Сетевой стек Solarflare OpenOnload. В чем и почему он обыгрывает ядро Linux

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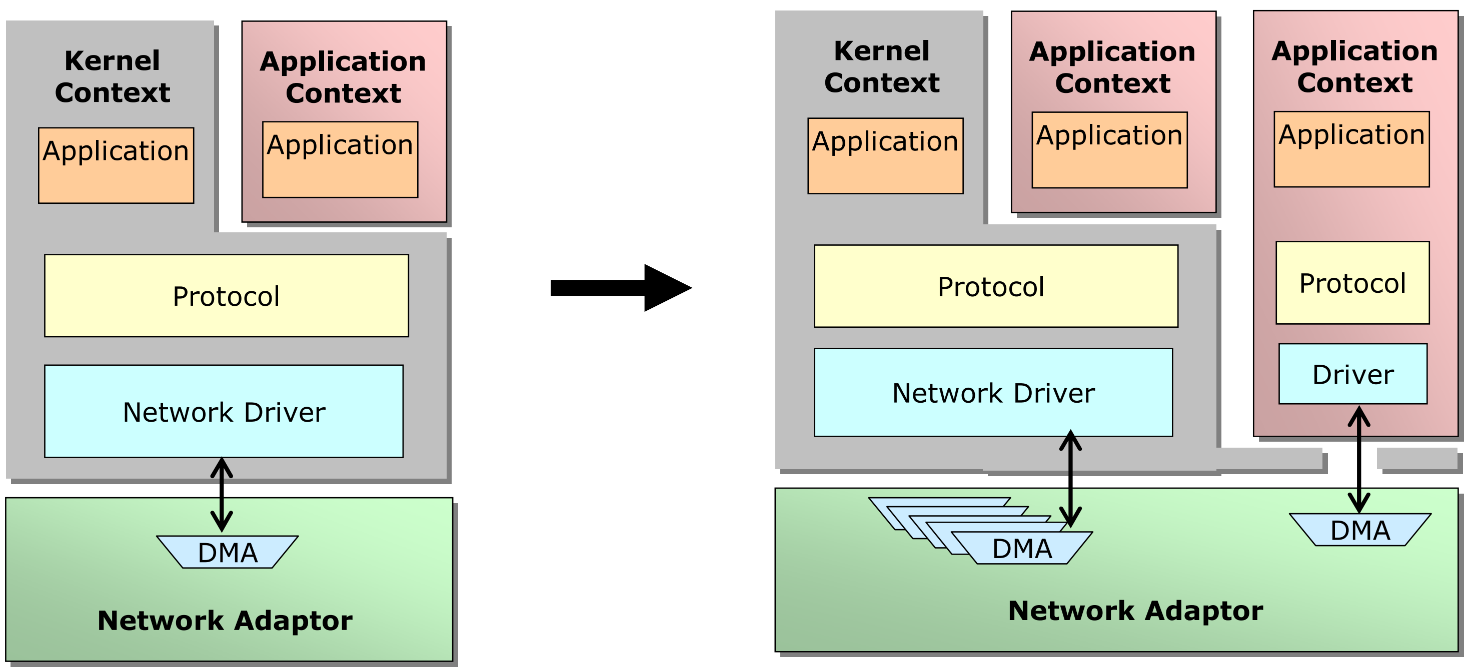
Content

- Kernel bypass networking
- Onload architecture and motivation behind it
- Safety and security
- Implementation challenges
- What's faster: examples

Kernel bypass networking

- Getting application closer to the network

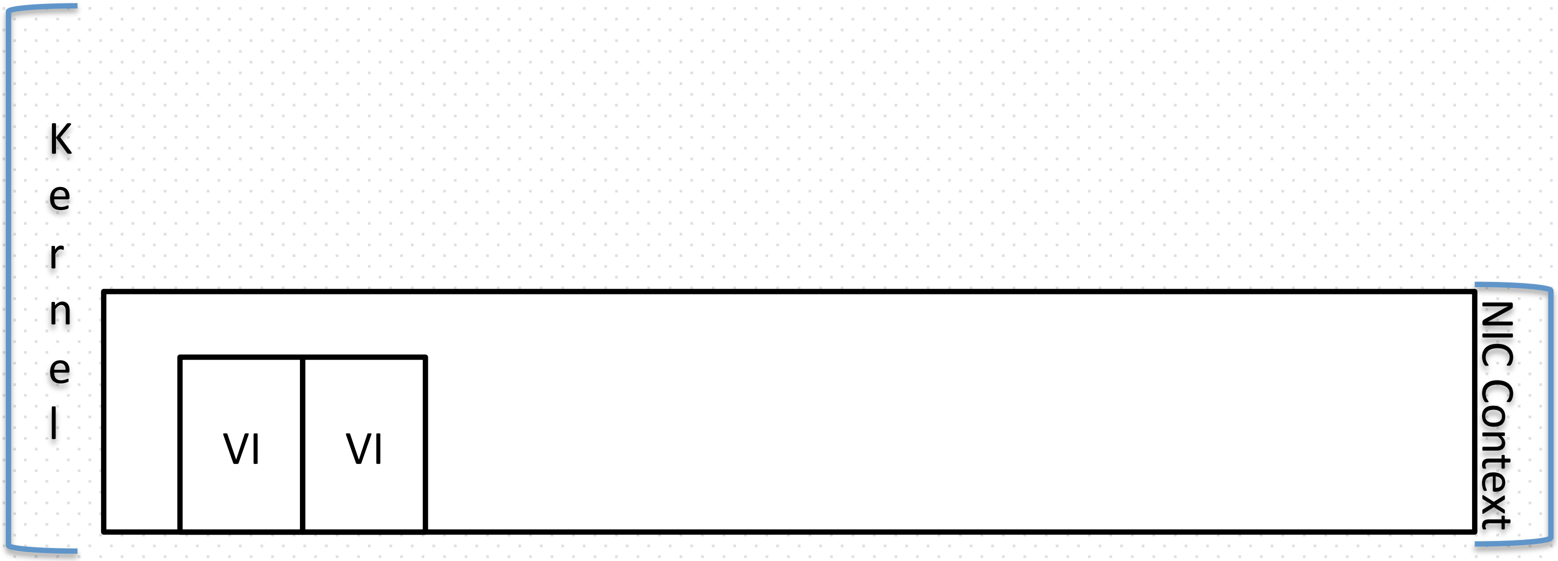


Approaches: APIs

- Socket API (socket(), send(), poll(), epoll_wait() etc.)
  - OpenOnload
- Special APIs
  - Solarflare EF_VI
  - DPDK
  - netmap
  - Infiniband verbs
  - etc.

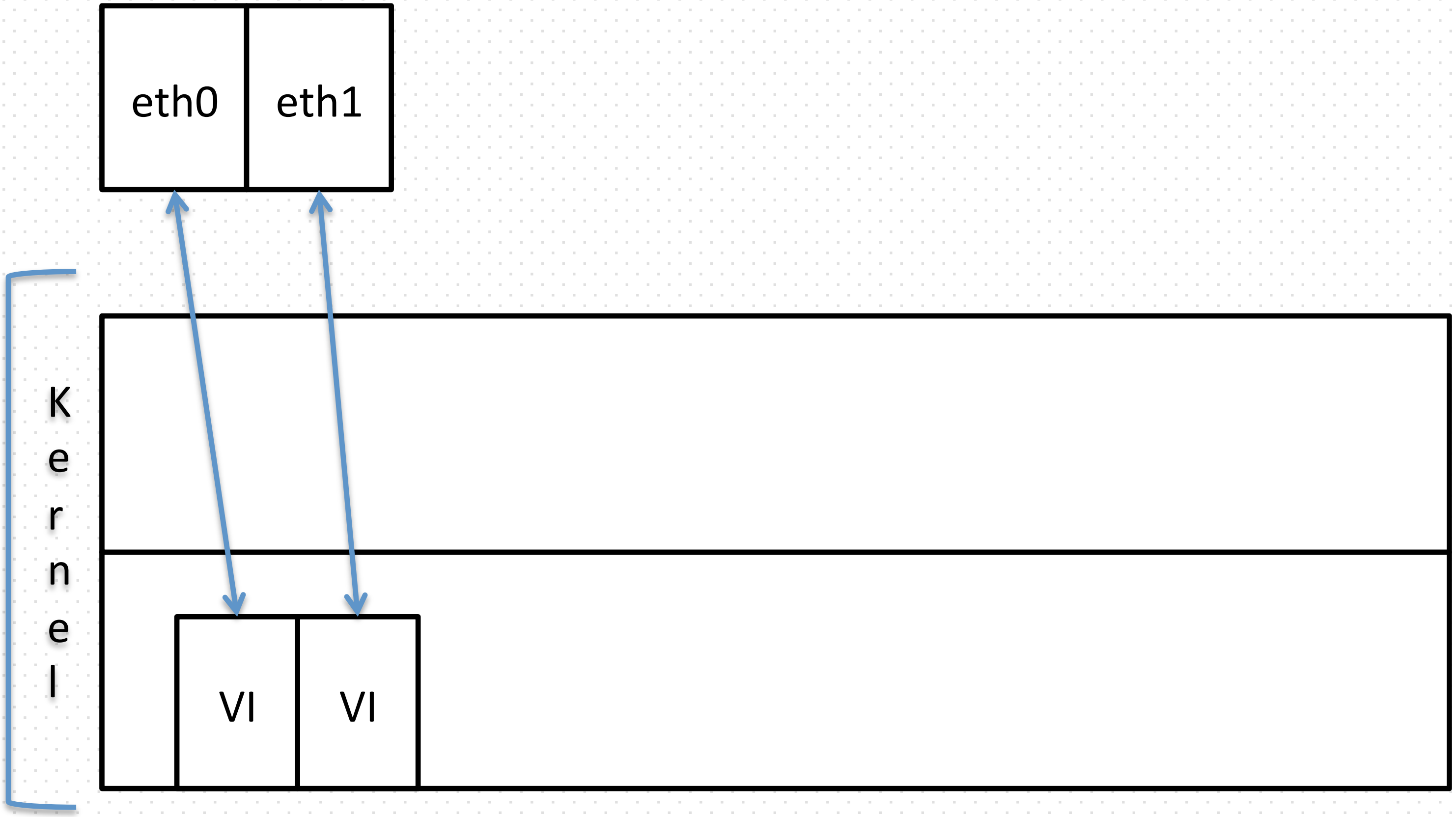
Architecture [1/5]

- VI (Virtual Interface ; v-nic): minimum set of resources required to send/receive traffic
  - TX
  - RX
  - notification queue (EVQ)
- Filtering

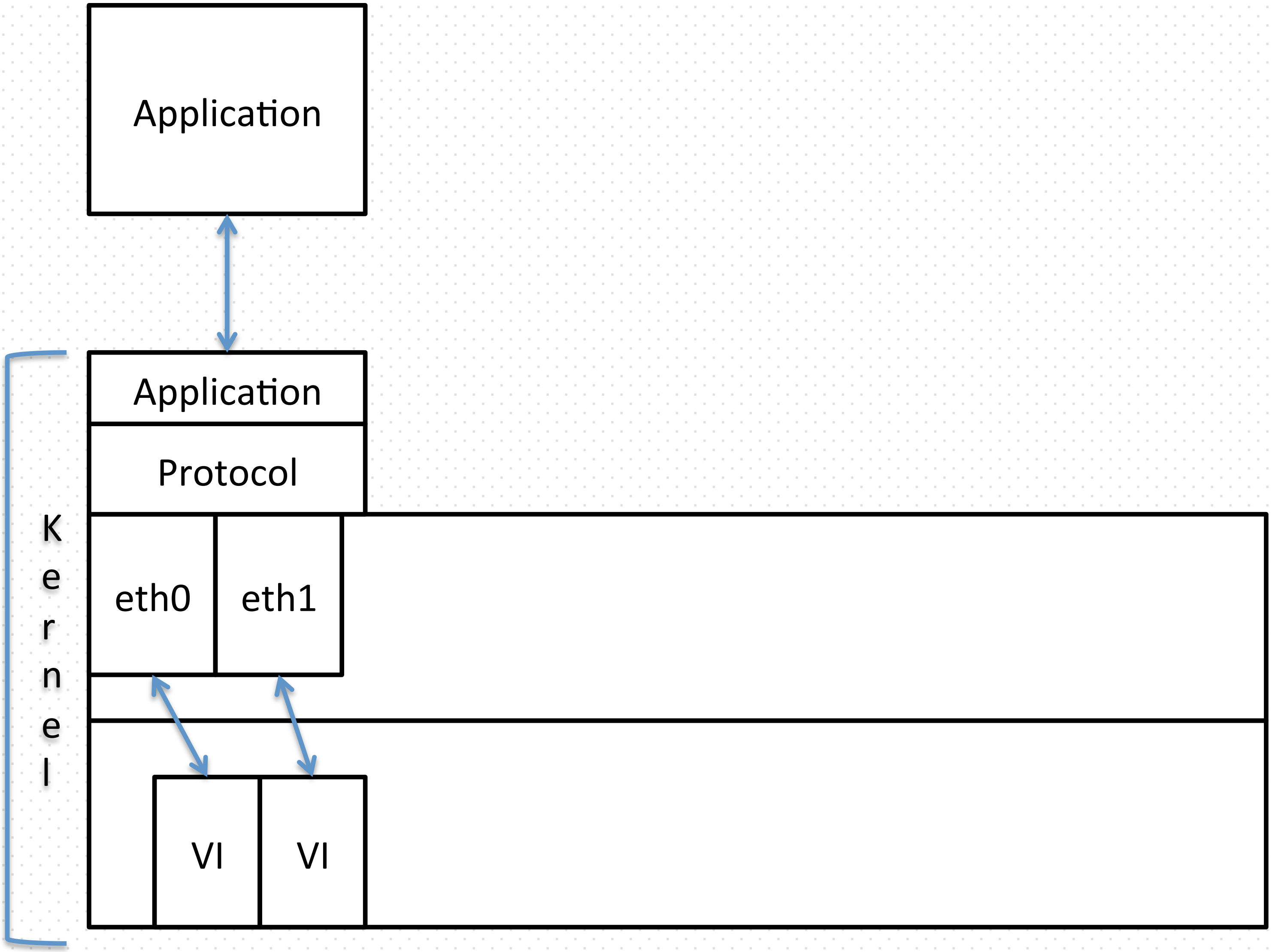


Architecture [2/5]

