Arrakis

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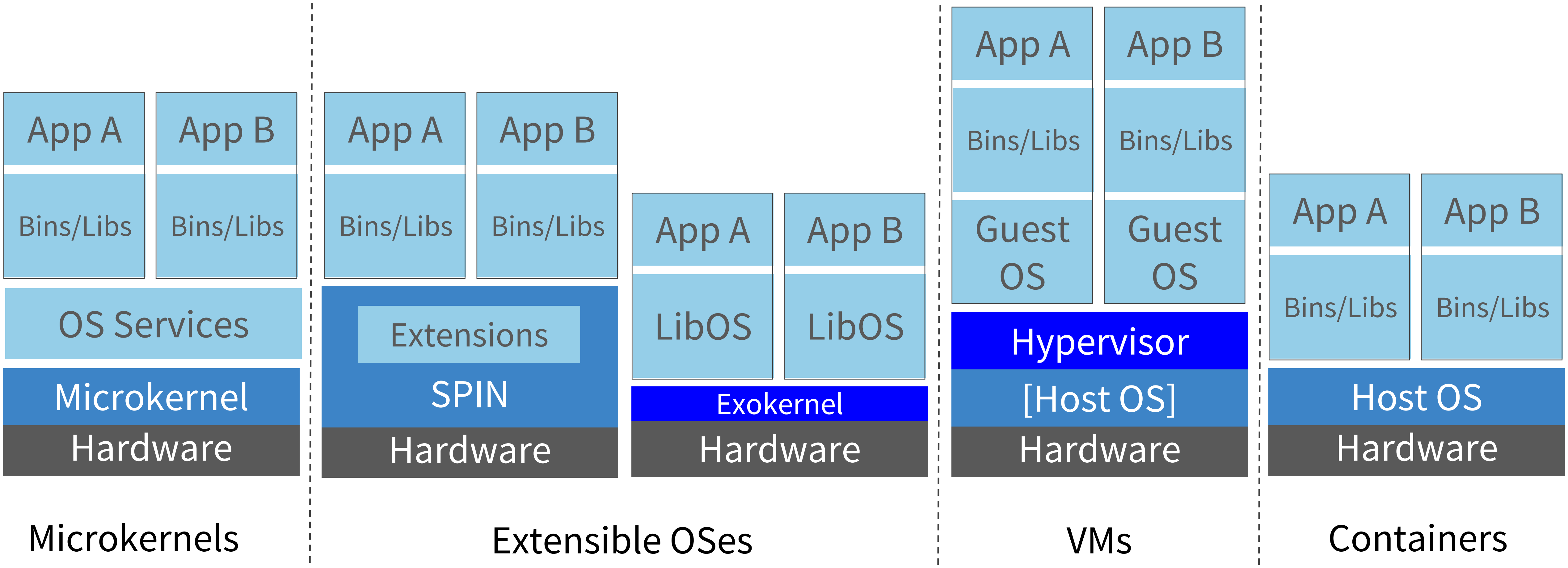
CS380L

Arrakis faux quiz (pick 2, 5 min)

- Compare and contrast interposition techniques in ESX, Xen, Arrakis
- What is the difference between Arrakis/P and Arrakis/N?
- How much control does the OS have over I/O scheduling in Arrakis?
- How would you implement a MLFQ I/O scheduler in Arrakis? An priority aging I/O scheduler?
- What new abstractions does Arrakis suggest for user-space I/O?
- Compare/contrast Arrakis with Exokernel.
- How are file systems shared across processes in Arrakis?

Box drawing Potpourri: OSes, VMs, Containers



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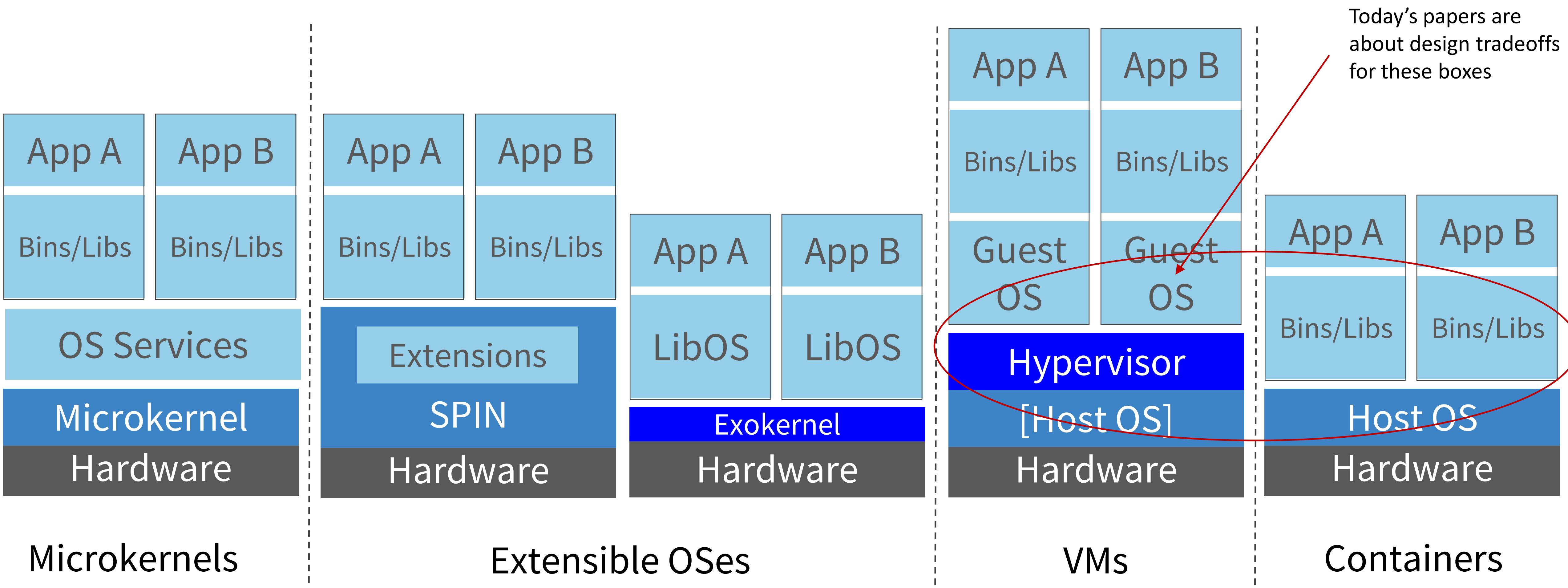


