG_LOAD command */
            __u32          prog_type;    /* one of enum bpf_prog_type */
            __u32          insn_cnt;
            __aligned_u64 insns;
            __aligned_u64 license;
            __u32          log_level;    /* verbosity level of verifier */
            __u32          log_size;     /* size of user buffer */
            __aligned_u64 log_buf;      /* user supplied buffer */
            __u32          kern_version; /* checked when prog_type=kprobe */
            __u32          prog_flags;
            char           prog_name[BPF_OBJ_NAME_LEN];
            __u32          prog_ifindex; /* ifindex of netdev to prep for */
            /* For some prog types expected attach type must be known at
             * load time to verify attach type specific parts of prog
             * (context accesses, allowed helpers, etc).
             */
            __u32          expected_attach_type;
      };
```

BPF Object Creation (`libbpf`)

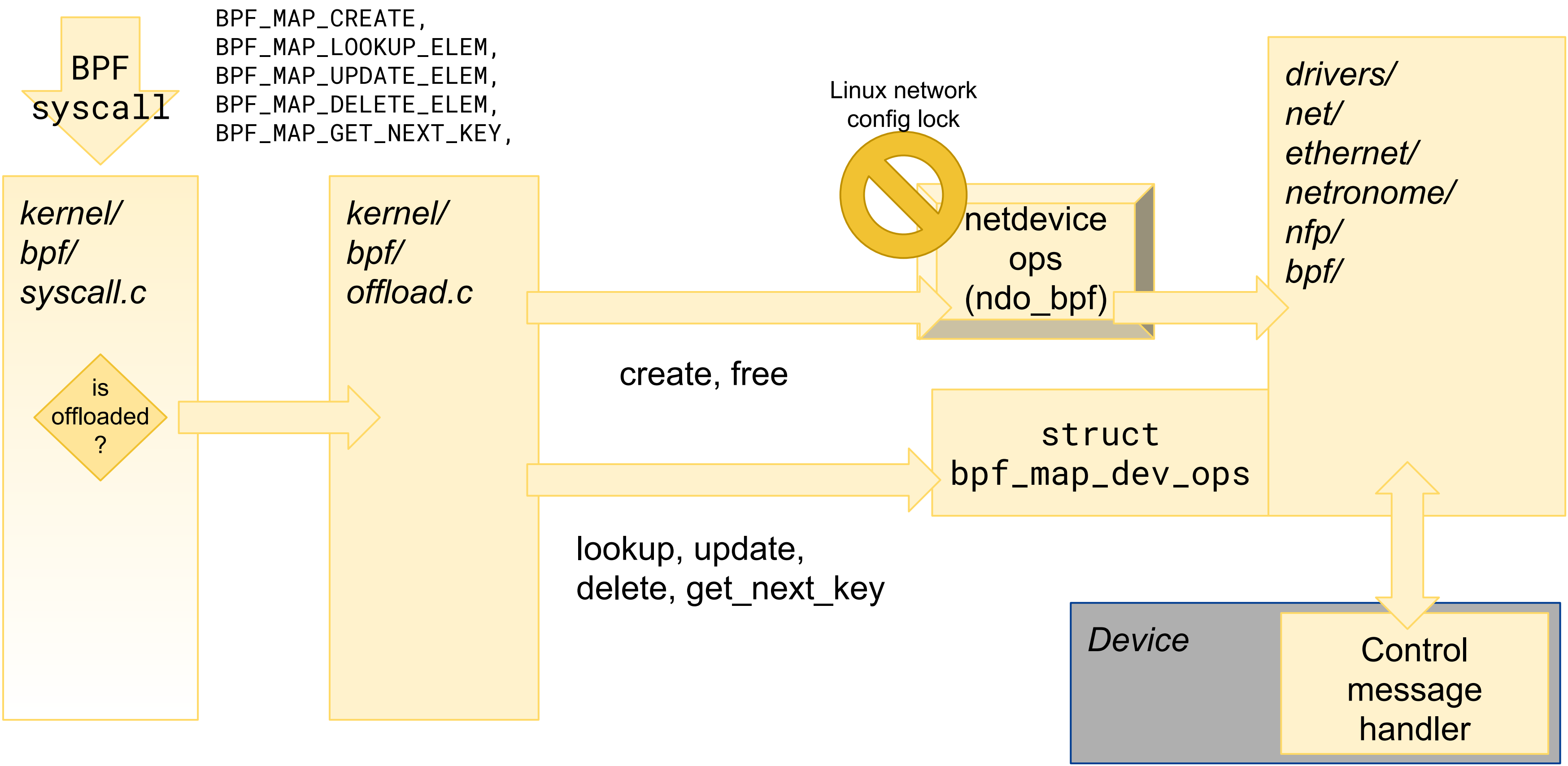
- With `libbpf` use the extended attributes to set the ifindex:

```
struct bpf_prog_load_attr {
        const char *file;
        enum bpf_prog_type prog_type;
        enum bpf_attach_type expected_attach_type;
        int ifindex;
};

int bpf_prog_load_xattr(const struct bpf_prog_load_attr *attr,
                        struct bpf_object **pobj, int *prog_fd);
```

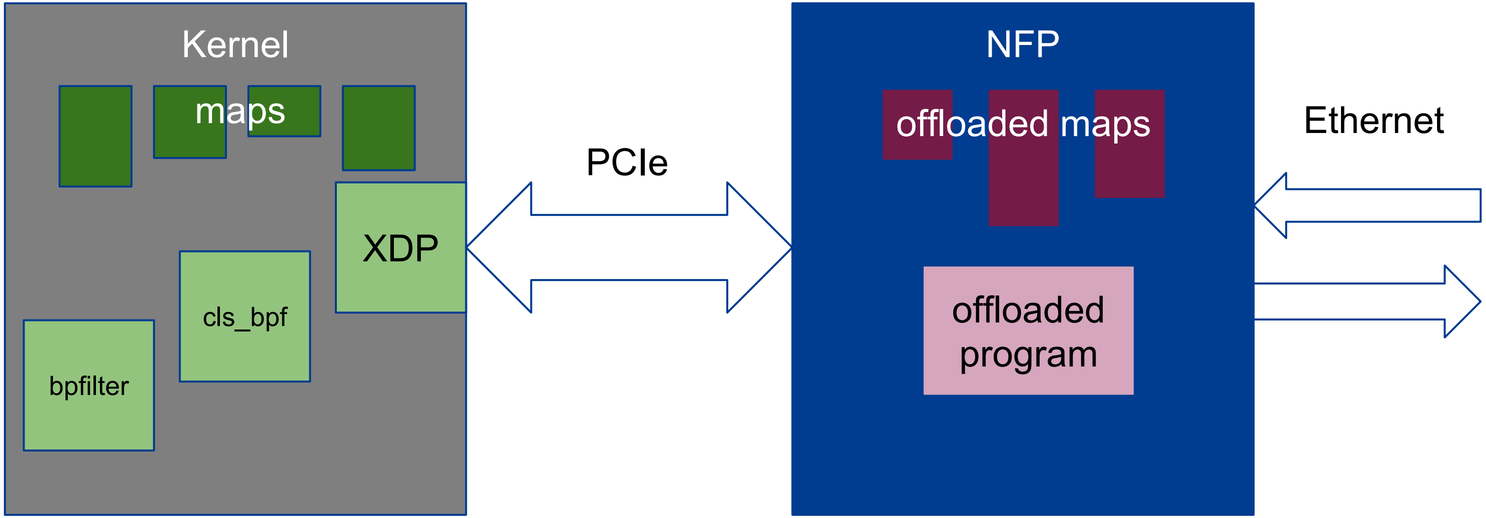
Normal kernel BPF ABIs are used, opt-in for offload by setting ifindex.

Map Offload


BPF syscall
BPF_MAP_CREATE,
BPF_MAP_LOOKUP_ELEM,
BPF_MAP_UPDATE_ELEM,
BPF_MAP_DELETE_ELEM,
BPF_MAP_GET_NEXT_KEY,
kernel/ bpf/ syscall.c
is offloaded ?
kernel/ bpf/ offload.c