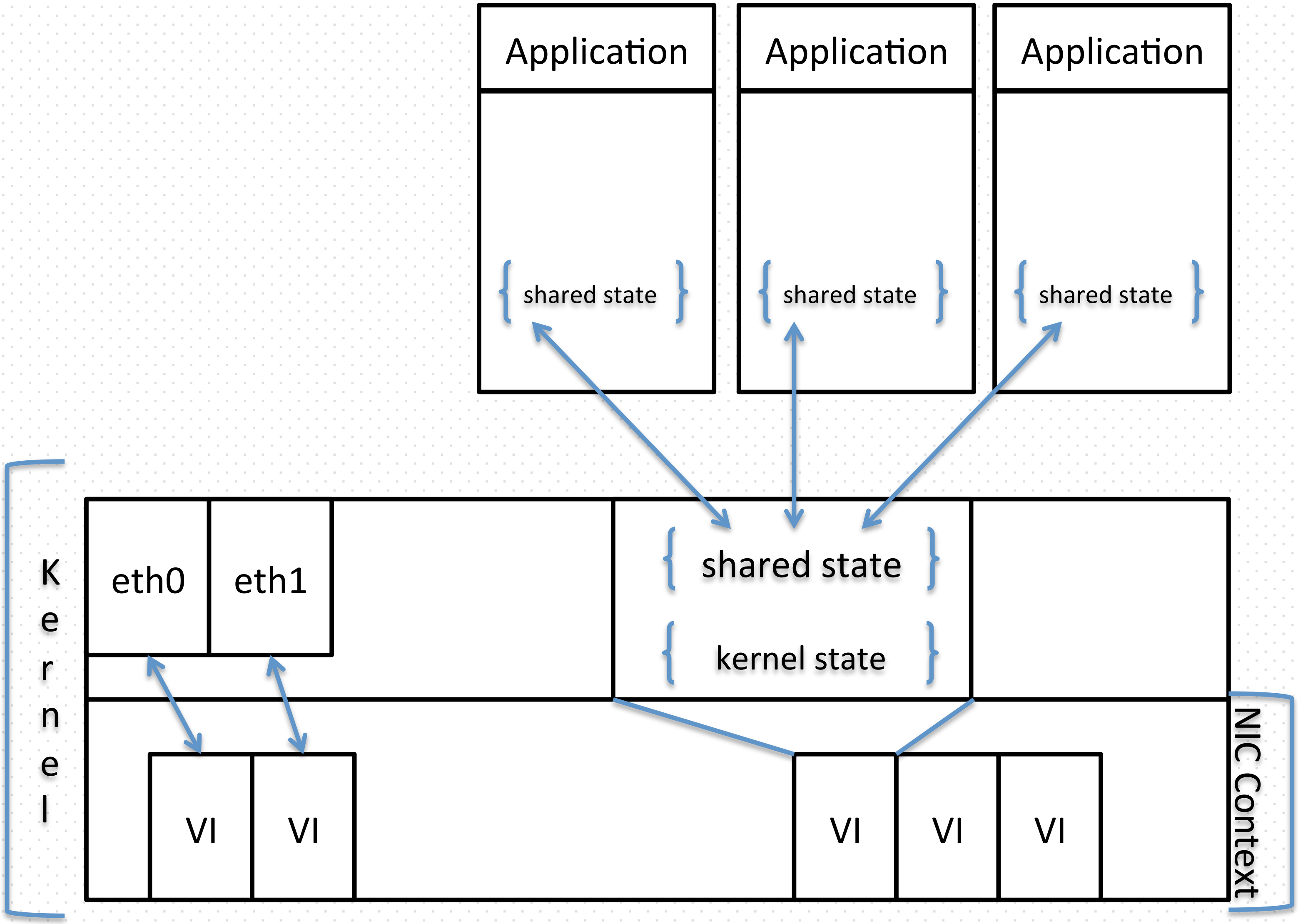
- Traditional interfaces



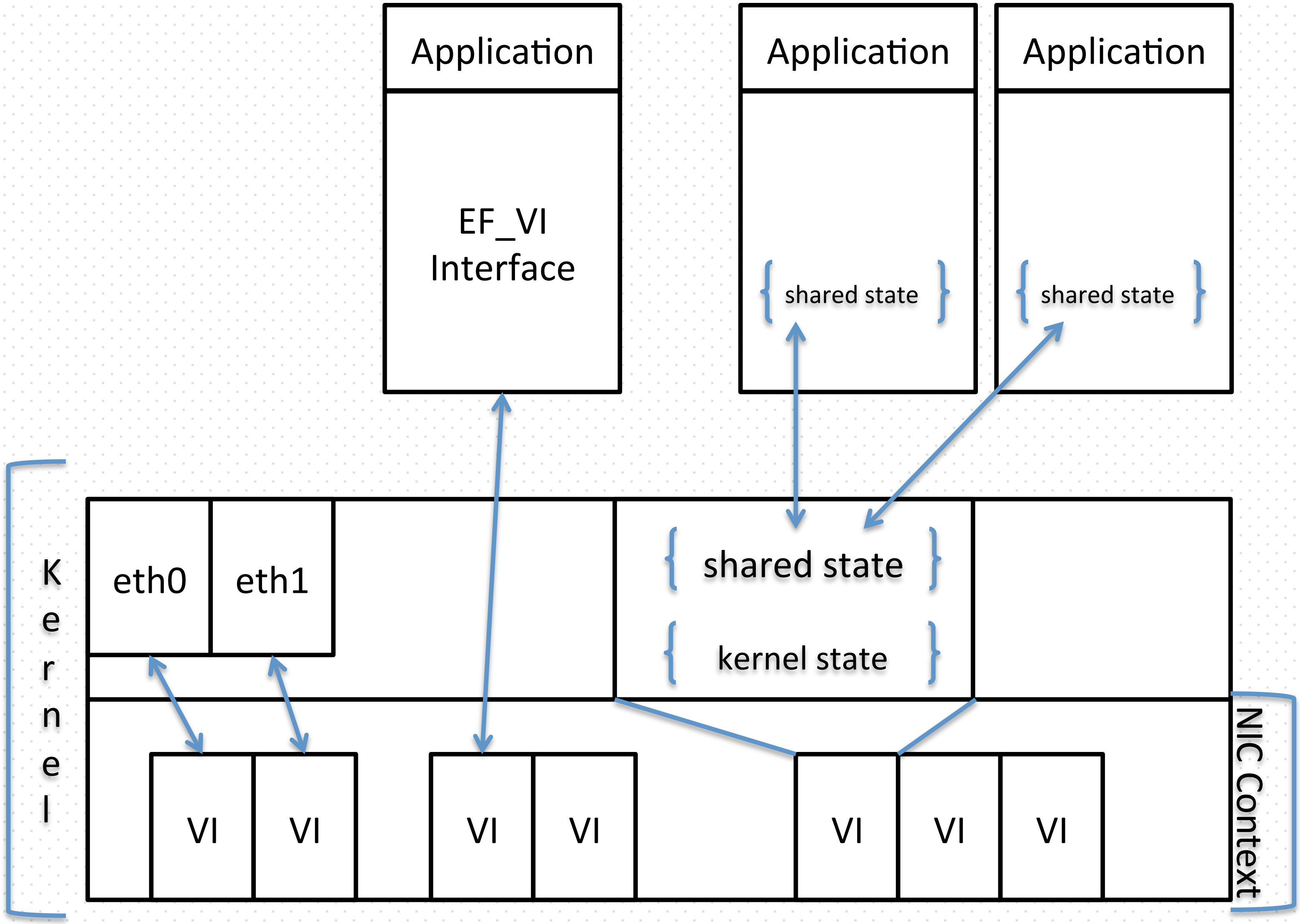
Architecture [2/5]



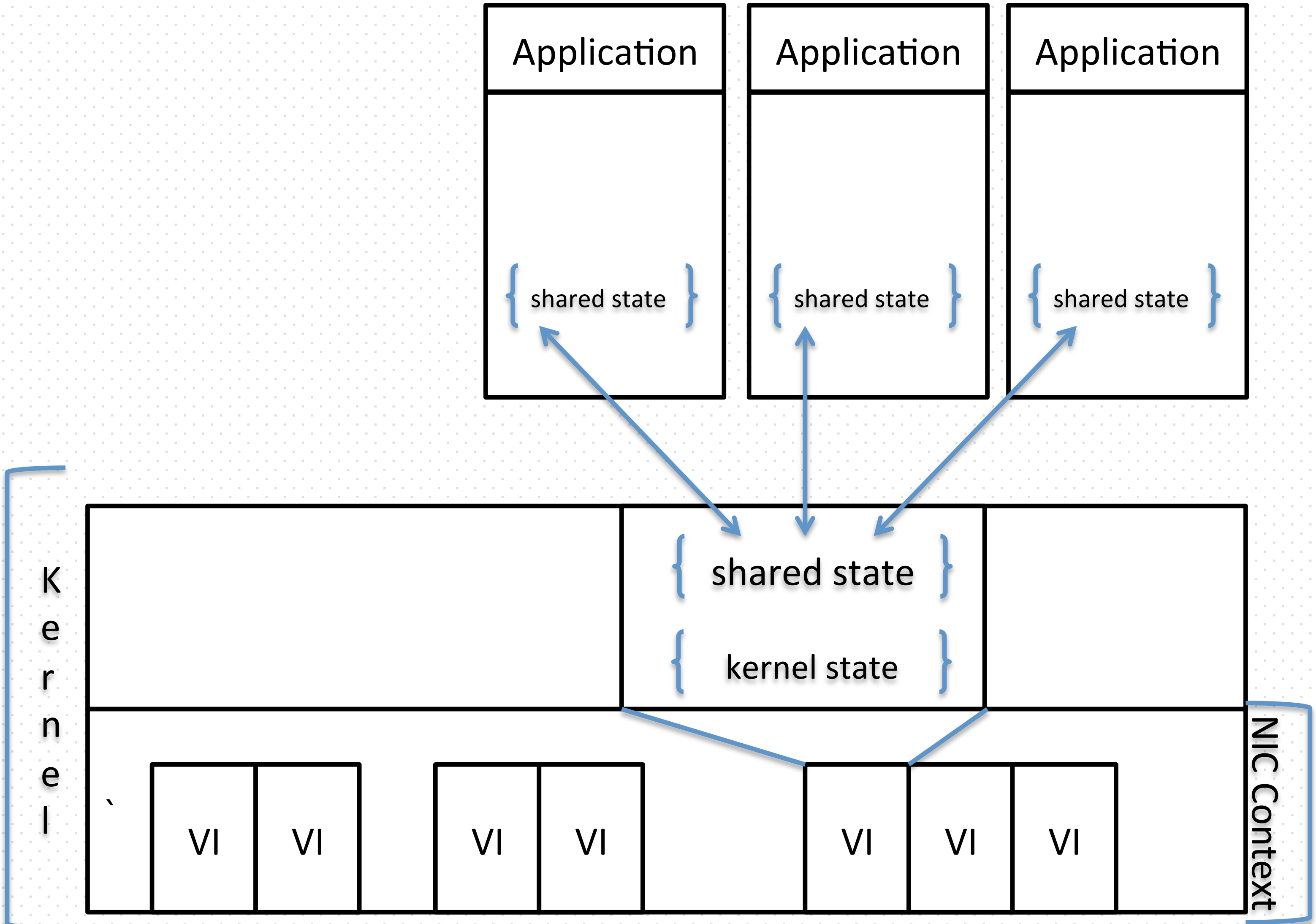
Architecture [3/5]



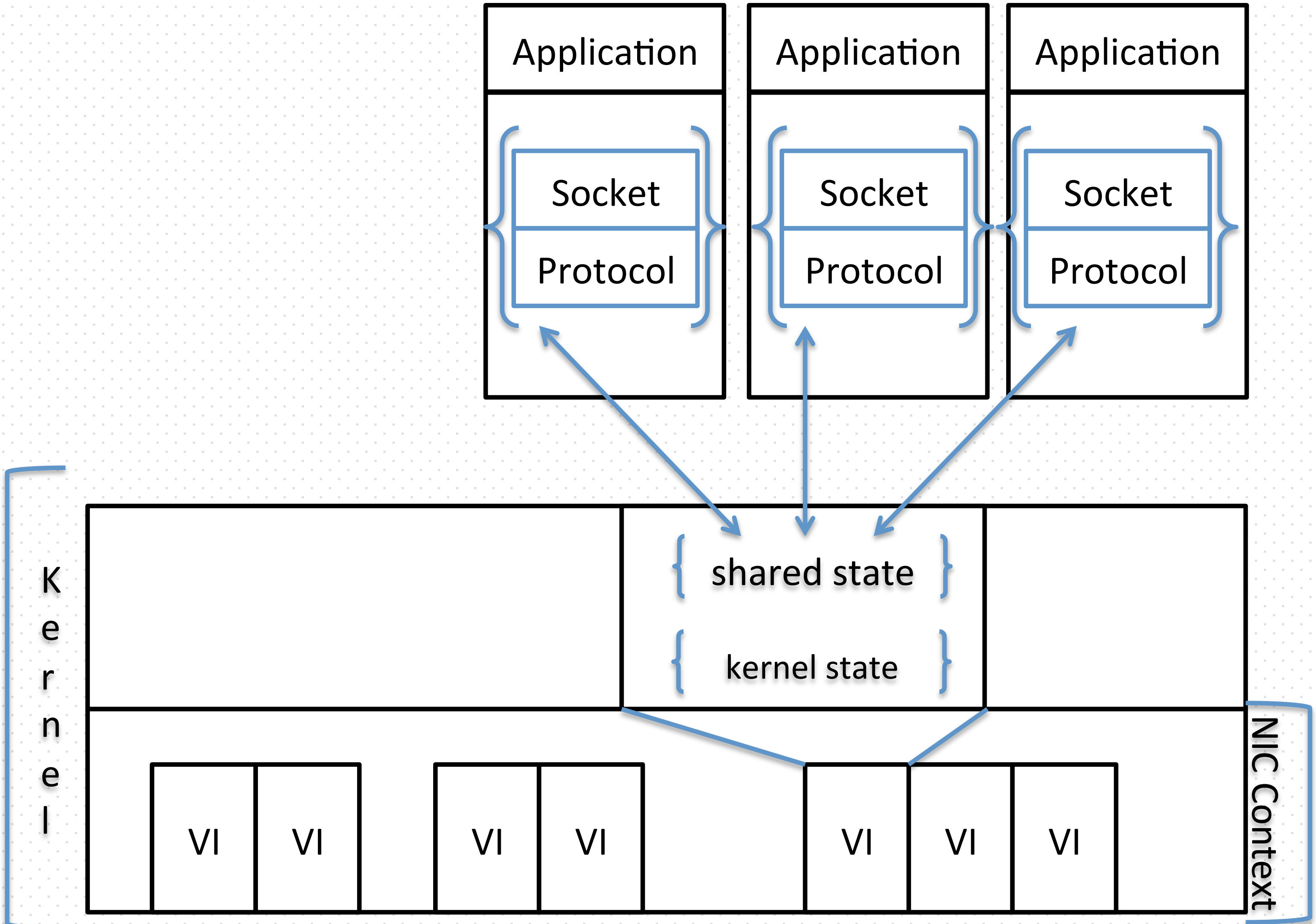
Architecture [4/5]



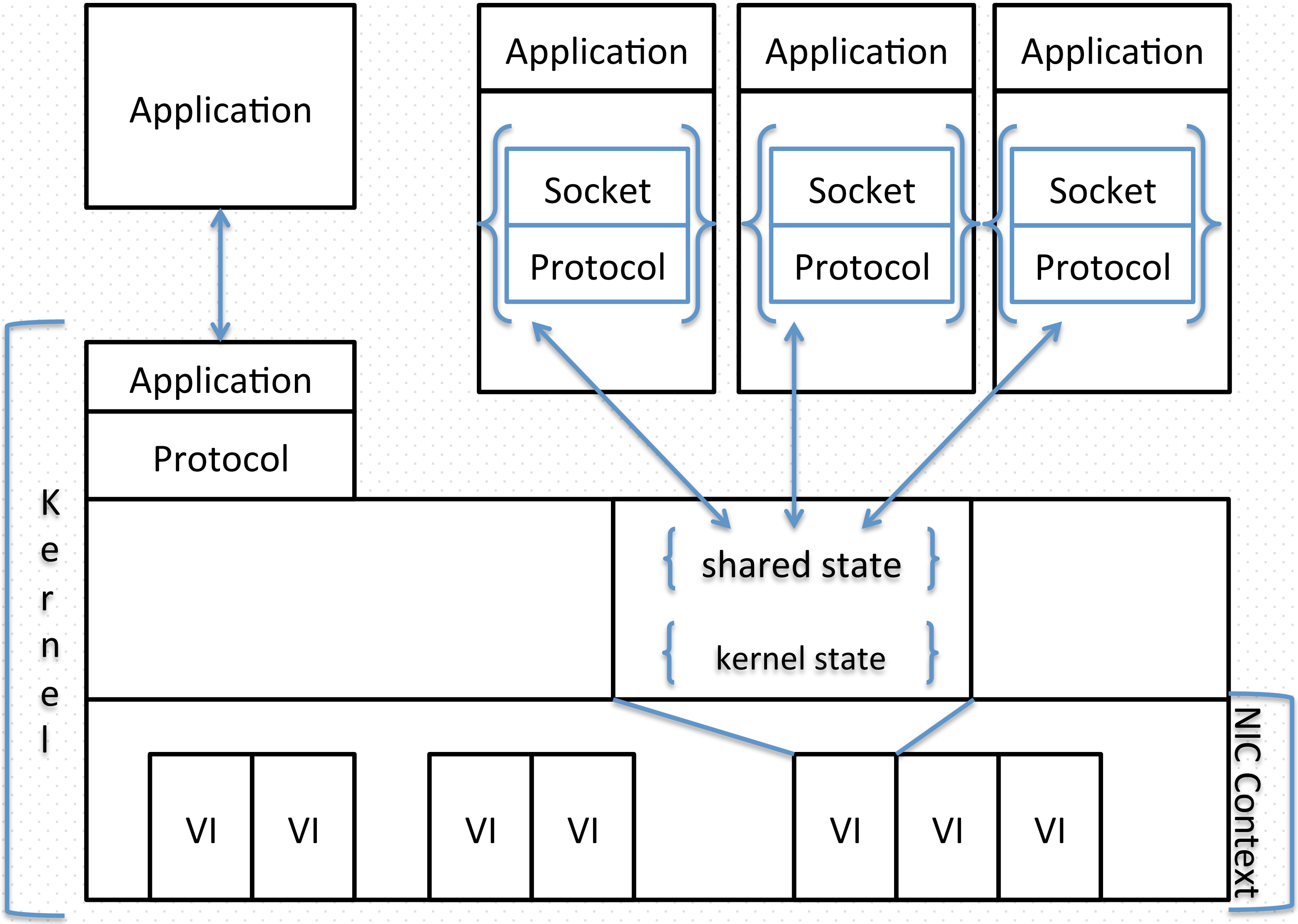
Architecture [5/5]