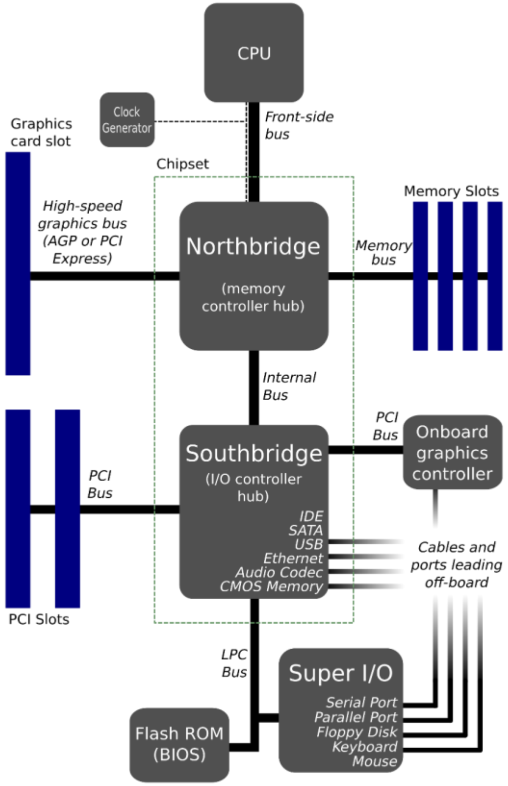
Arrakis

- Background
  - I/O Architecture
  - DMA
  - I/O Virtualization
  - SR-IOV
- Arrakis
  - Some slides adapted (with thanks!) from:

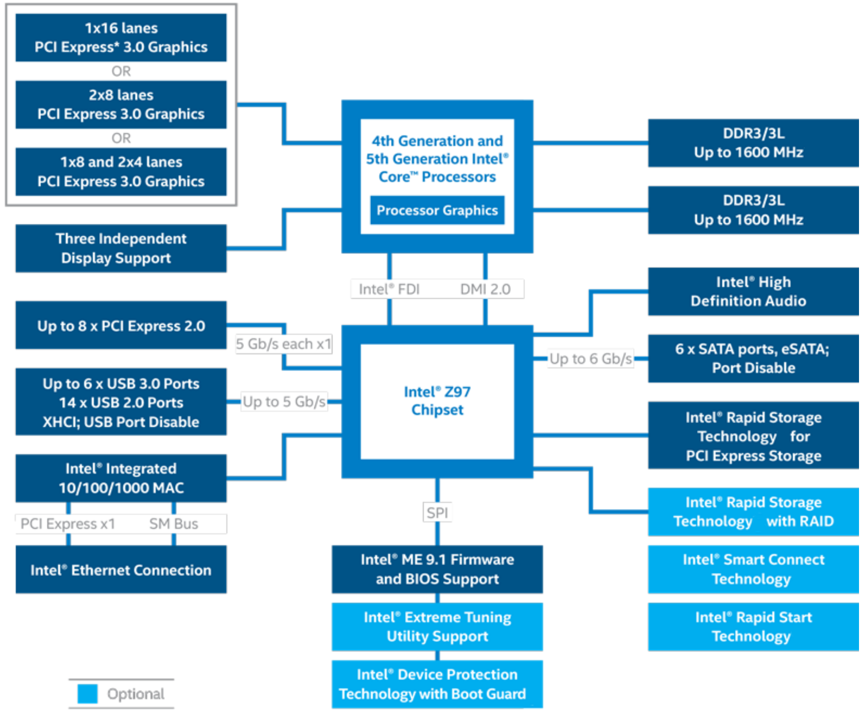
    web.eecs.umich.edu/~mosharaf/Slides/EECS582/2016.../101916-JimmyArrakis.pptx

    Some slide materials adapted from Simon's OSDI talk

I/O Architecture



Traditional
w/ Northbridge/Southbridge



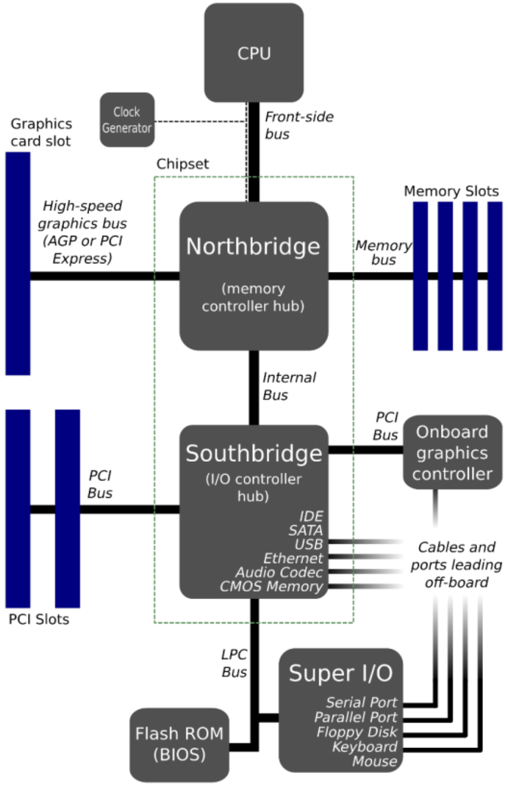
Modern:
QPI or HyperTransport

PCIe 4.0 reaches 2 GB/s per lane

I/O Architecture

Things to observe:

- Significant evolution of path from devices to memory
- Significant diversity in I/O architectures/chipsets
- DMA dominant data movement primitive



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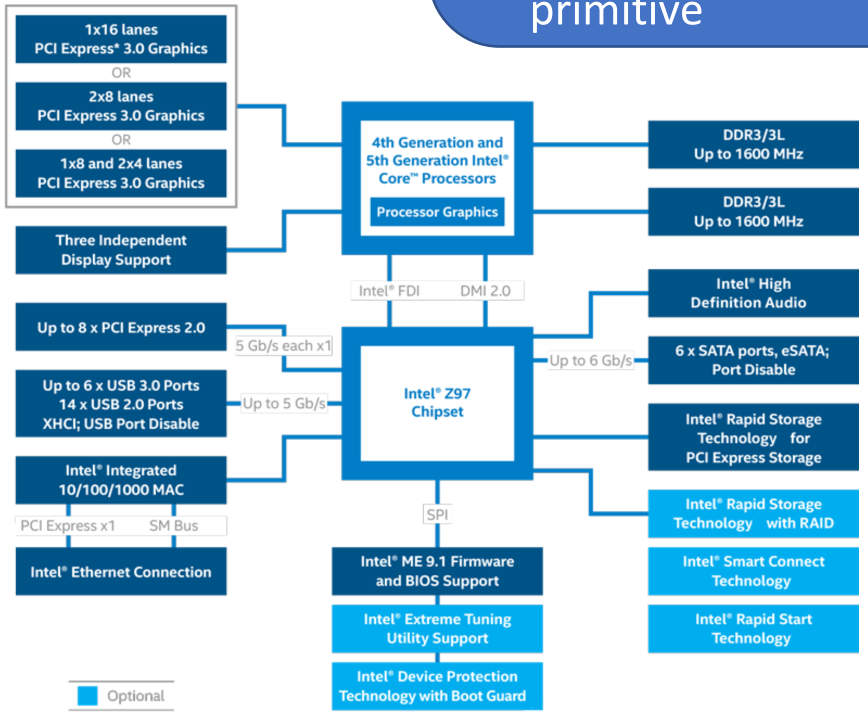