Linux network config lock
netdevice ops (ndo_bpf)
create, free
struct bpf_map_dev_ops
lookup, update, delete, get_next_key
drivers/ net/ ethernet/ netronome/ nfp/ bpf/
Device
Control message handler

Map Offload

- Maps reside entirely in device memory
- Programs running on the host do not have access to offloaded maps and vice versa (because host cannot efficiently access device memory)
- User space API remains unchanged



Map Offload

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- Each map in the kernel has set of ops associated:

```
/* map is generic key/value storage optionally accessible by eBPF programs */
struct bpf_map_ops {
	/* funcs callable from userspace (via syscall) */
	int (*map_alloc_check)(union bpf_attr *attr);
	struct bpf_map *(*map_alloc)(union bpf_attr *attr);
	void (*map_release)(struct bpf_map *map, struct file *map_file);
	void (*map_free)(struct bpf_map *map);
	int (*map_get_next_key)(struct bpf_map *map, void *key, void *next_key);

	/* funcs callable from userspace and from eBPF programs */
	void *(*map_lookup_elem)(struct bpf_map *map, void *key);
	int (*map_update_elem)(struct bpf_map *map, void *key, void *value, u64 flags);
	int (*map_delete_elem)(struct bpf_map *map, void *key);
};
```

- Each map type (array, hash, LRU, LPM, etc.) has its own set of ops which implement the map specific logic
- If `map_ifindex` is set the ops are pointed to an empty set of “offload ops” regardless of the type (`bpf_offload_prog_ops`)
- Only calls from user space will now be allowed

Program Offload

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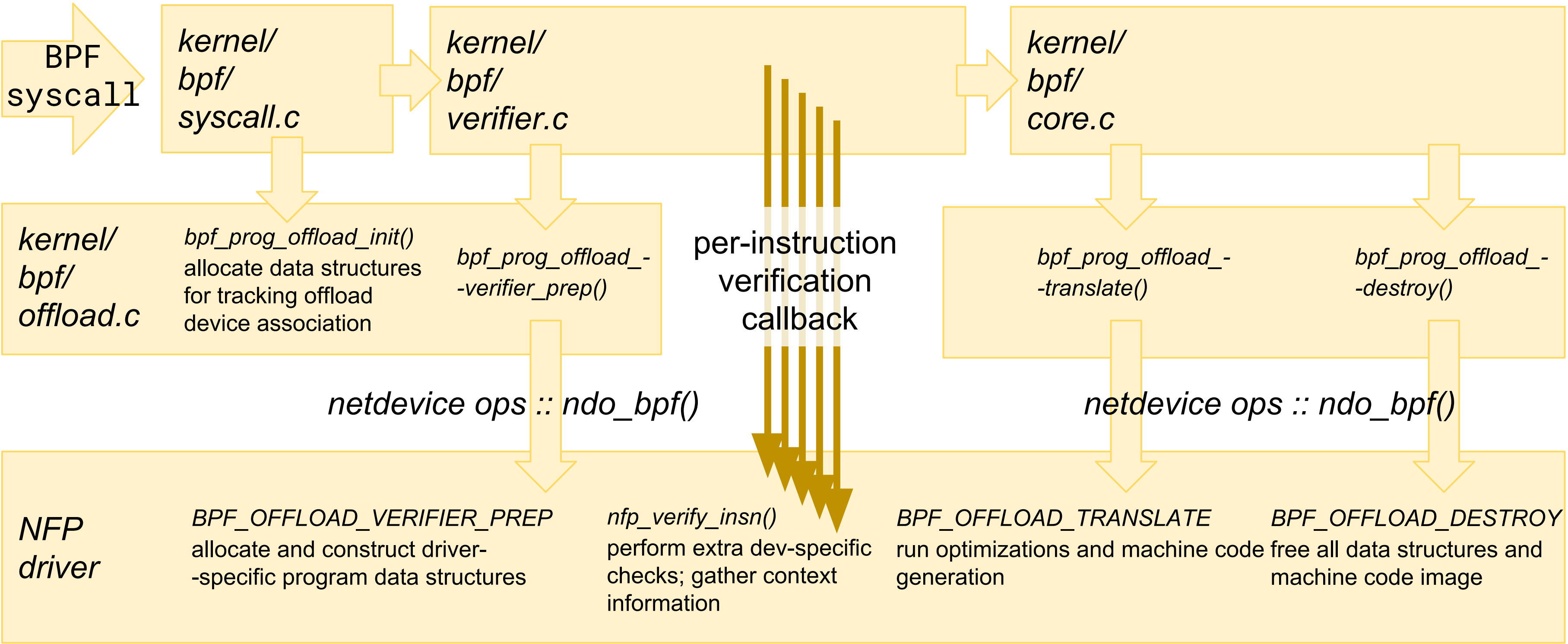