Architecture [5/5]



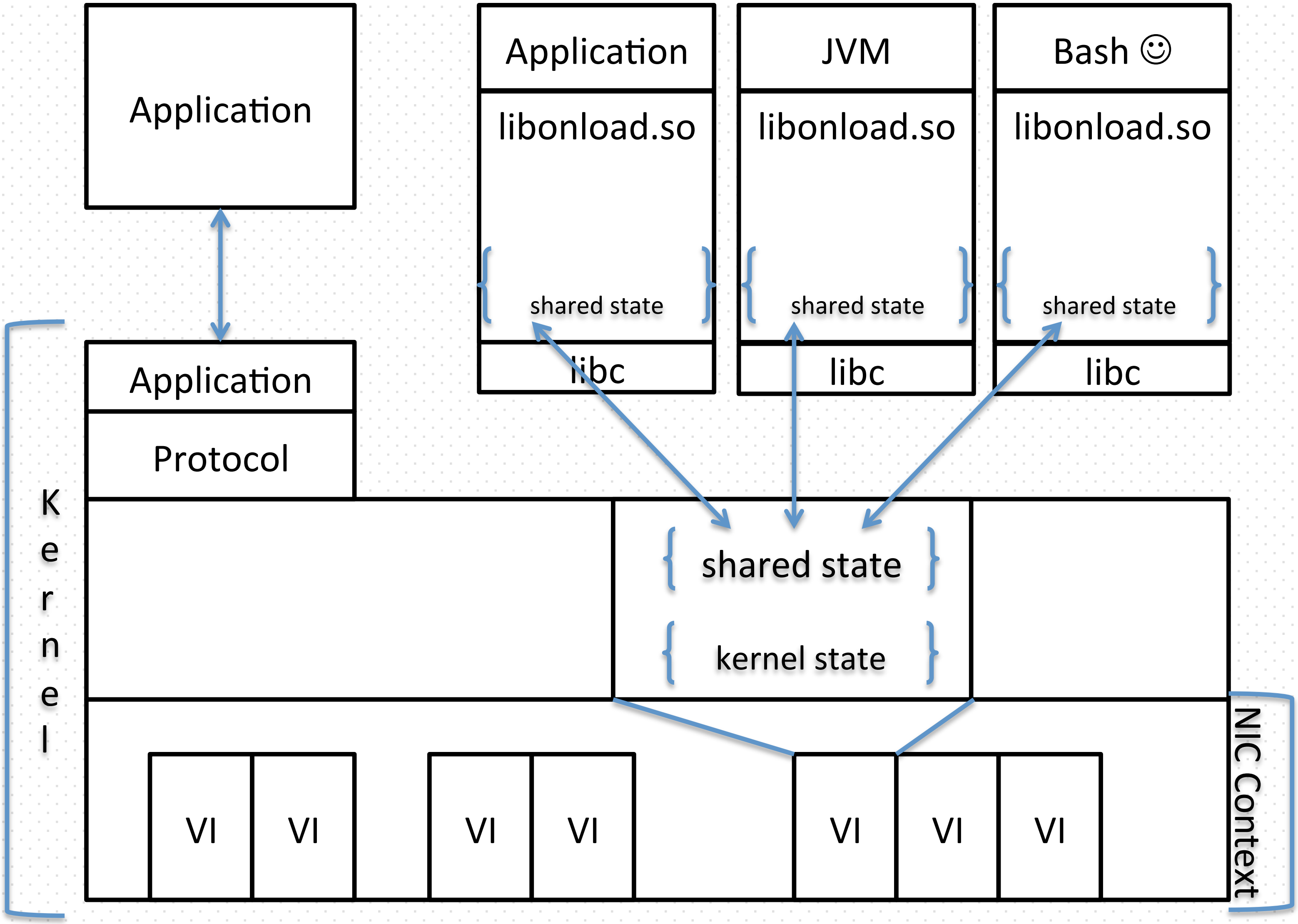
Architecture [5/5]



API

- socket(), listen(), connect(), accept(), recv(), send(), read(), write(), select(), poll(), epoll_wait(), fcntl(), dup(), accept4(), ioctl(), setsockopt() etc. – full Socket API
  - you don't know how many functions people use and in which ways…
- Access point of the API is **socket file descriptor**
- **LD_PRELOAD** loads the library (libonload.so)
- libonload.so provides Linux compatible Socket API

API: LD_PRELOAD



API: recv()/poll()

1) if receive queue not empty -> return data;
2) if notification queue not empty -> handle the event -> return data;
3) <here we have neither data nor event>
4) spin?
   - spin (for some time) in userland waiting for an event
5) go to the kernel ← slow
6) wait for interrupt and “wake up the socket”
7) wake up in userland -> return data

→: copy to user buffer; Zero Copy API get rids of it

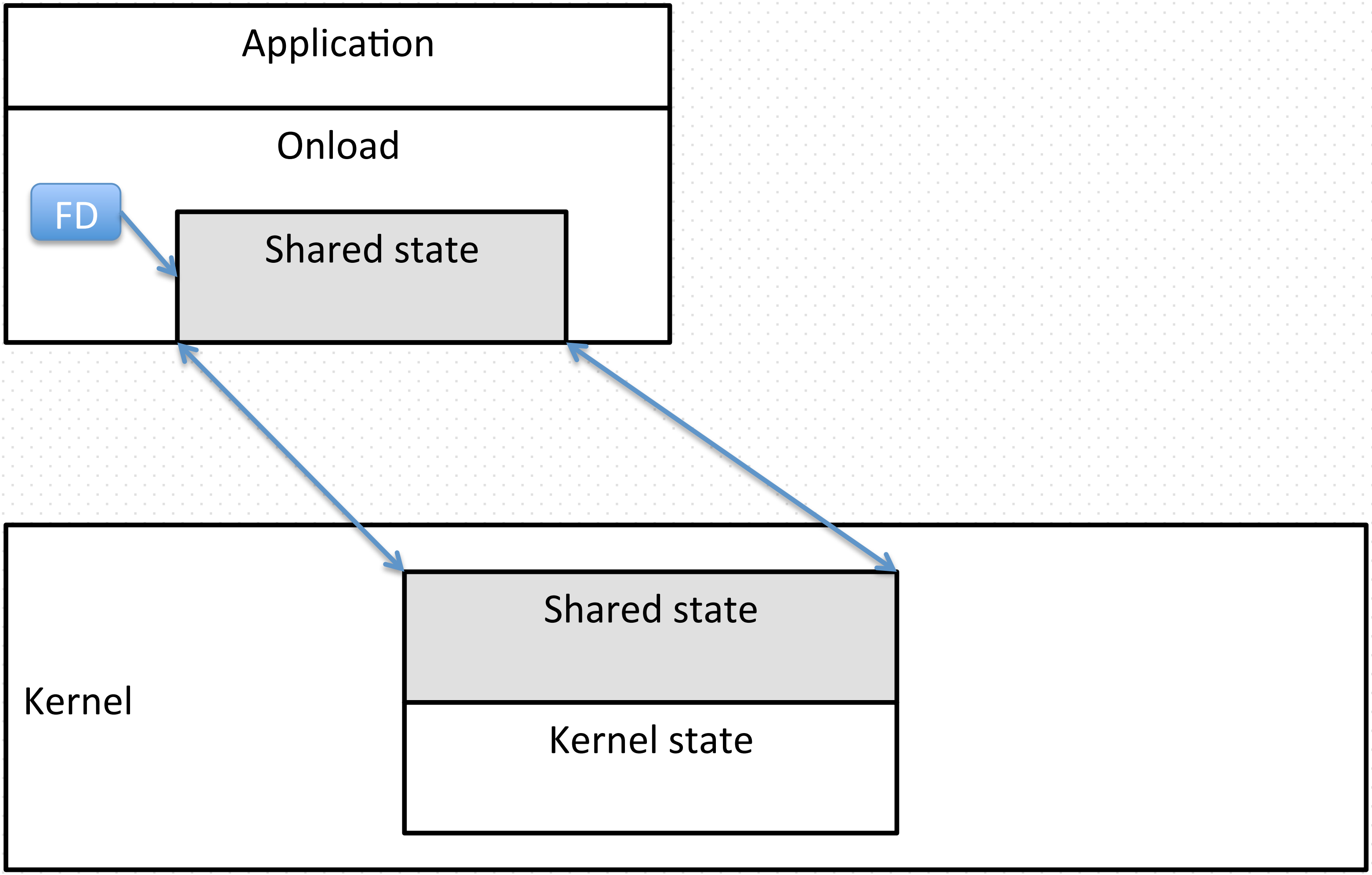
API: TCP send()

- copy user data -> packet buffer
- packet buffer is added into socket sendq
  - sendq is in shared state
- send window & congestion window OK
  - can send => send into the VI (NIC)
- otherwise send provoked by event handler (in userland OR kernel)

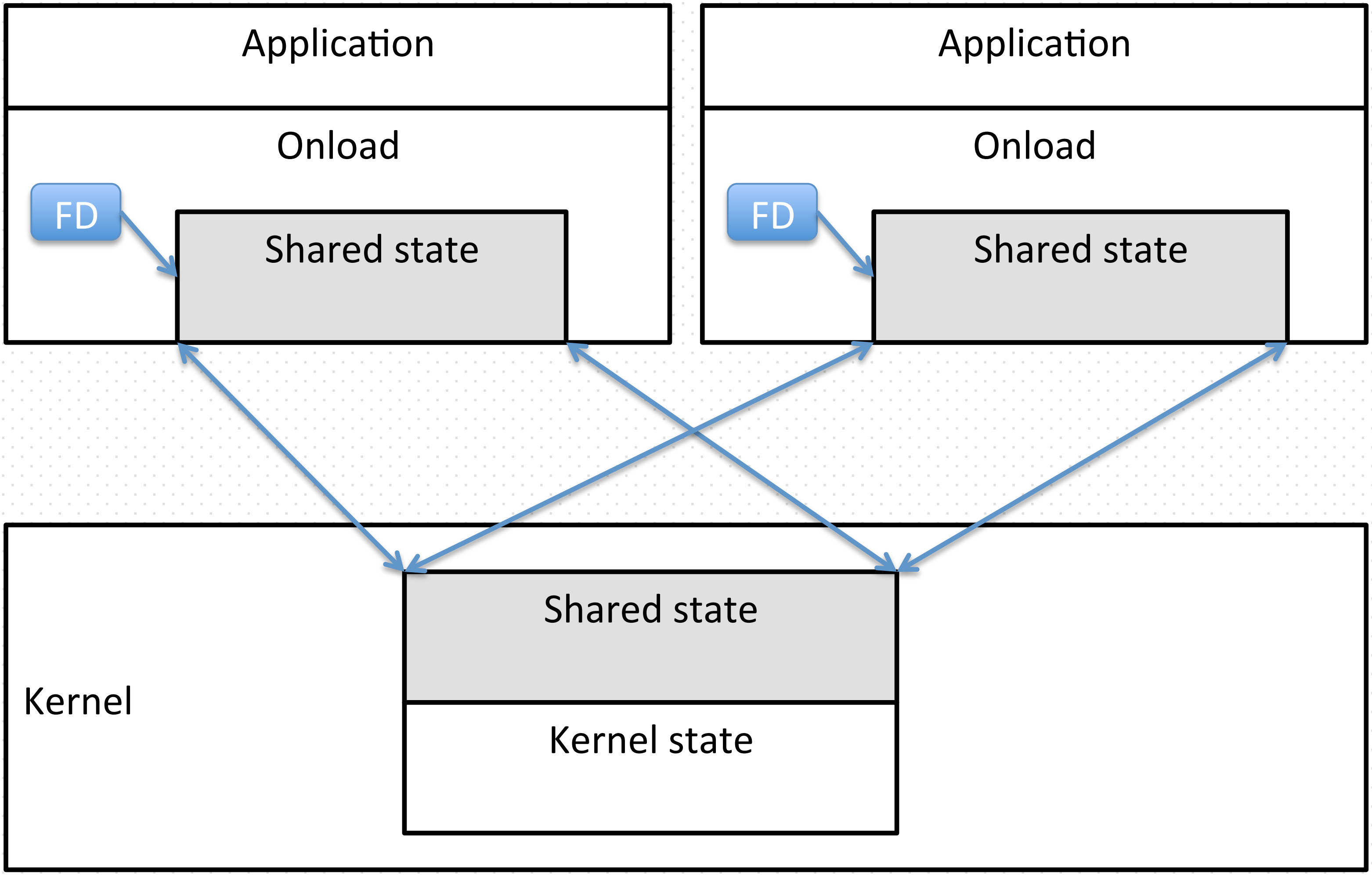
Why do we need Shared State

- fork() : duplicates everything, need to be in sync
- exec() : just wipes everything out
- Process can send fd/socket via UNIX domain socket
- Process exits (perhaps in fire): data should be delivered + socket should be shut down