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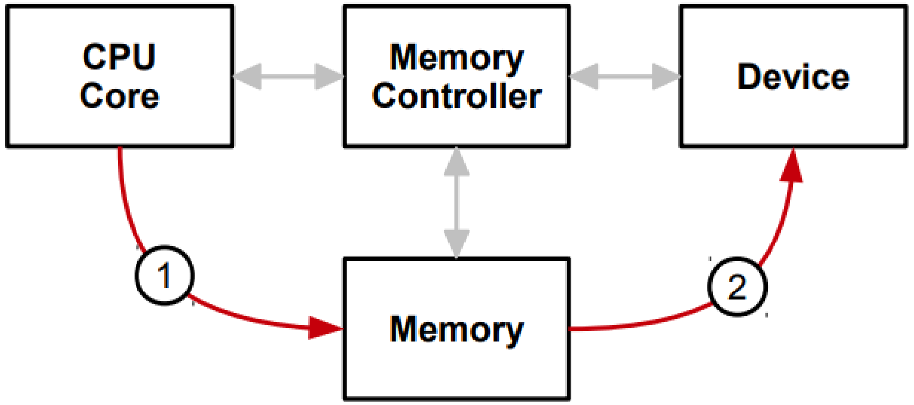
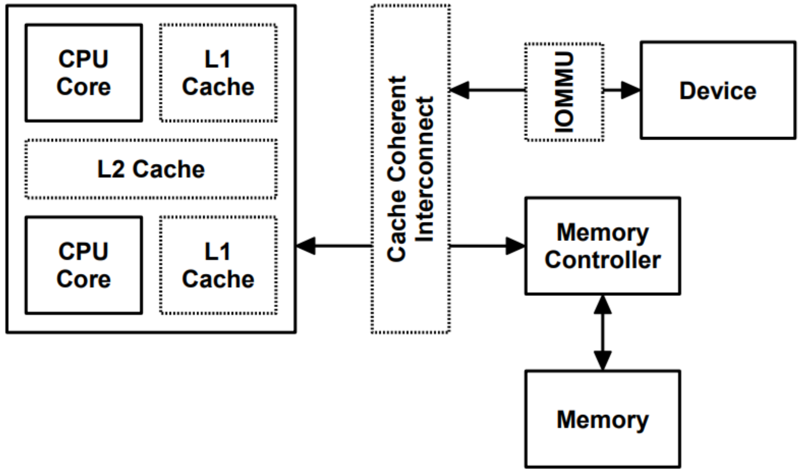
DMA evolution



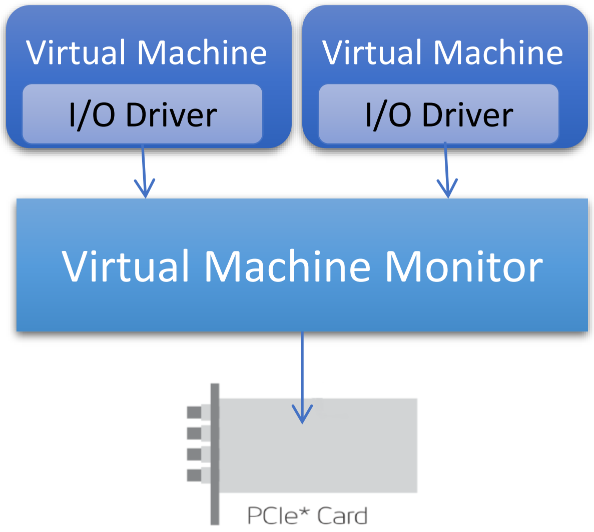


- Device can read/write memory
- CPU sets up DMA transfers
- Device uses ***physical*** address space
  - When is/isn't that OK?

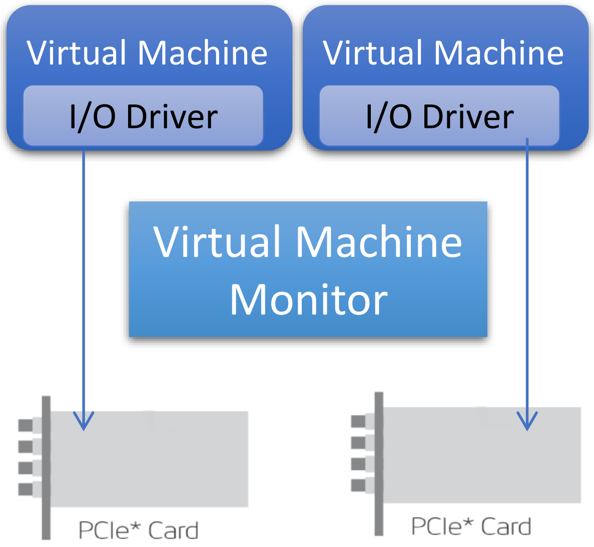
- Device uses translated ***device*** addresses
  - DMA mappings must be configured
  - What mappings to use?
  - Who configures IOMMU mappings?
  - How many device address spaces?
- Simple if OS mediates access to device
  - How to virtualize in VMM?

I/O Virtualization Techniques

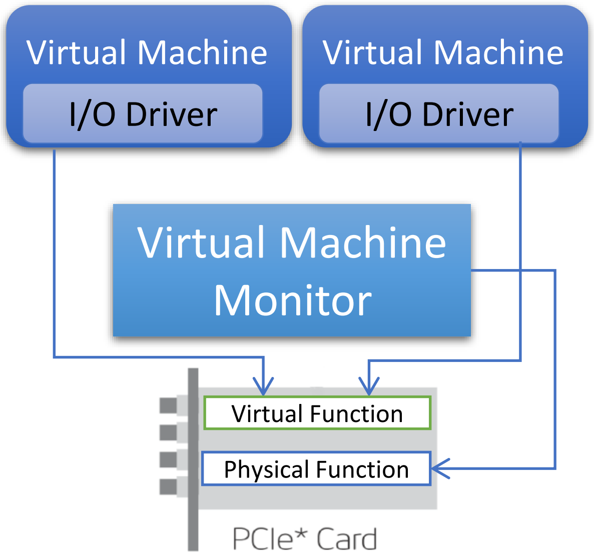
- A - Software only
- B - Directed I/O **(enhance performance)**
- C – Directed I/O and Device Sharing **(resource saving)**