- Kernel verifier performs verification and some of common JIT steps for the host architectures
- For offload these steps cause loss of context information and are incompatible with the target
- Allow device translator to access the loaded program as-is:
  - IDs/offsets not translated:
    - structure field offsets
    - functions
    - map IDs
  - No prolog/epilogue injected
  - No optimizations made

For offloaded devices the verifier skips the extra host-centric rewrites.

Program Offload Lifecycle



Program Offload

- After program has been loaded into the kernel the subsystem specific handling remains unchanged
- For network programs offloaded program can be attached to device ingress to XDP (`BPF_PROG_TYPE_XDP`) or `cls_bpf` (`BPF_PROG_TYPE_SCHED_CLS`)
- Program can be attached to any of the ports of device for which it was loaded
- Actually loading program to device memory only happens when it's being attached

BPF Offload - Summary

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- BPF VM/sandbox is well suited for a heterogeneous processing engine
- BPF offload allows loading a BPF program onto a device instead of host CPU
- All user space tooling and ABIs remain unchanged
- No vendor-specific APIs or SDKs
- BPF offload is part of the upstream Linux kernel (recent kernel required)
- BPF programs loaded onto device can take advantage of HW accelerators such as HW memory lookup engines
- Try it out today on standard NFP server cards! (academic pricing available on open-nfp.org 😊)
- Reach out with BPF-related questions:
  - https://help.netronome.com/a/forums/
  - https://groups.google.com/forum/#!forum/open-nfp
  - xdp-newbies@vger.kernel.org
- Register for the next webinar in this series!