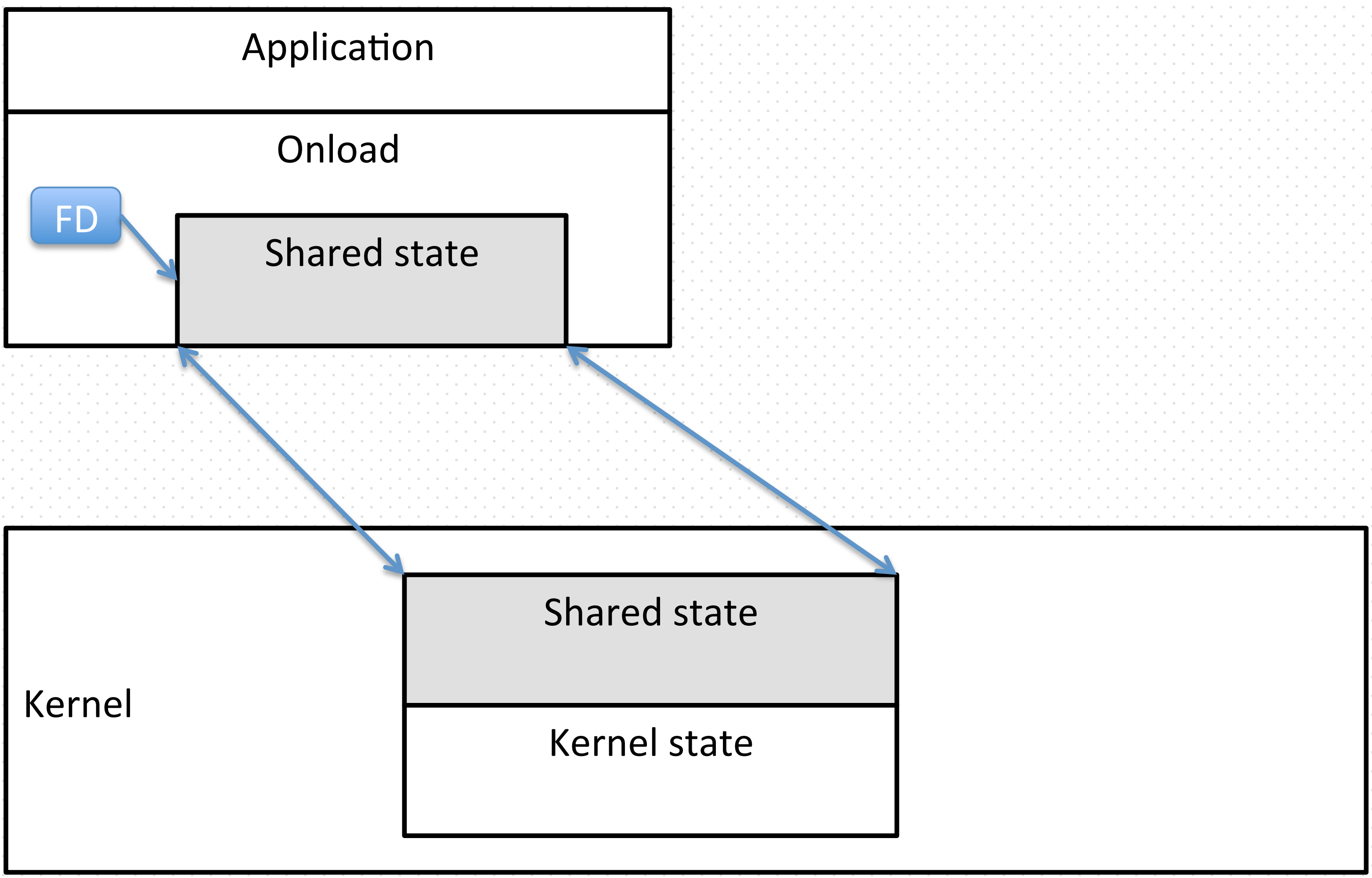
Shared state: fork()



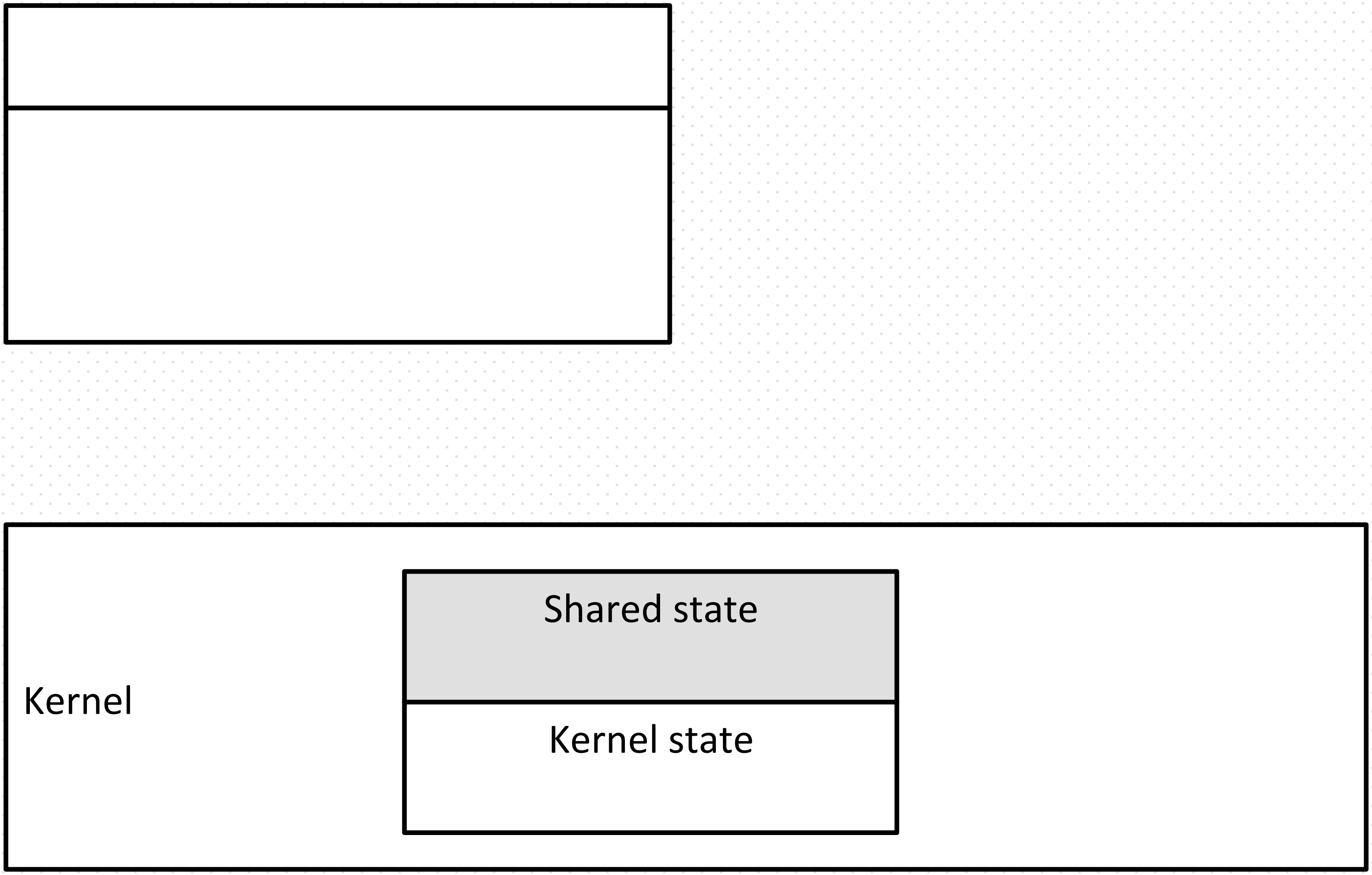
Shared state: fork()



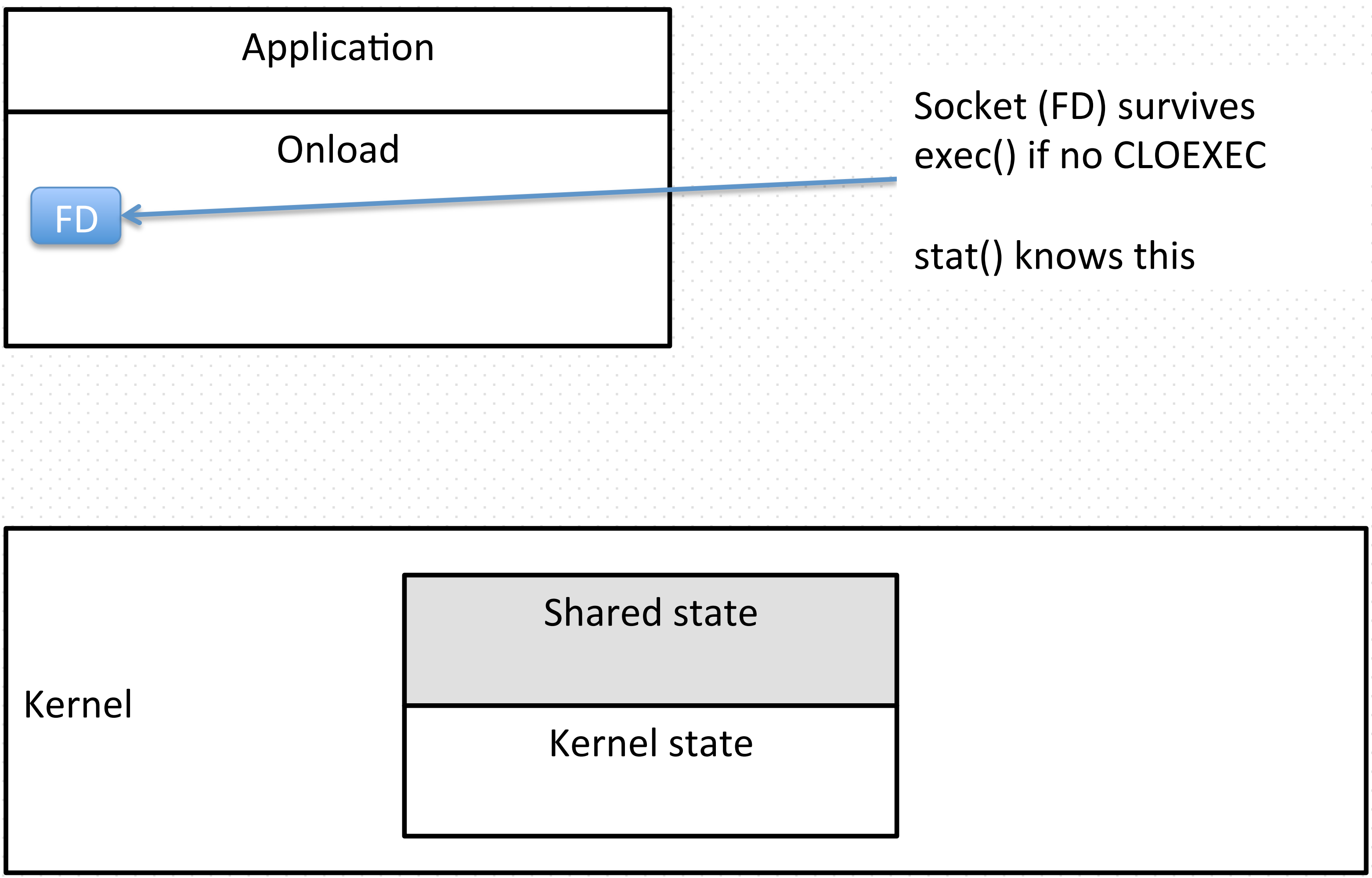
Shared state: exec()



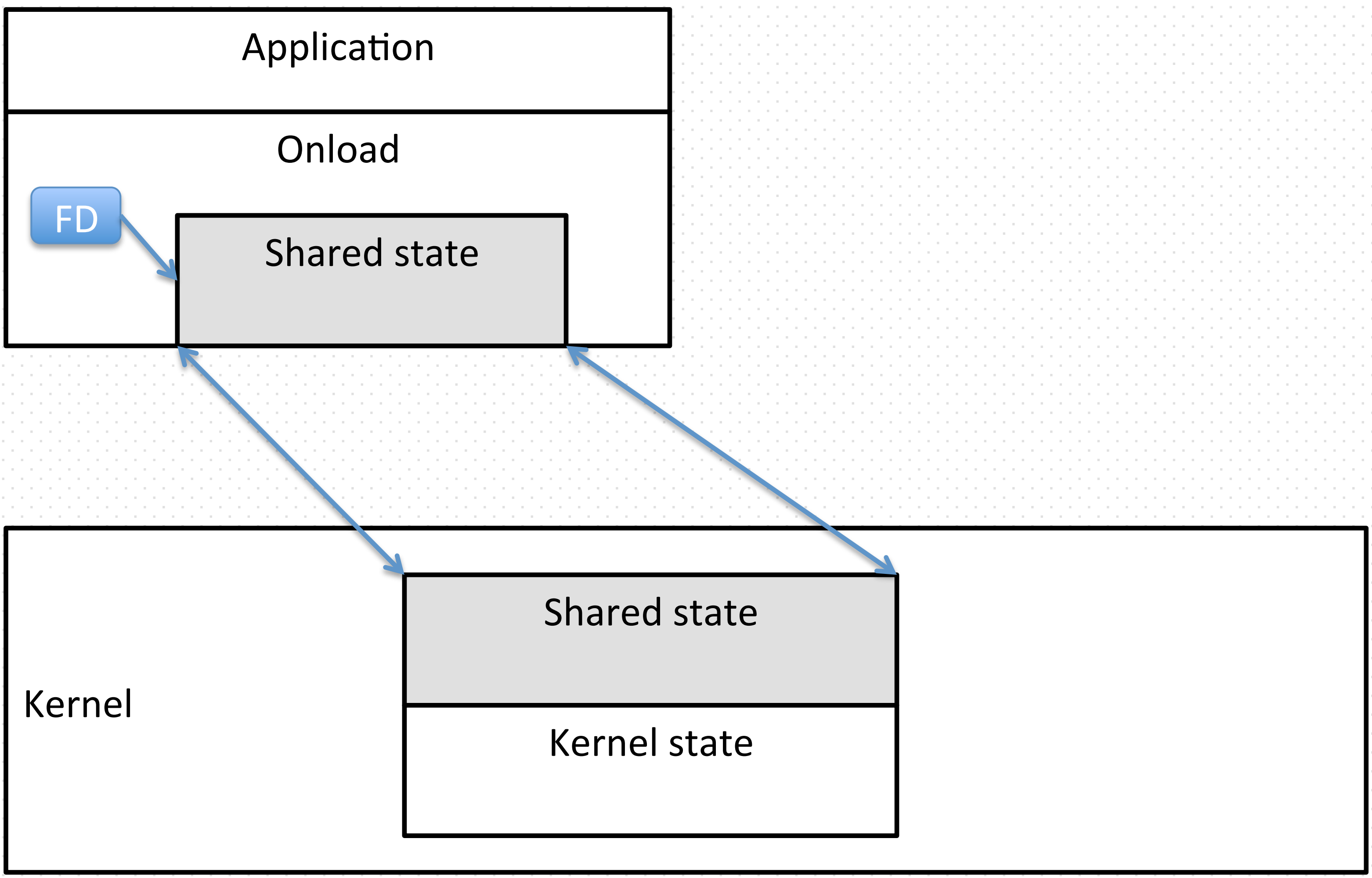
Shared state: exec() – wipes it all



Shared state: exec()



Shared state: exec()



Shared state: internals

- What is in it:
  - sockets,
  - packet buffers,
  - VI state,
  - timers (retransmit, keepalive etc.),
  - free resources,
  - configuration,
  - demux table (selects socket).

Shared state: Addressing

- Mapped into multiple processes + kernel
  - pointers are indirect and kernel-managed,
  - sockets and packet buffers are identified by index,
  - other fields identified by offset.