A – Software only

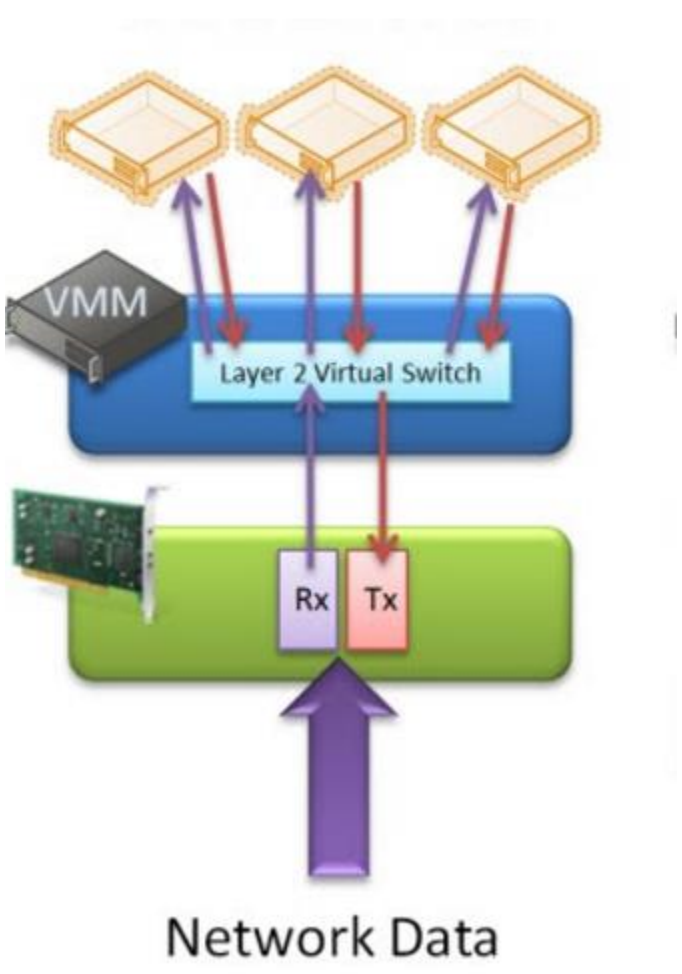


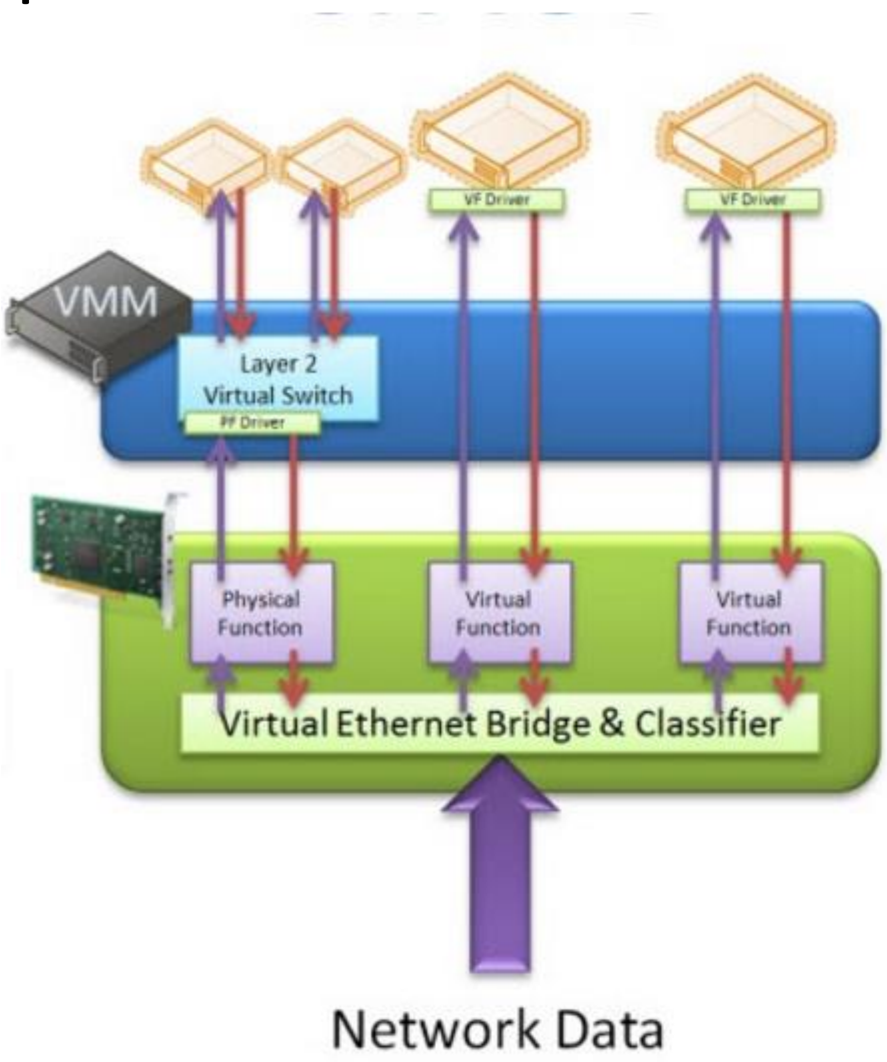
B – Directed I/O



C – Directed I/O & Device Sharing

I/O Virtualization Techniques





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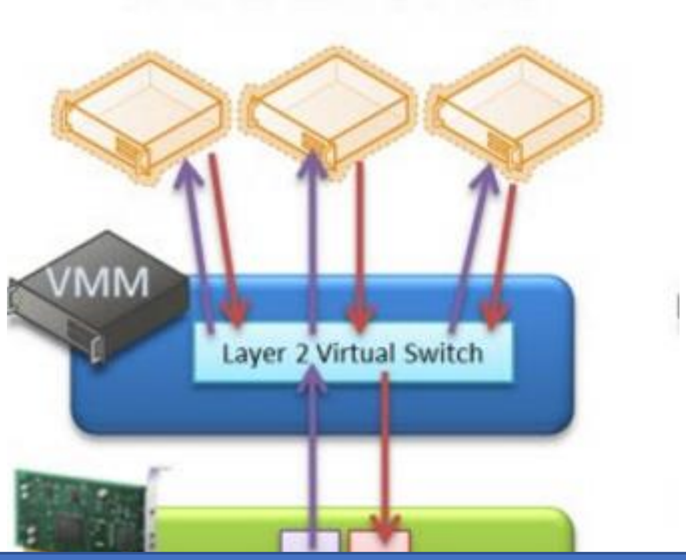
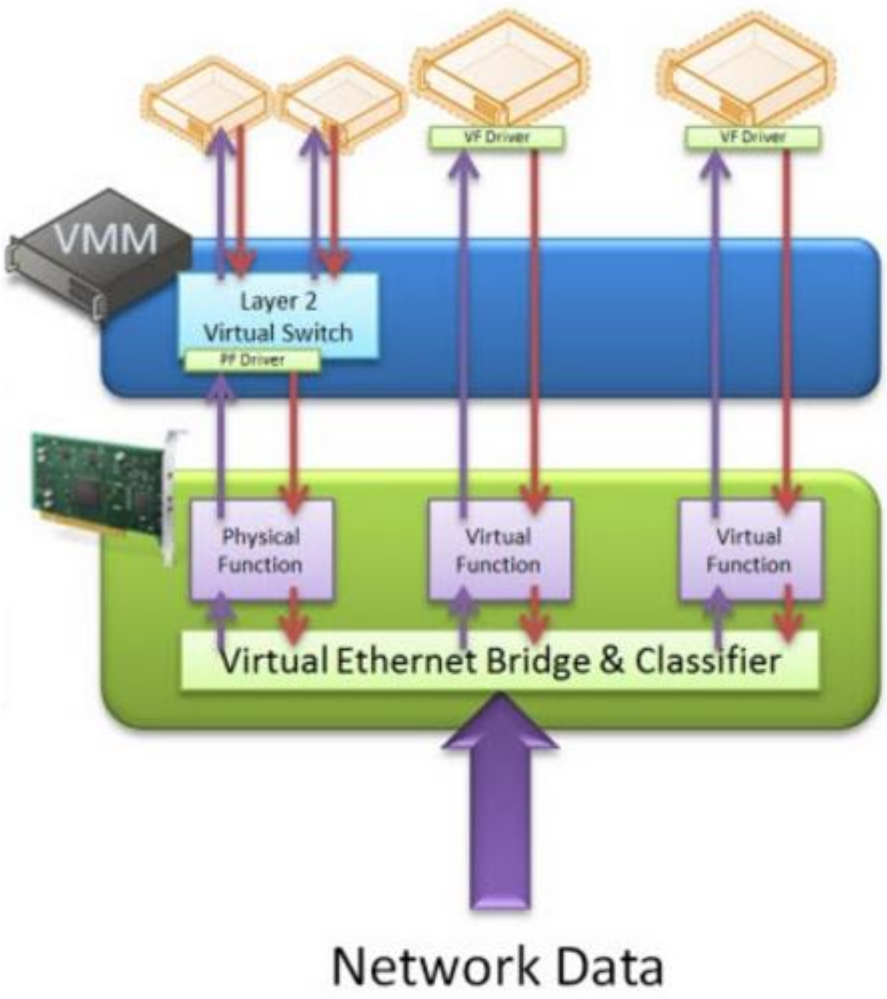
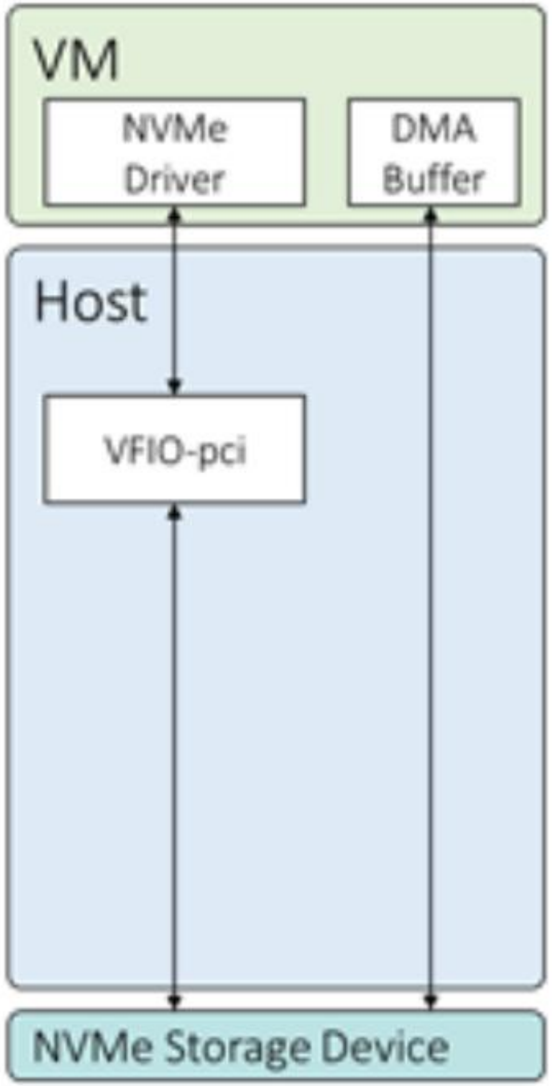