- User-space code can corrupt the state
  - state sharing = trust

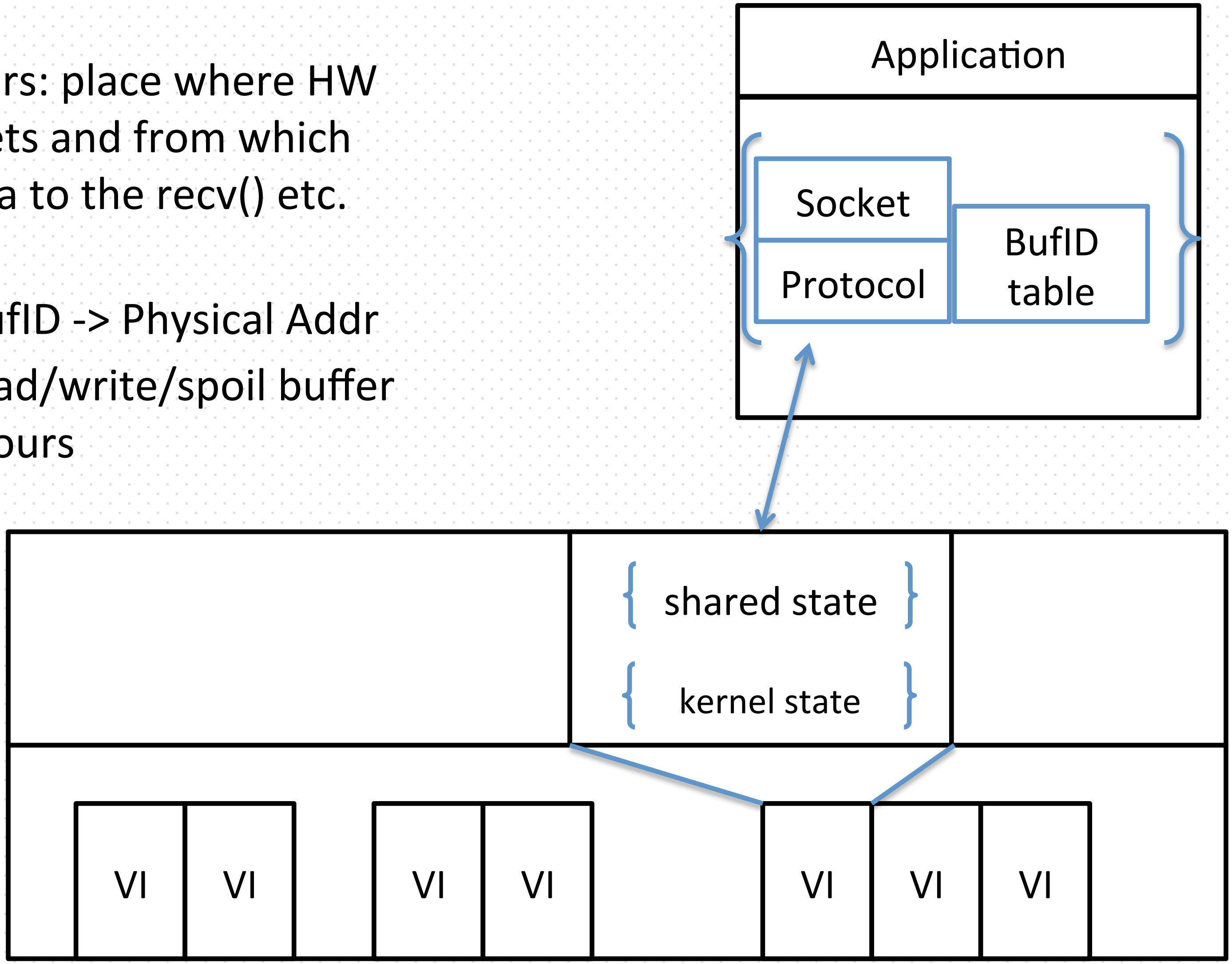
- Kernel code should check state is not corrupted by user-space code

Security: Kernel state

- Kernel state = Trusted state
- Pointers = offsets
  - kernel: verified and converted
  - userland: not verified and converted
- Lists: you can loop them even with valid pointers
  - traverse stack with a counter

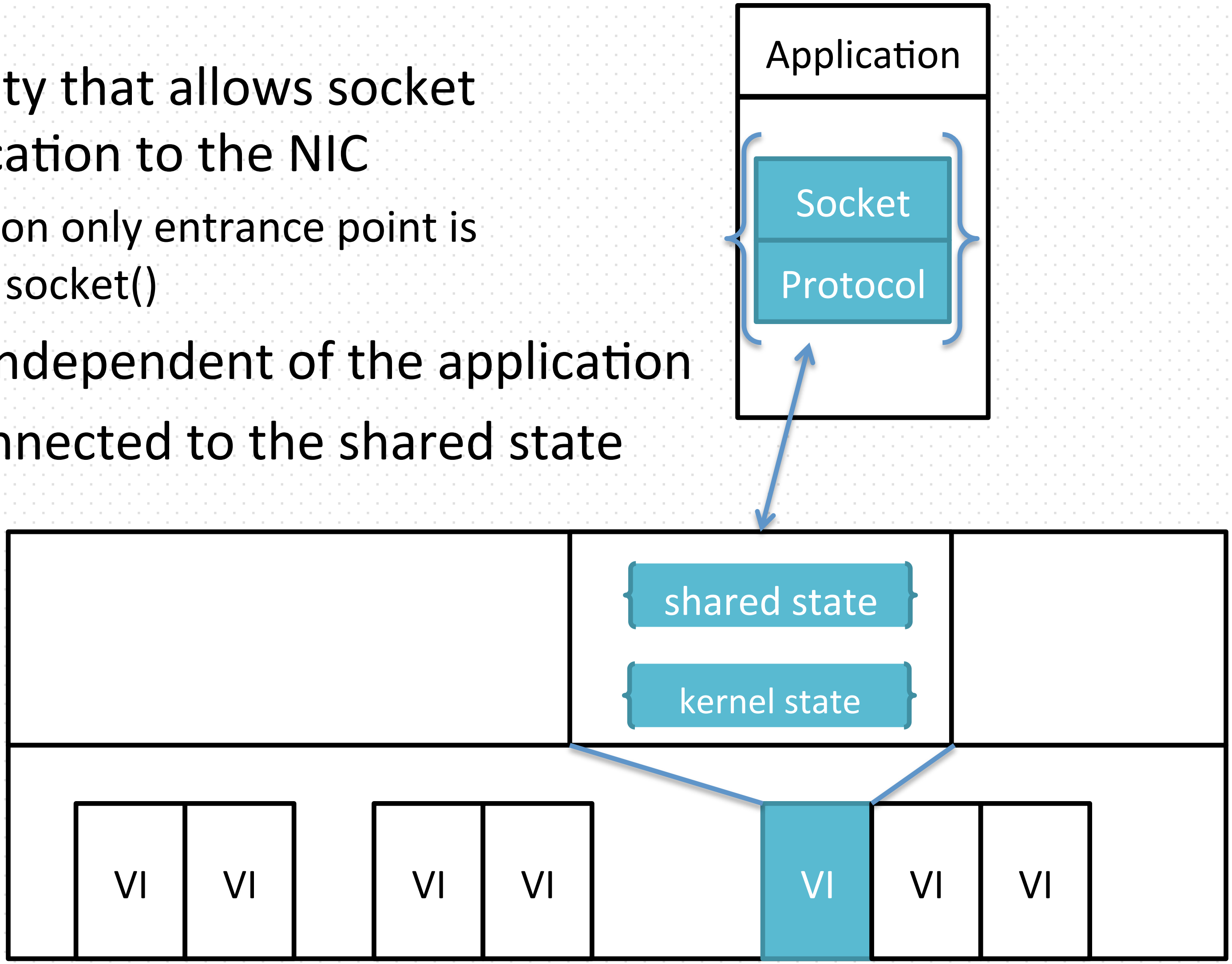
More security!

- Packet buffers: place where HW writes packets and from which we copy data to the recv() etc. buffers
- NIC maps BufID -> Physical Addr
- You can't read/write/spoil buffer that is not yours



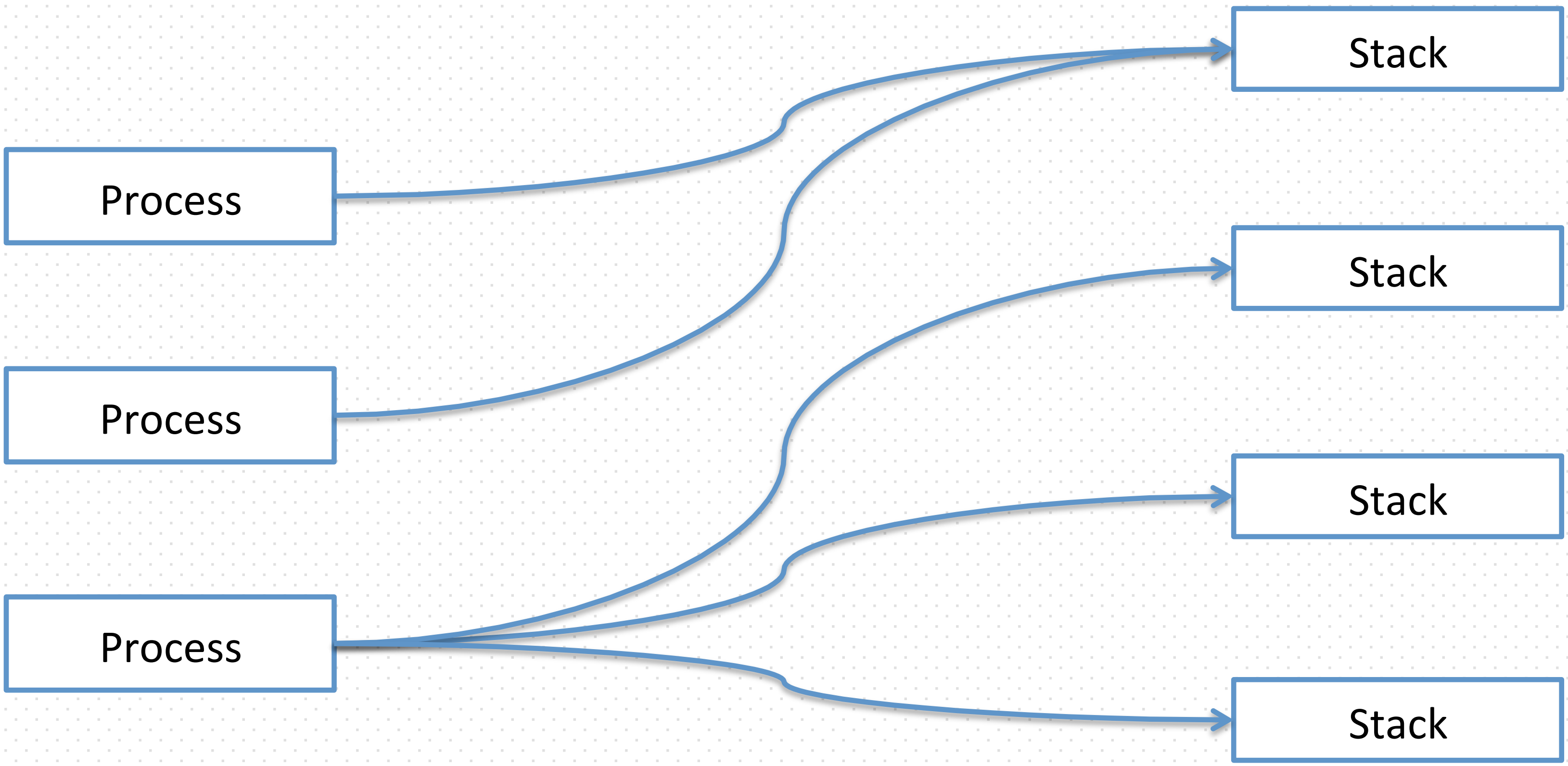
Stack: basics

- Stack: entity that allows socket communication to the NIC
  - application only entrance point is socket = socket()
- Lifetime: independent of the application
- Tightly connected to the shared state



Stack: <-> processes

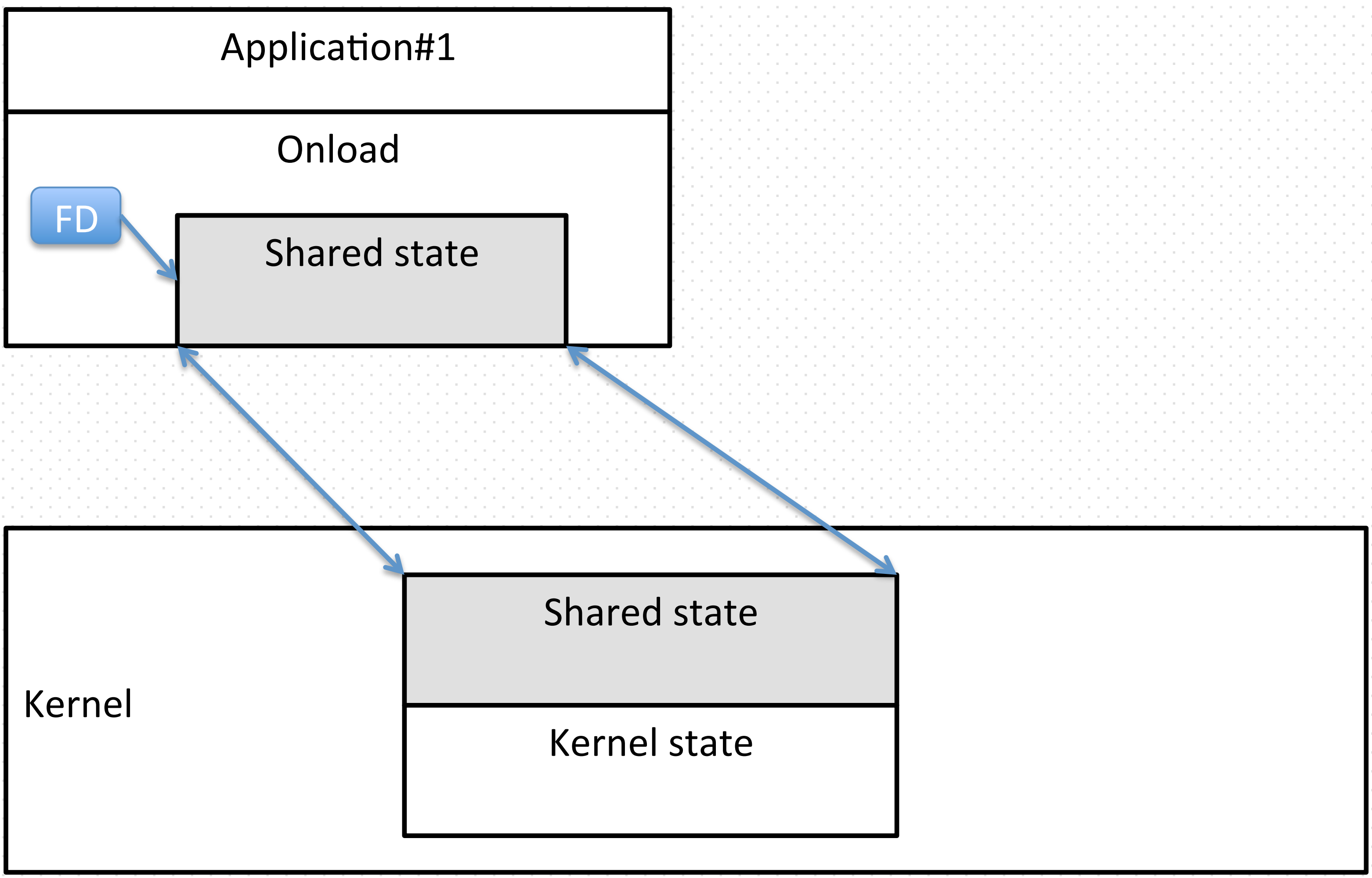
- Arbitrary mapping
- Can change over time



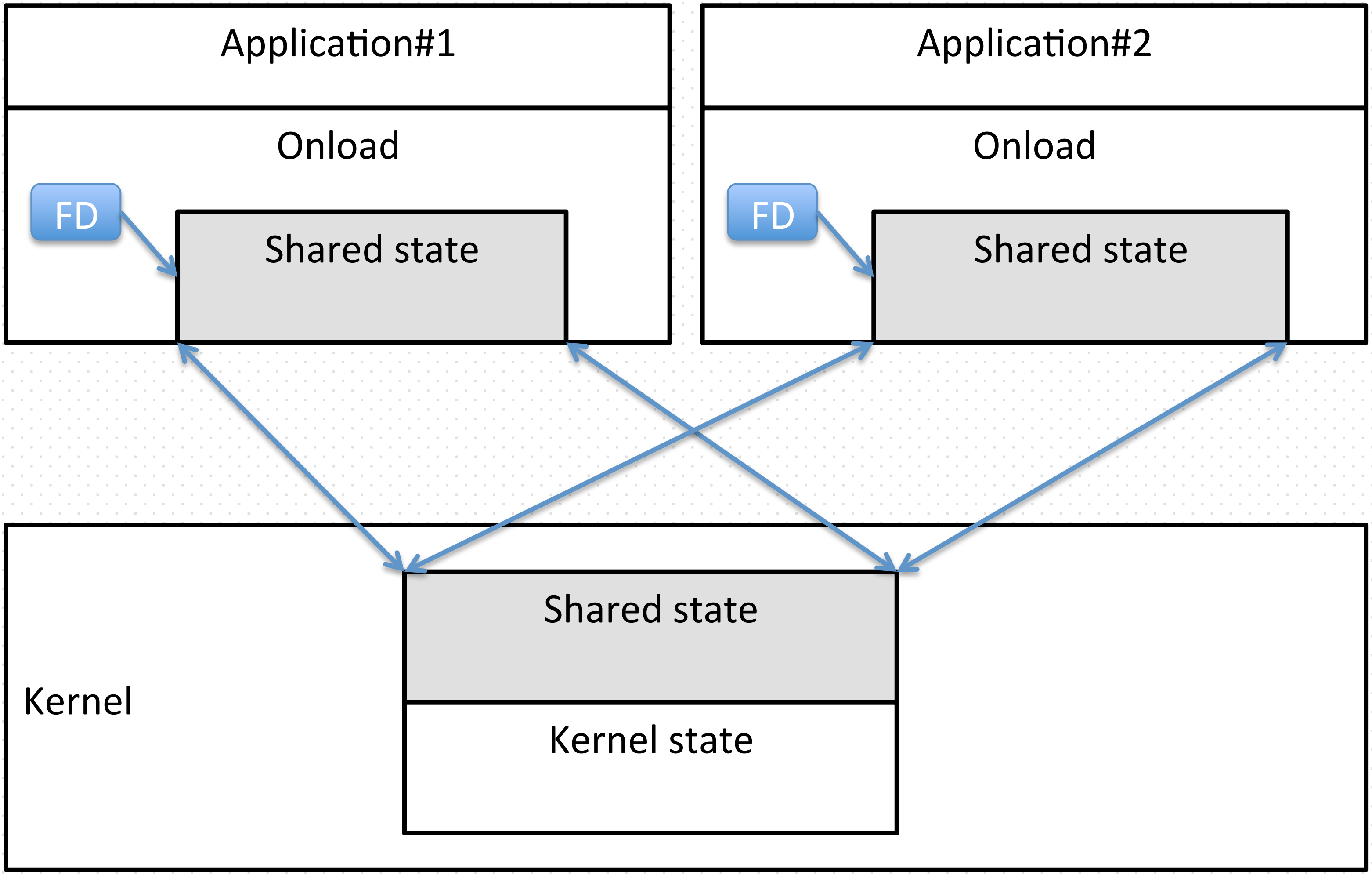
Stack: default stack for the process

- Default stack is where socket() creates a socket
- Default can be changed
- Default depends on how we got here
  - fork, exec, settings etc.
- If there is actually no stack -> socket() creates a stack
  - slow and logic avoids this
- close():
  - destroys stack if it's the last socket
  - **does not** destroy default process stack

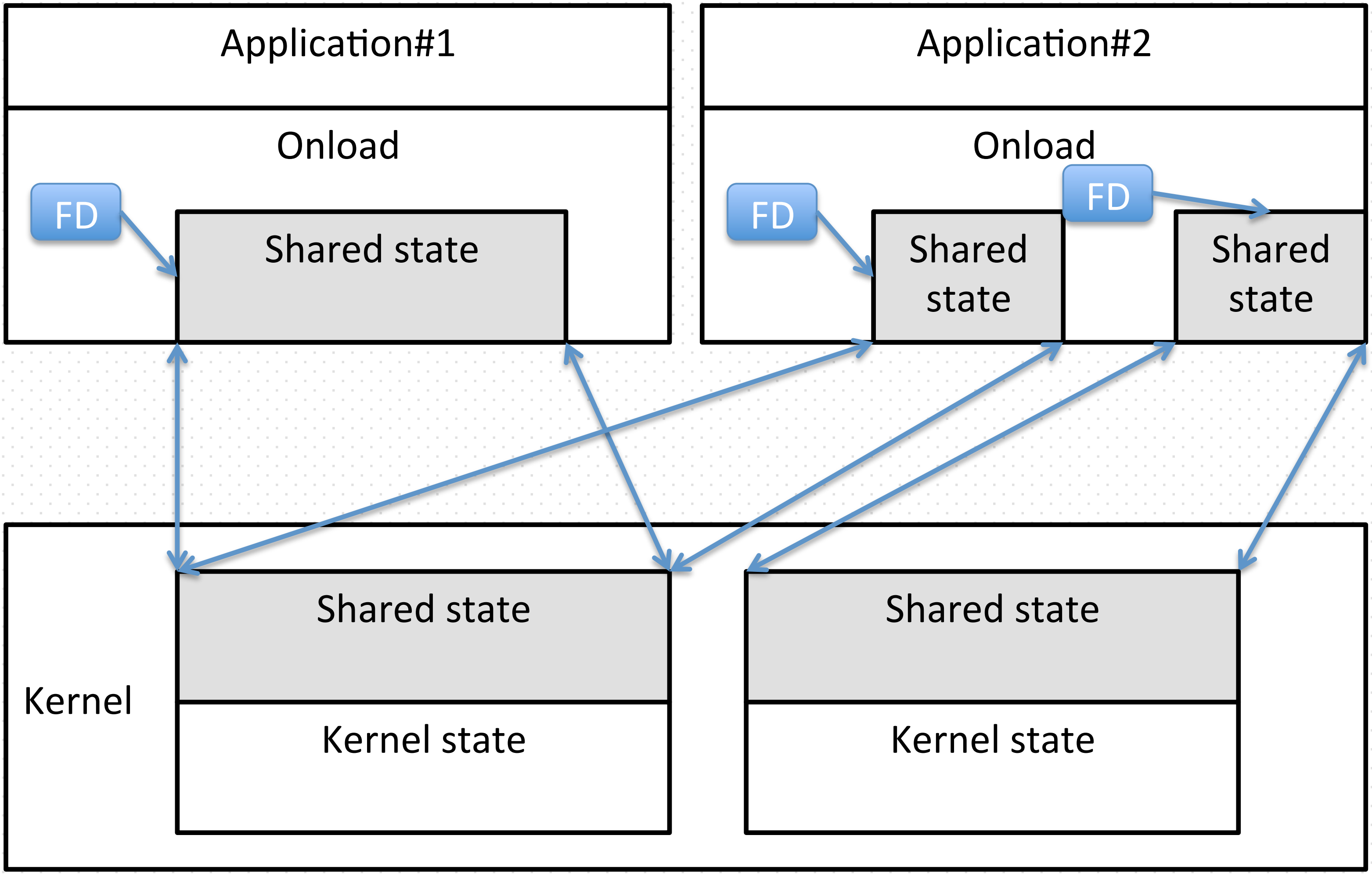
Default stack: socket()



Default stack: fork()



Default stack: socket() in Application#2: default behaviour



Stack for a socket

- EF_NAME: just tell the stack name to your process
- Granular policies:
  - different users -> different processes
  - different groups -> different processes
  - etc.
- Move socket between stacks: in some cases

Stack: locks

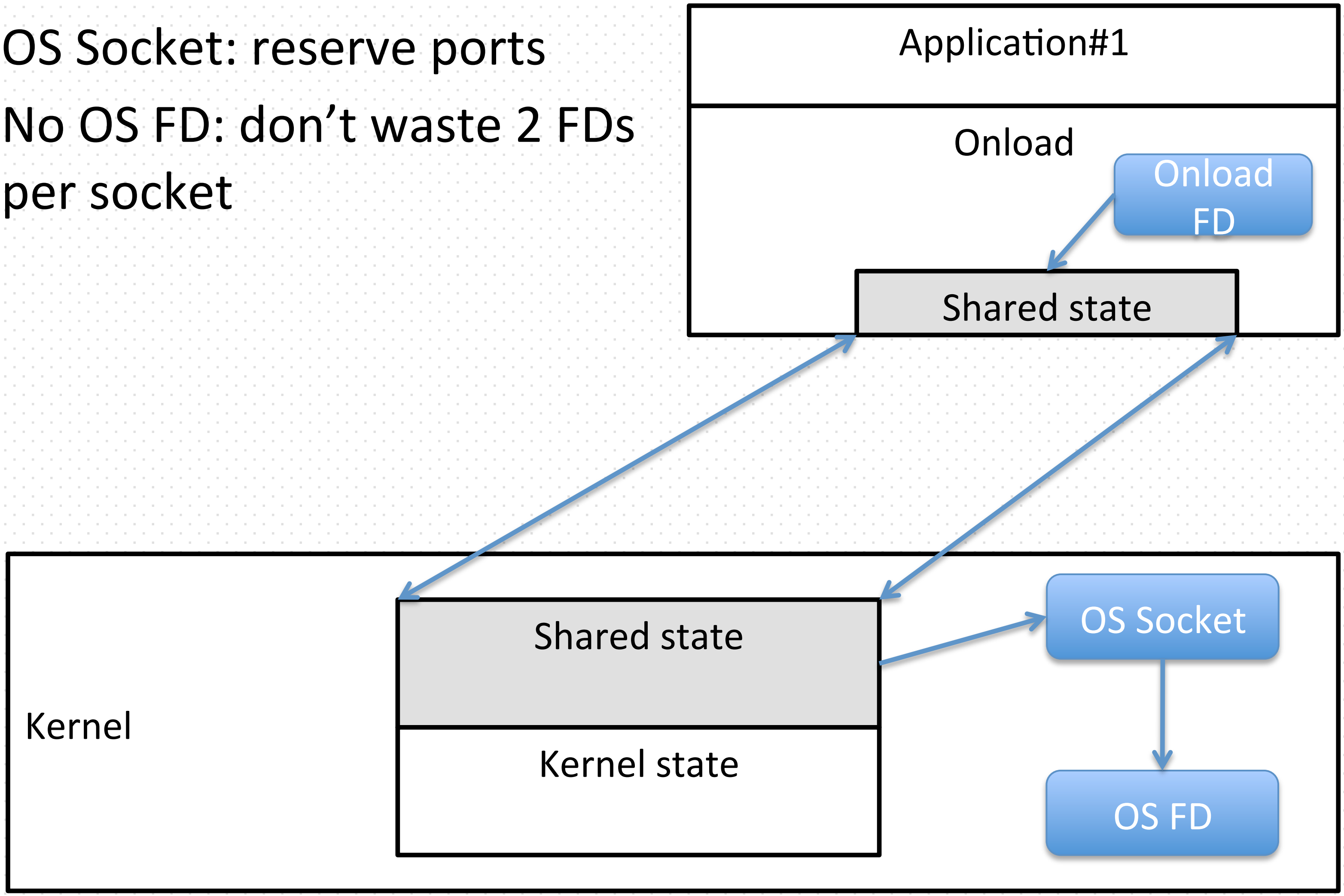
- Smart mix of:
  - stack lock
  - socket lock
  - atomics
- Atomics are expensive
- Receive path: HW should be able to queue packets while socket reads them
- Transmit path: sendq + pre-queue mechanism that allows socket to queue packets without taking the stack lock

Onload FD: onloadfs

- Socket is an FD
- Onload socket is also an FD
- /proc/pid/fd/239 : special onloadfs
  - similar to socketfs
- It's an FD, so even **without Onload:**
  - read()
  - write()
  - poll(), epoll_wait(), select()

Onload FD: OS socket

- OS Socket: reserve ports
- No OS FD: don’t waste 2 FDs per socket



Onload FD: OS socket

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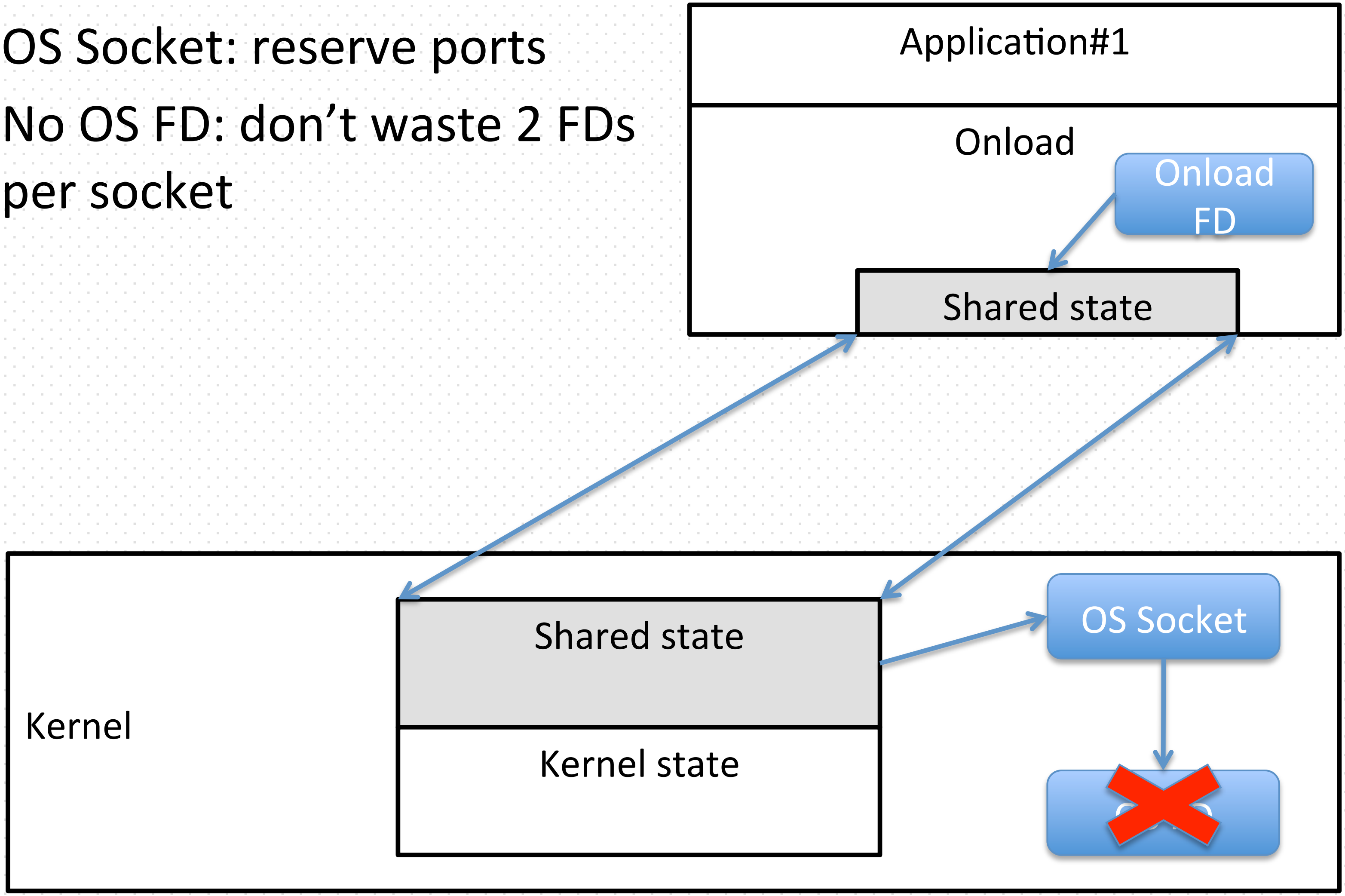
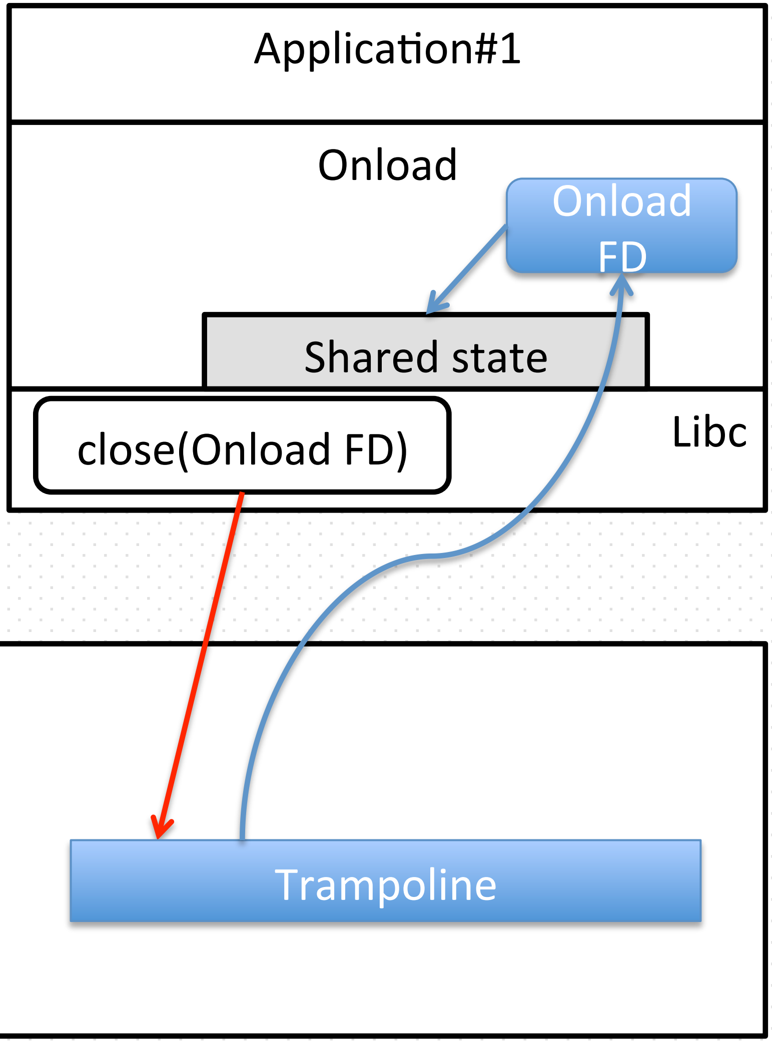