SR-IOV

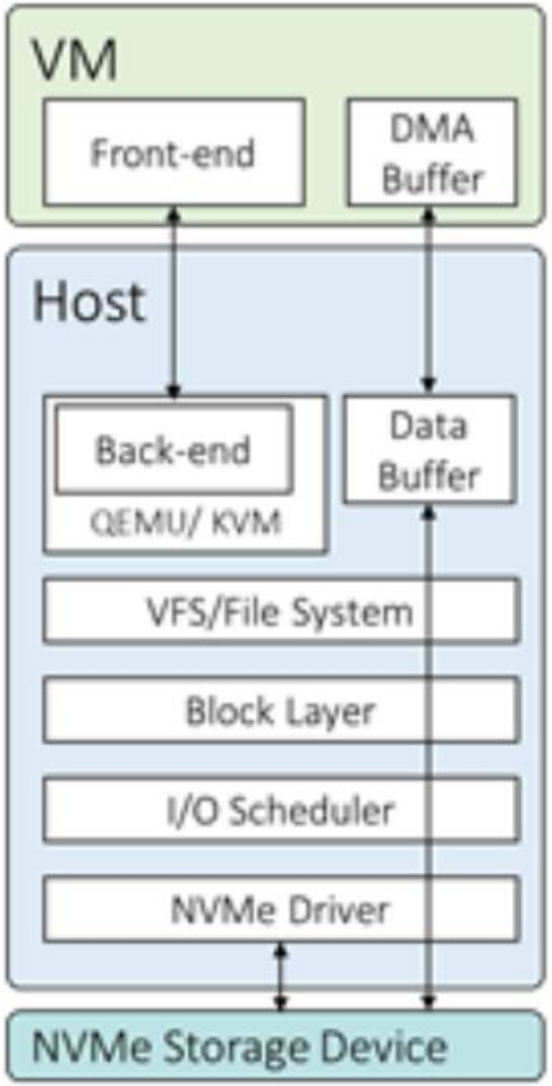
- Illusion of multiple virtual devices supported in HW
- Simplifies sharing for VMM
- Enables direct VM → device communication
- Drawbacks?
- MR-IOV?



Storage vritualization



SR-IOV



Common software approach

Modern HW is fast

Typical commodity desktop (Dell PowerEdge R520 ~$1000):

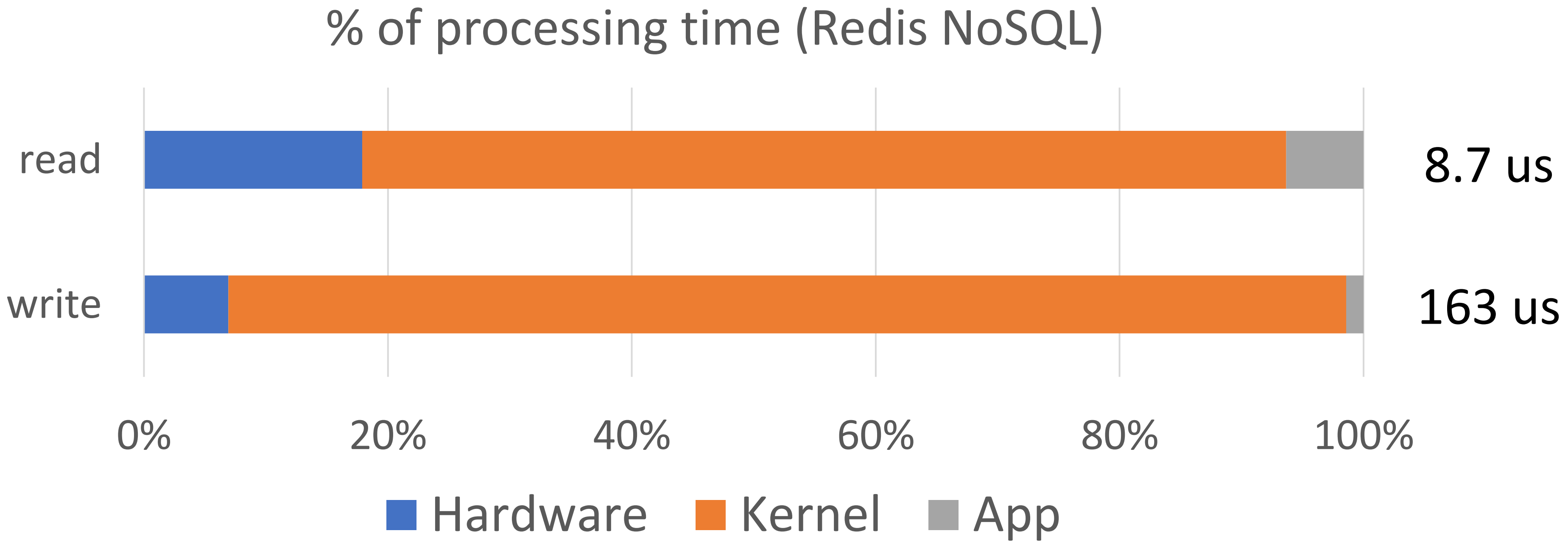
10G NIC
~2us / 1KB pkt

6-core CPU

RAID w/ 1G cache
~25 us / 1KB write

Background

- Balance between I/O and CPU speeds has shifted
- CPUs can't keep up!



Where are all the in-kernel cycles going?

	Read hit				Durable write			
	Linux		Arrakis/P		Linux		Arrakis/P	
`epoll`	2.42	(27.91%)	1.12	(27.52%)	2.64	(1.62%)	1.49	(4.73%)
`recv`	0.98	(11.30%)	0.29	(7.13%)	1.55	(0.95%)	0.66	(2.09%)
Parse input	0.85	(9.80%)	0.66	(16.22%)	2.34	(1.43%)	1.19	(3.78%)
Lookup/set key	0.10	(1.15%)	0.10	(2.46%)	1.03	(0.63%)	0.43	(1.36%)
Log marshaling	-		-		3.64	(2.23%)	2.43	(7.71%)
`write`	-		-		6.33	(3.88%)	0.10	(0.32%)
`fsync`	-		-		137.84	(84.49%)	24.26	(76.99%)
Prepare response	0.60	(6.92%)	0.64	(15.72%)	0.59	(0.36%)	0.10	(0.32%)
`send`	3.17	(36.56%)	0.71	(17.44%)	5.06	(3.10%)	0.33	(1.05%)
Other	0.55	(6.34%)	0.46	(11.30%)	2.12	(1.30%)	0.52	(1.65%)
Total	8.67	($\sigma = 2.55$)	4.07	($\sigma = 0.44$)	163.14	($\sigma = 13.68$)	31.51	($\sigma = 1.91$)
99th percentile	15.21		4.25		188.67		35.76	

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System Calls are slow:

- epoll : 27% time of read
- recv : 11% time of read
- send : 37% time of read
- fsync : 84% time of write

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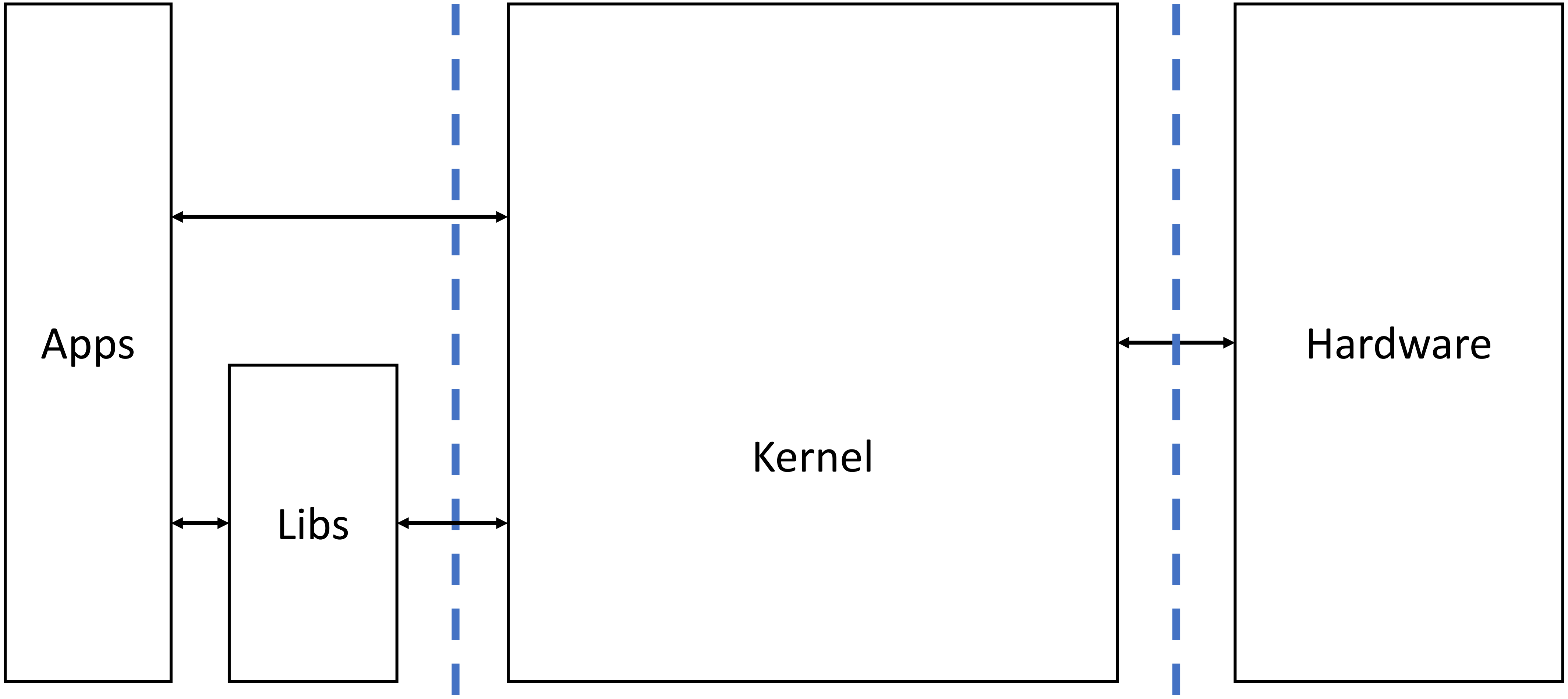
Arrakis→I/O centric design

- *Bypass* kernel
- Abstractions: user-space device access
- SR-IOV higher in stack
  - Leverage packet filter/load-balance/scheduling support