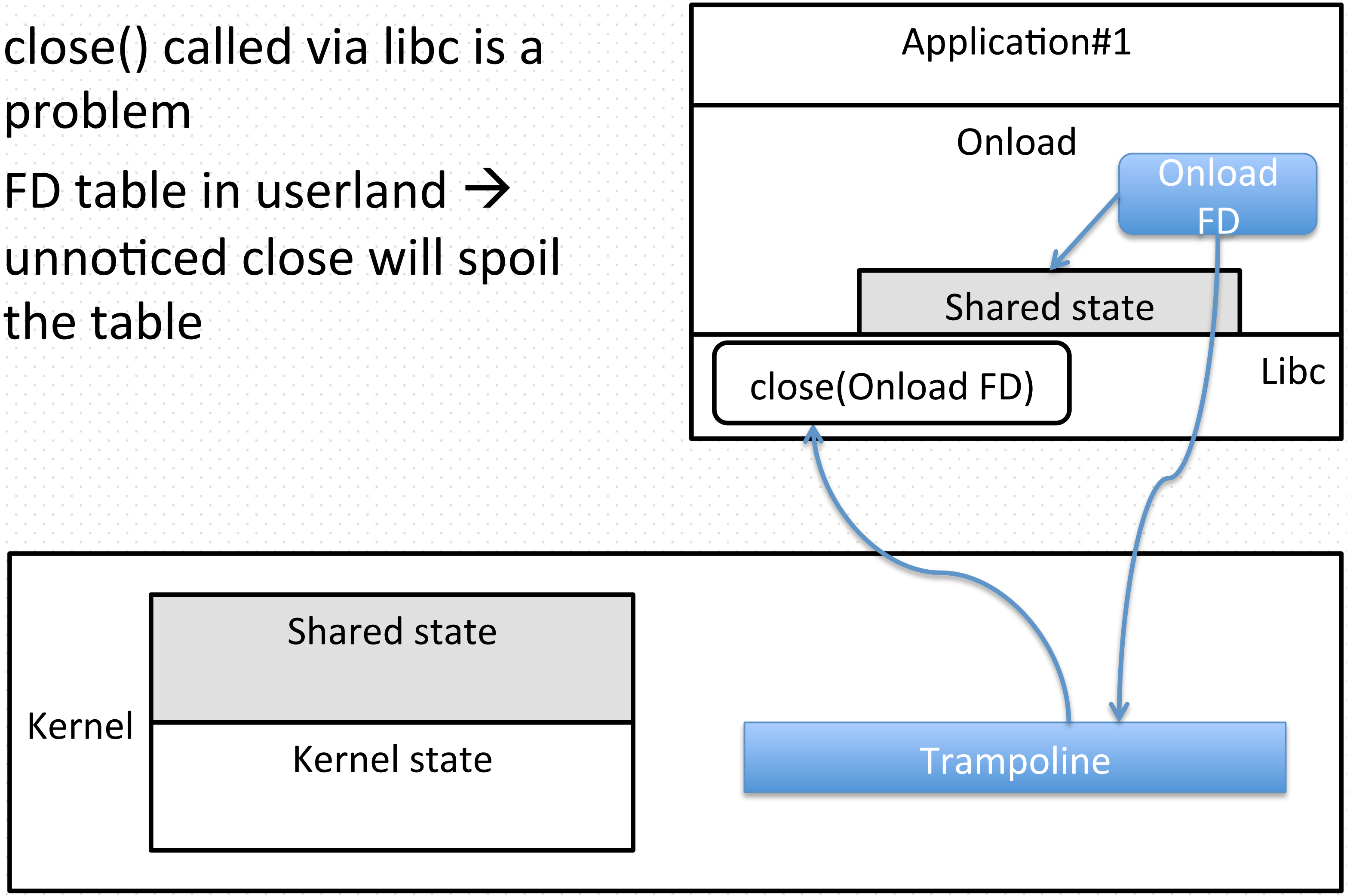
close(): what if OS closes the socket

- close() called via libc is a problem
- FD table in userland → unnoticed close will spoil the table



close(): return properly!

- close() called via libc is a problem
- FD table in userland → unnoticed close will spoil the table



What if I send via non-SF NIC

- 1: socket(, SOCK_DGRAM,) -> s1
- 2: sendto(s1,) → accelerated interface
- 3: sendto(s1,) → non-accelerated interface

- Onload detects that you're working with non-SF adapter and passes packet in (3) to the kernel

- 1: socket(, SOCK_STREAM,) -> s1
- 2: bind(INADDR_ANY) + listen()
- 3: s2 = accept(): checks Onload connections and then "Linux" connections

- If s2 is Linux we'll honor it

Control Plane

- ARP
- Route (no multi-table setup)
- Interface addresses
- ip rule (no source-based routing)
- iptables:
  - limited support,
  - SolarSecure provides improved support, cool statistics and Norse Darklists integration
- Control plane structures are RO for userland

Diff with Linux

- Automatic detection (>15000 testcases)
- Usually diversity is intentional and can be tweaked with env variable
- TCP protocol implementation is a bit different

Acceleration: some examples

- Latency
- Local communication:
  - TCP Loopback,
  - UDP Loopback & UDP Multicast,
  - PIPE
- Nginx

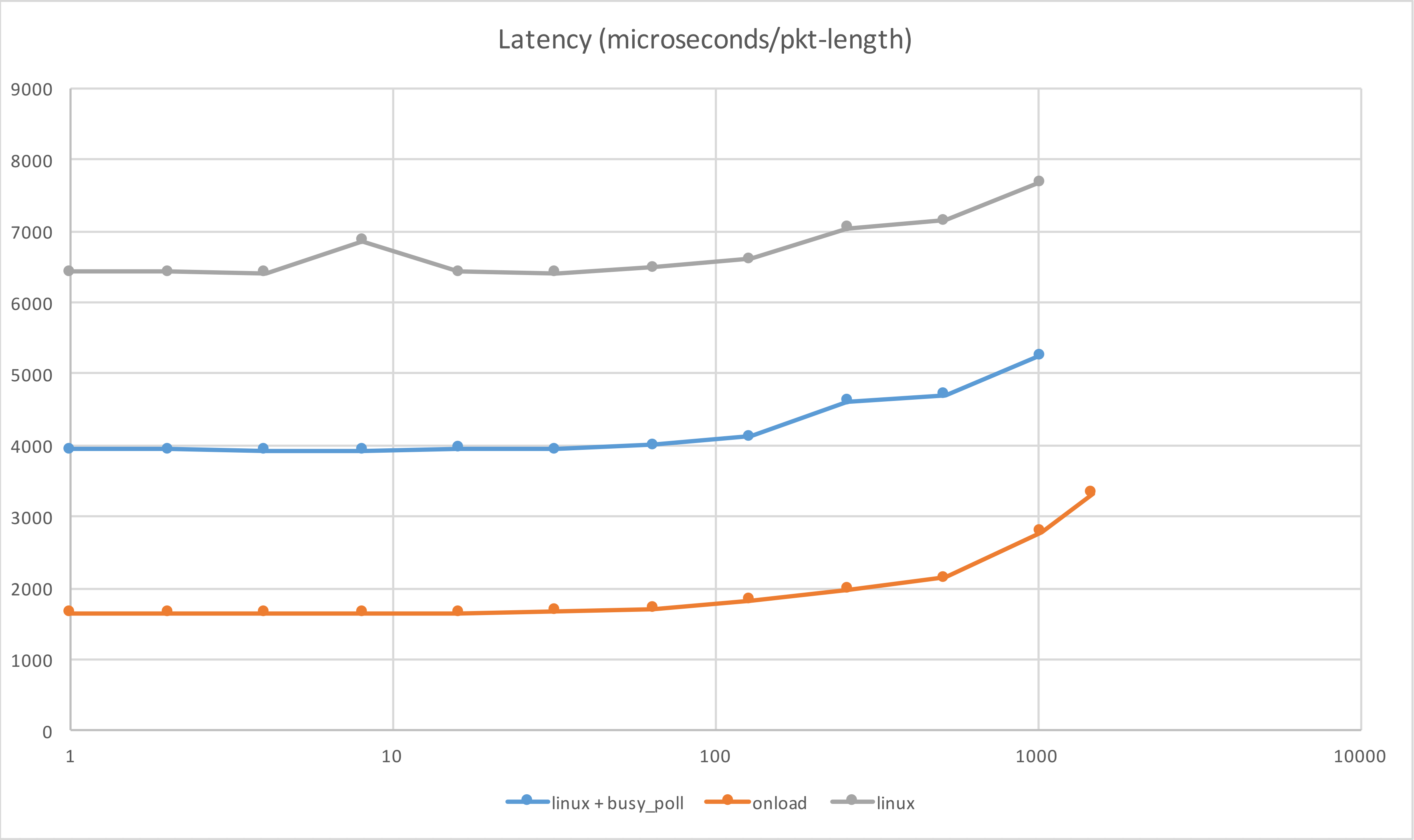
Latency (UDP)

- Linux raw data on 64B packets was: >10ms : terrible
  - Linux improves, but not fast
- Recent Linux has SO_BUSY_POLL:
  - works similar to SPIN mode of Onload
  - modify your application (Java?) or
  - enable it globally (CPU)
  - Onload spin happens in the application

Latency (UDP)

payload	RHEL7	RHEL7+busy_poll	onload
1	6428	3940	1653
2	6432	3947	1652
4	6405	3921	1651
8	6856	3925	1653
16	6419	3954	1653
32	6413	3940	1681
64	6484	3997	1707
128	6602	4127	1823
256	7046	4616	1974
512	7138	4699	2146
1024	7688	5255	2786
1472			3324

Latency (UDP)



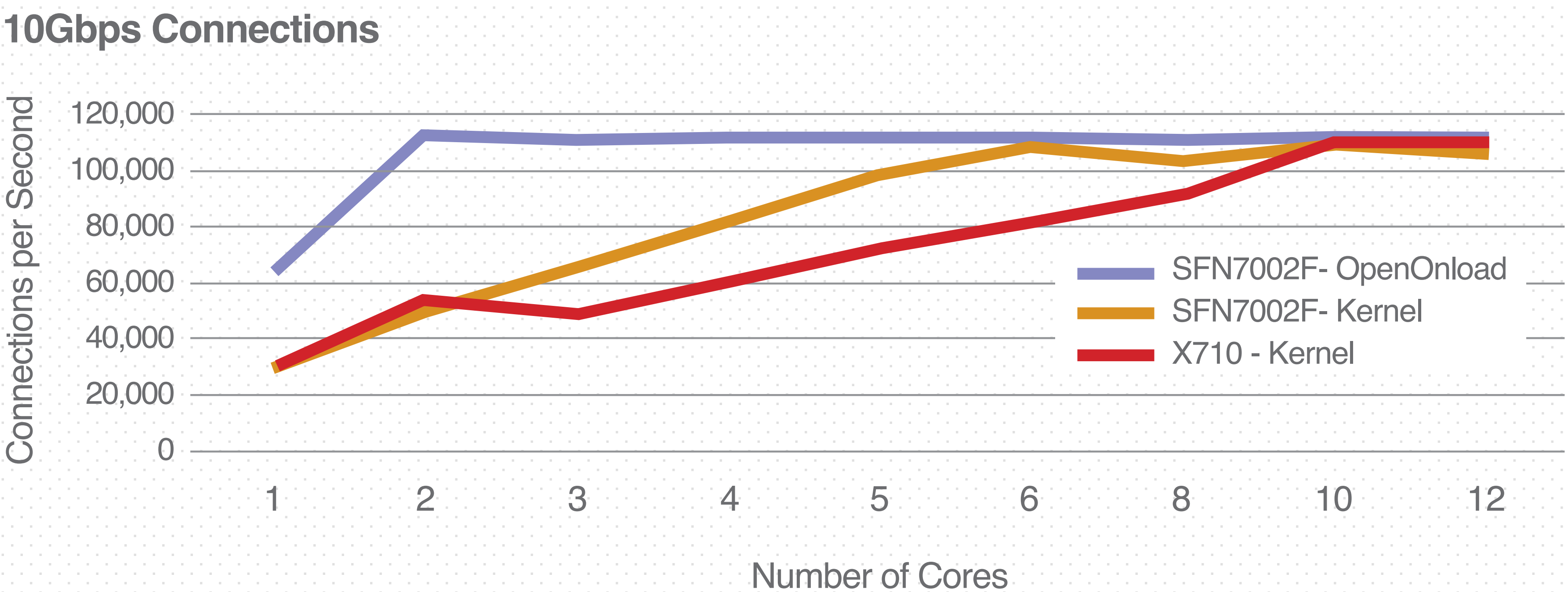
Latency (microseconds/pkt-length)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
10
100
1000
10000
linux + busy_poll
onload
linux

Loopbacks & PIPE

- TCP Loopback or UDP unicast
  - if sockets share the state, let's communicate through it
- One stack, but we have helpers that can:
  - move both sockets to either listen()-er or connect()-er socket,
  - create new stack and move both socket to it.
- UDP loopback (multicast):
  - replay to listeners in the same stack
  - replay to listeners from other stacks (and virtual machines) with HW assistance
- PIPE
  - ends in the same stack

Nginx: connection rate

- Maximize number of requests Nginx can handle
- Intel Xeon E5-2620 v3 processors with HT running at 2.4 GHz, and 64 GB DDR4 RAM running at 1867 MHz
- SO_REUSEPORT is set
- Static content; 10000 in length stored on RAM filesystem



Nginx: connection rate

- How any of what I've told helps connection rate?