Traditional OS



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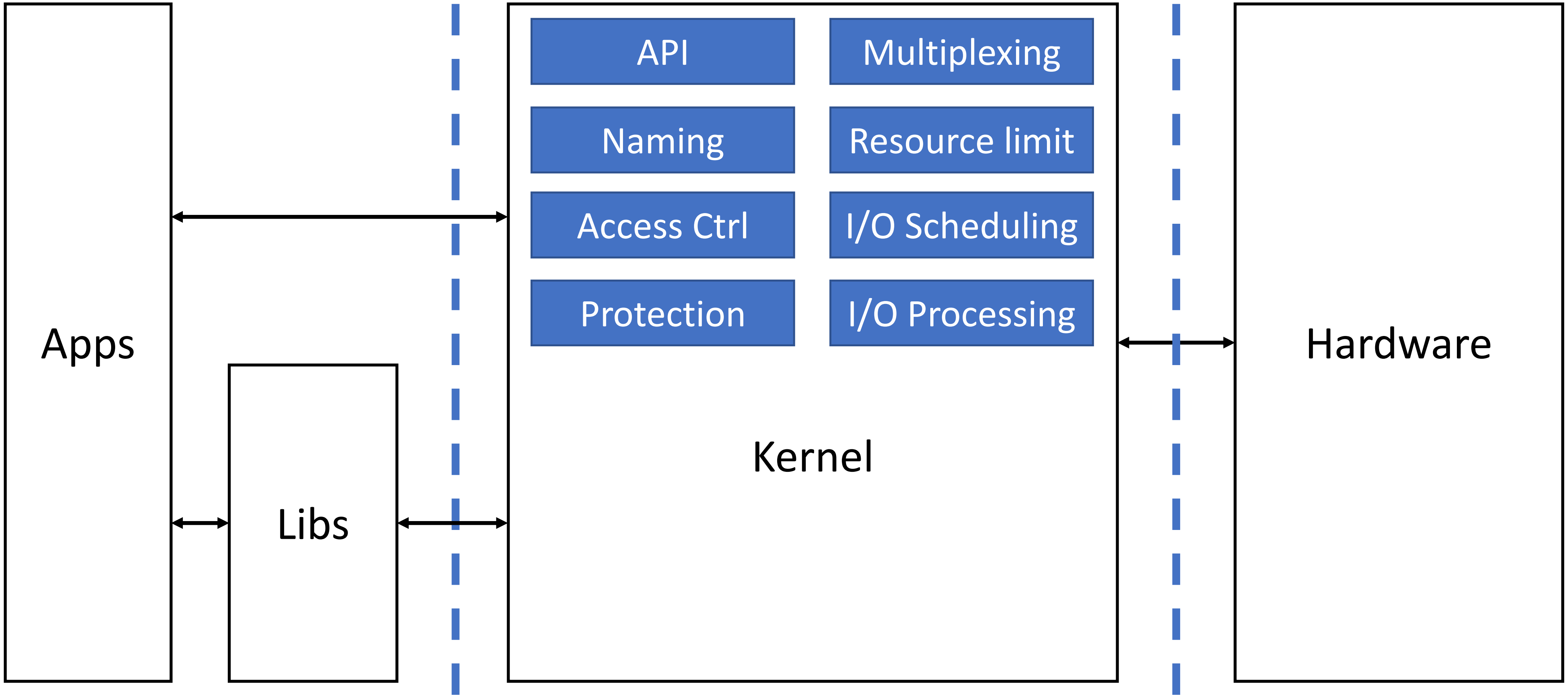
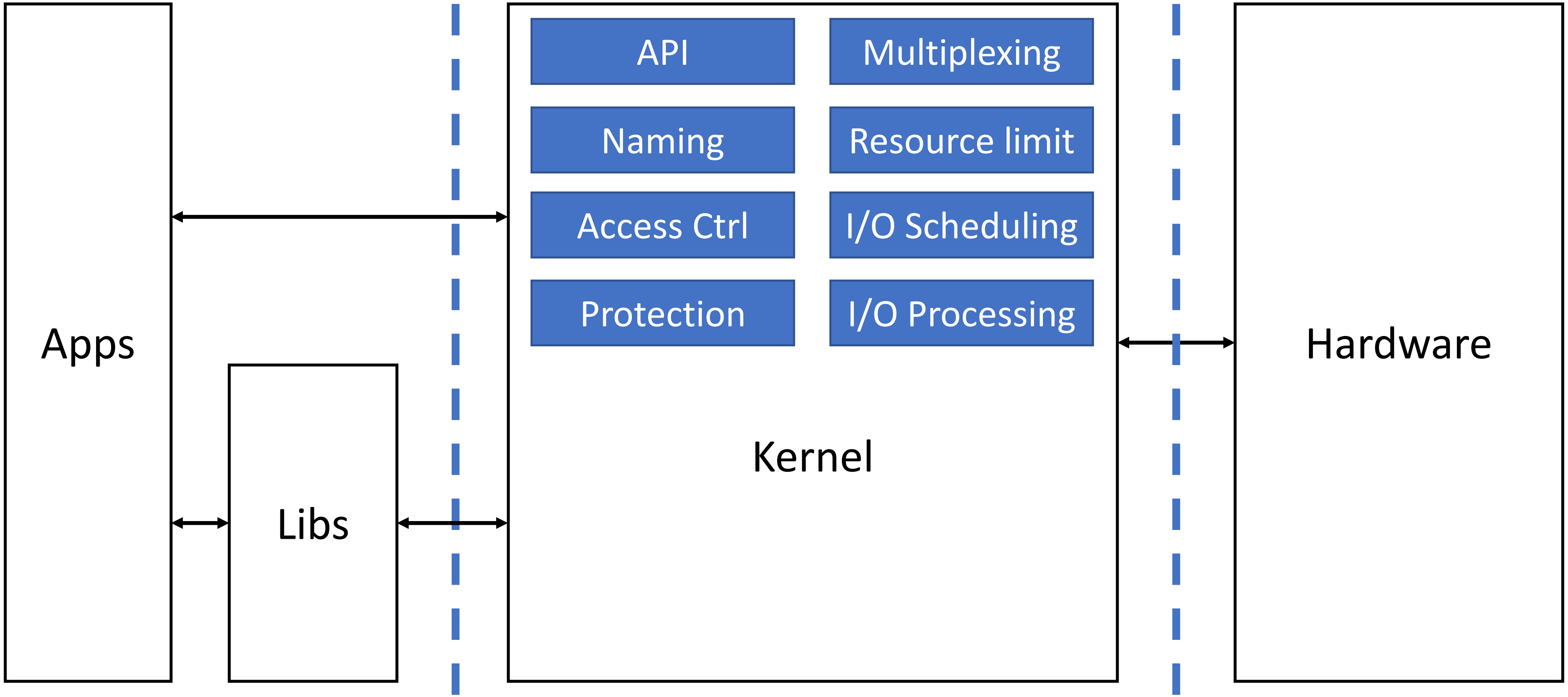