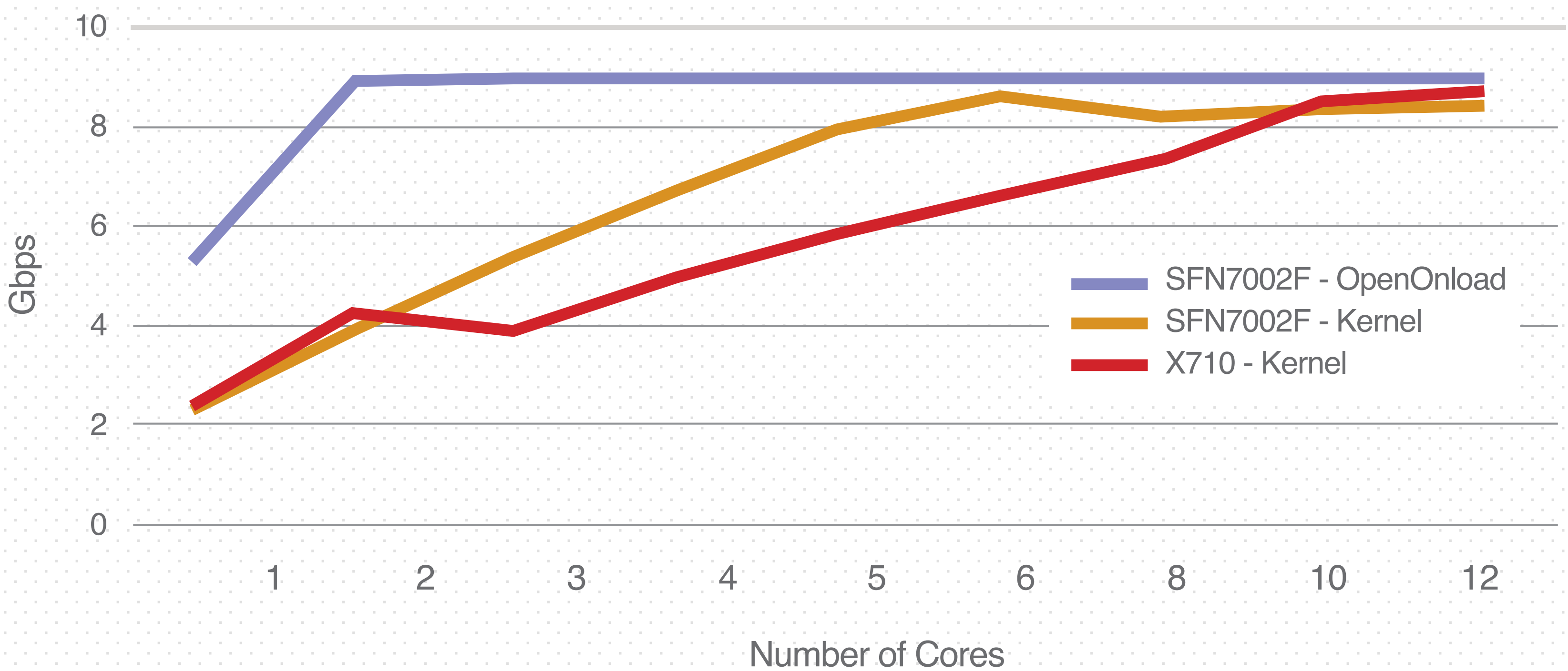
Nginx: reasons

- Reduced cost of networking calls
- Onload stack per worker means that almost nothing is shared: no lock contention and cache bouncing
- epoll_wait() scaling improved (latest release only!): O(1)

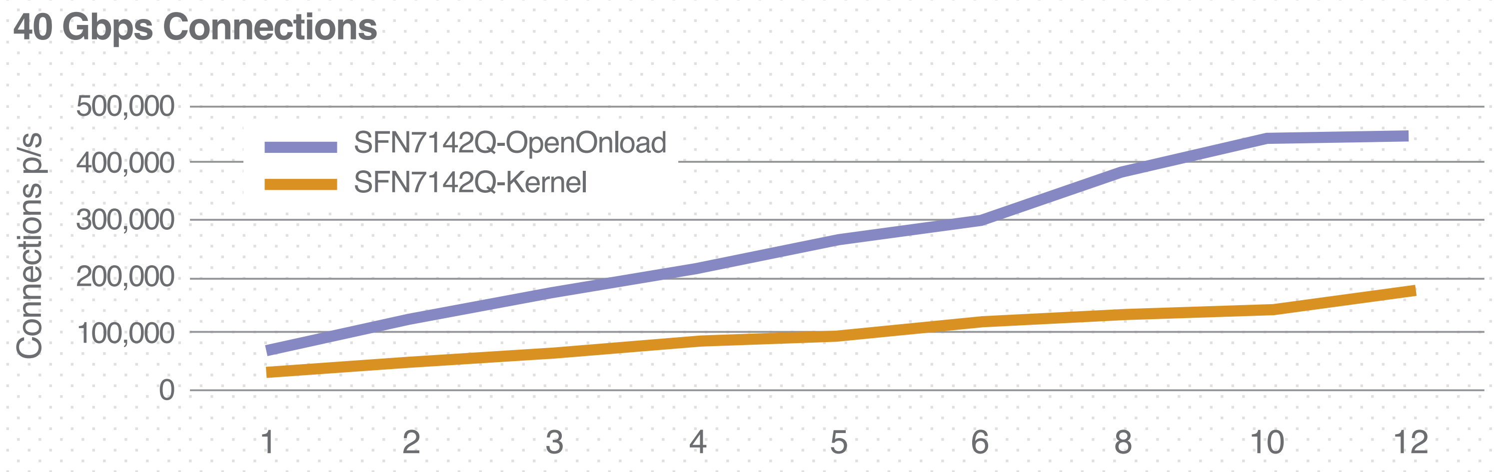
Nginx: socket caching

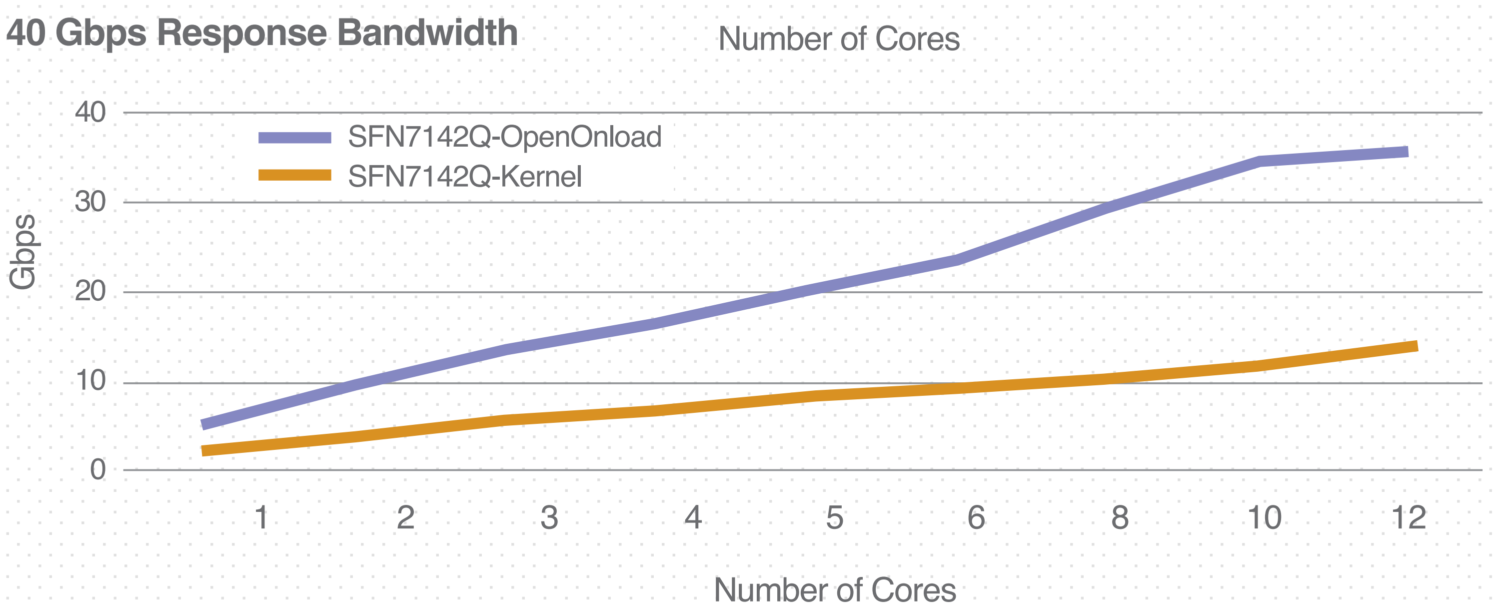
- We're not going into the kernel
- listen()
- accept() → s1
- accept() → s2
- close(s1)
- → SYN received:
  - take s1
  - no need to go to the kernel!

Nginx: response bandwidth (10G)



Nginx: response bandwidth (40G)





Nginx: VOD

- 1Mbps stream
- Watermark: 1MB buffer; next request if buffer is at 50%
- 20000 IP addresses
- WRK testbench

Nginx: VOD 10G

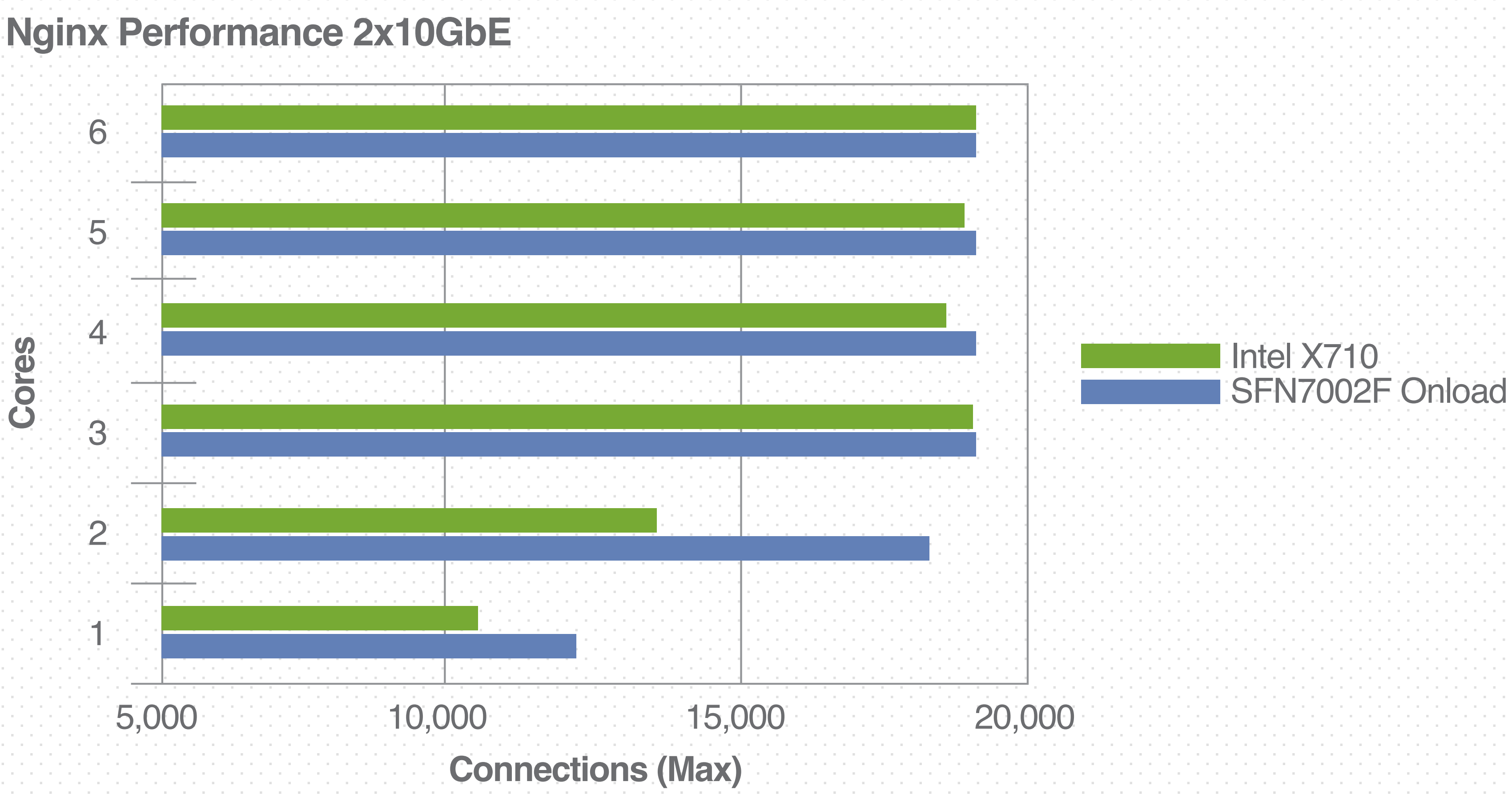


Figure 2. Maximum simultaneous connections vs. number of cores at 2x10GbE.

Nginx: VOD 40G

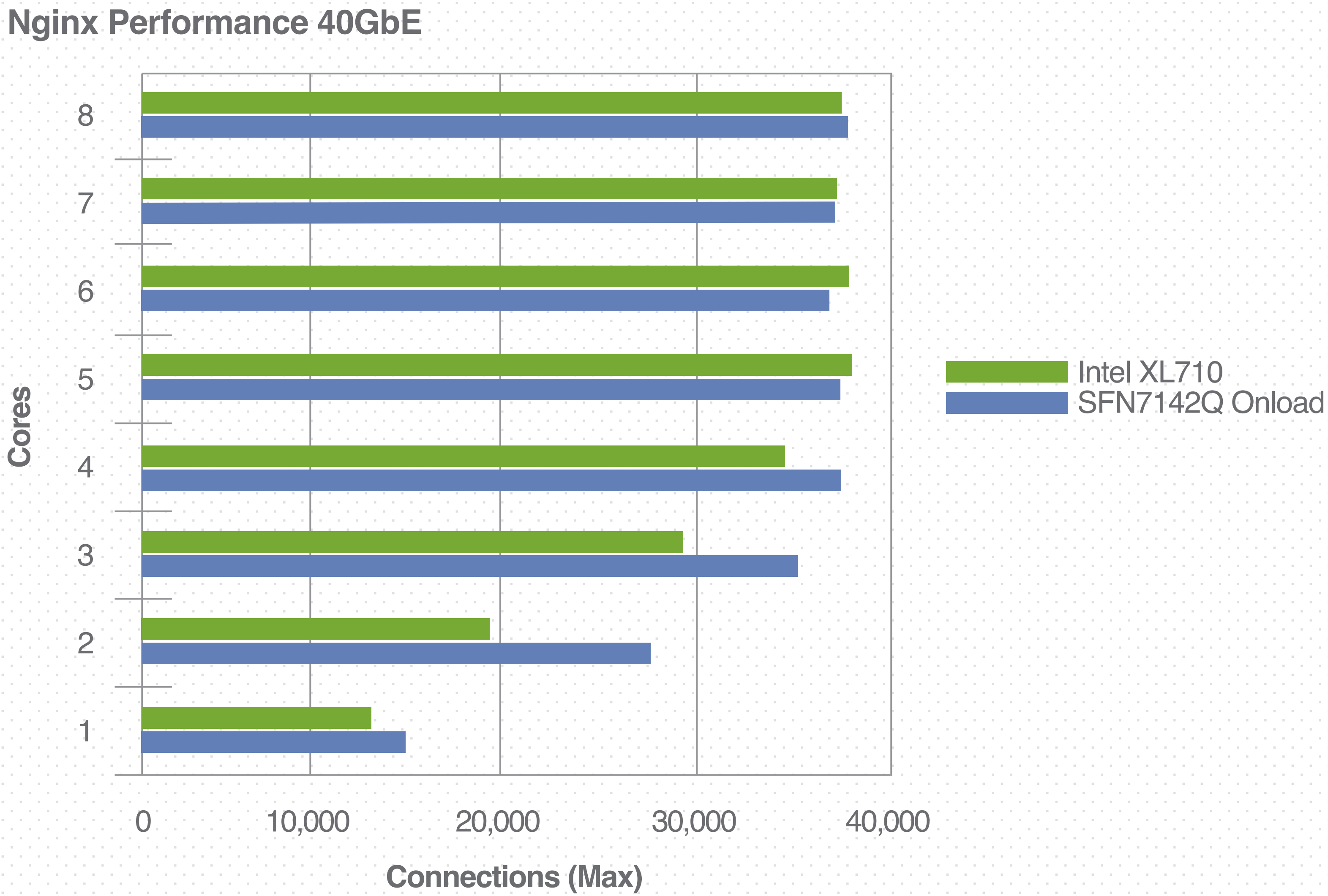


Figure 3. Maximum simultaneous connections vs. number of cores at 40GbE.

Performance/behaviour tuning

- Very granular:
  - Per-application
  - Per-stack
  - Per-socket (setsockopt() implementation)
- Non Socket API functions:
  - Zero Copy
  - Ordered epoll (RX packets from many sockets in wire order)

Thank you.

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