Kernel bypass



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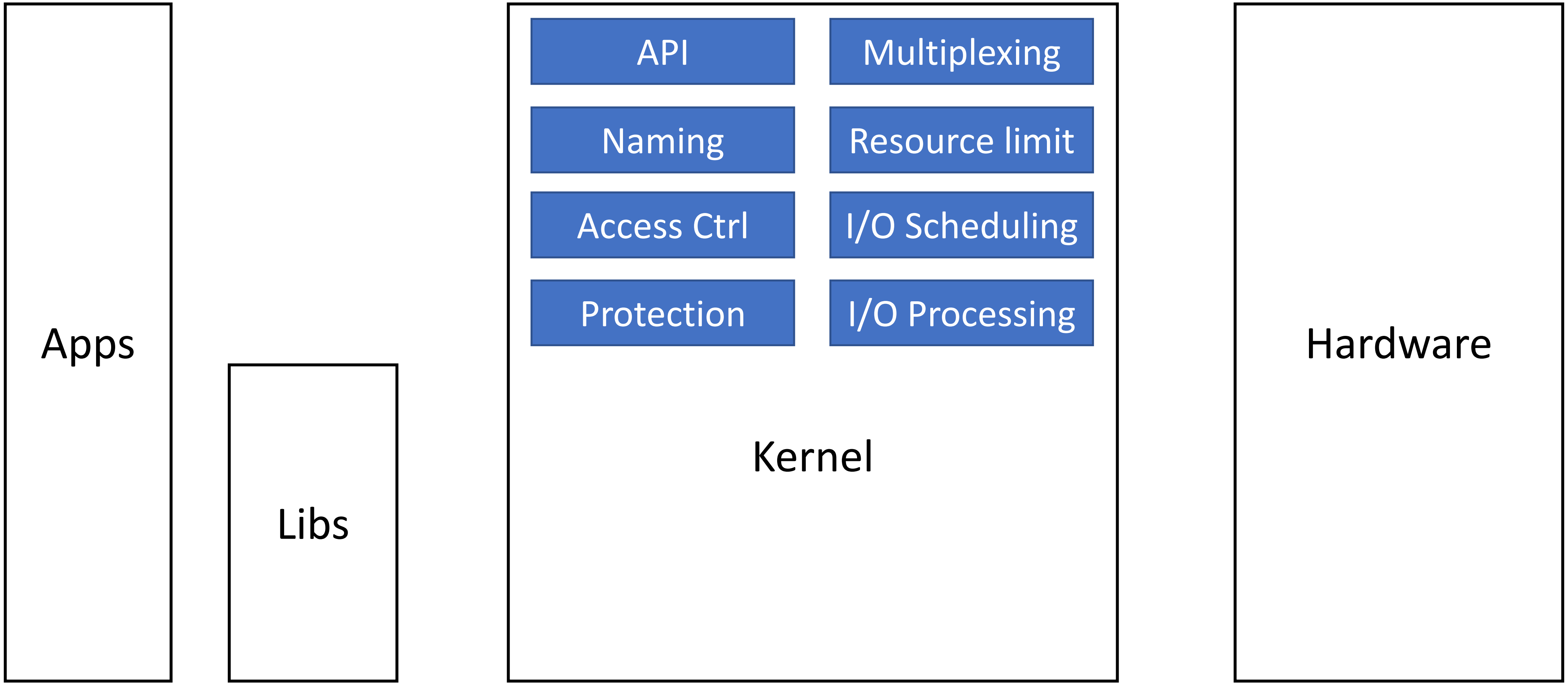

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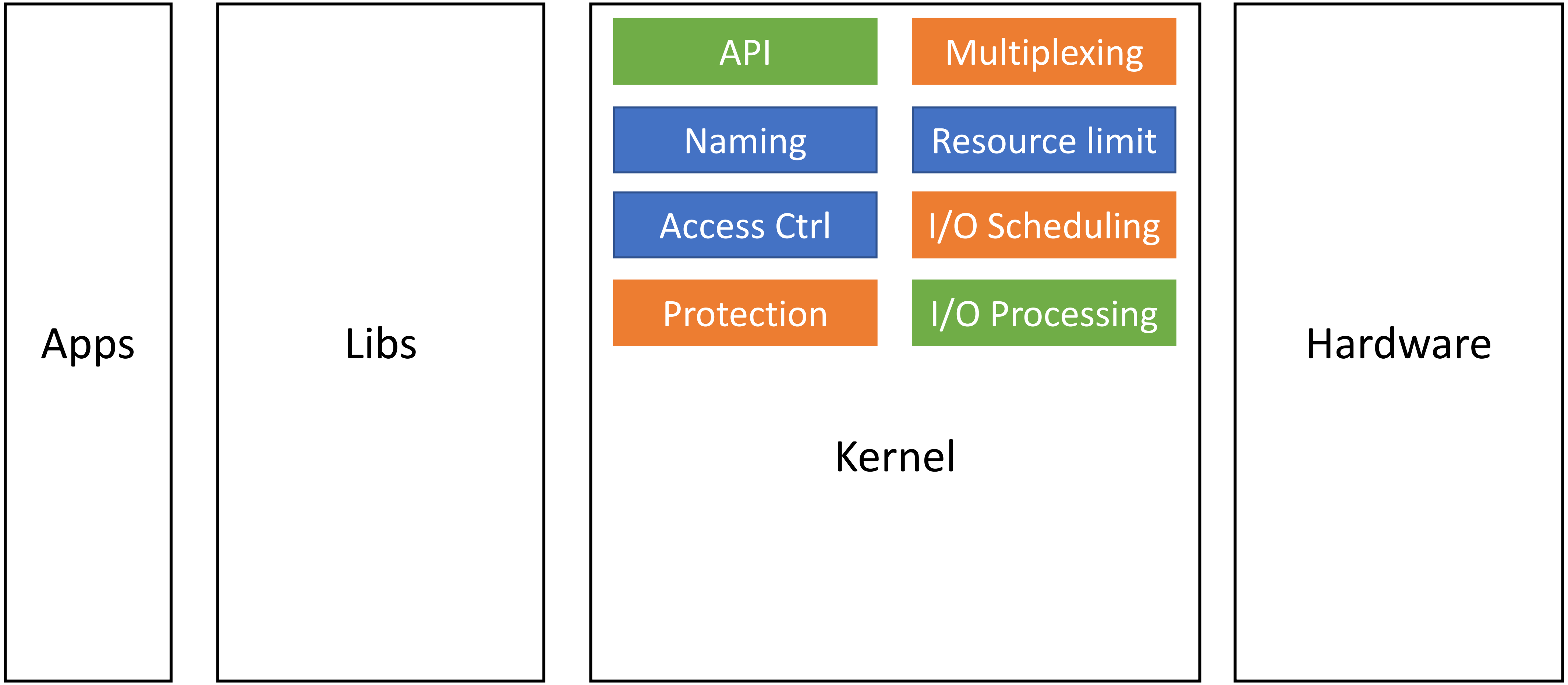
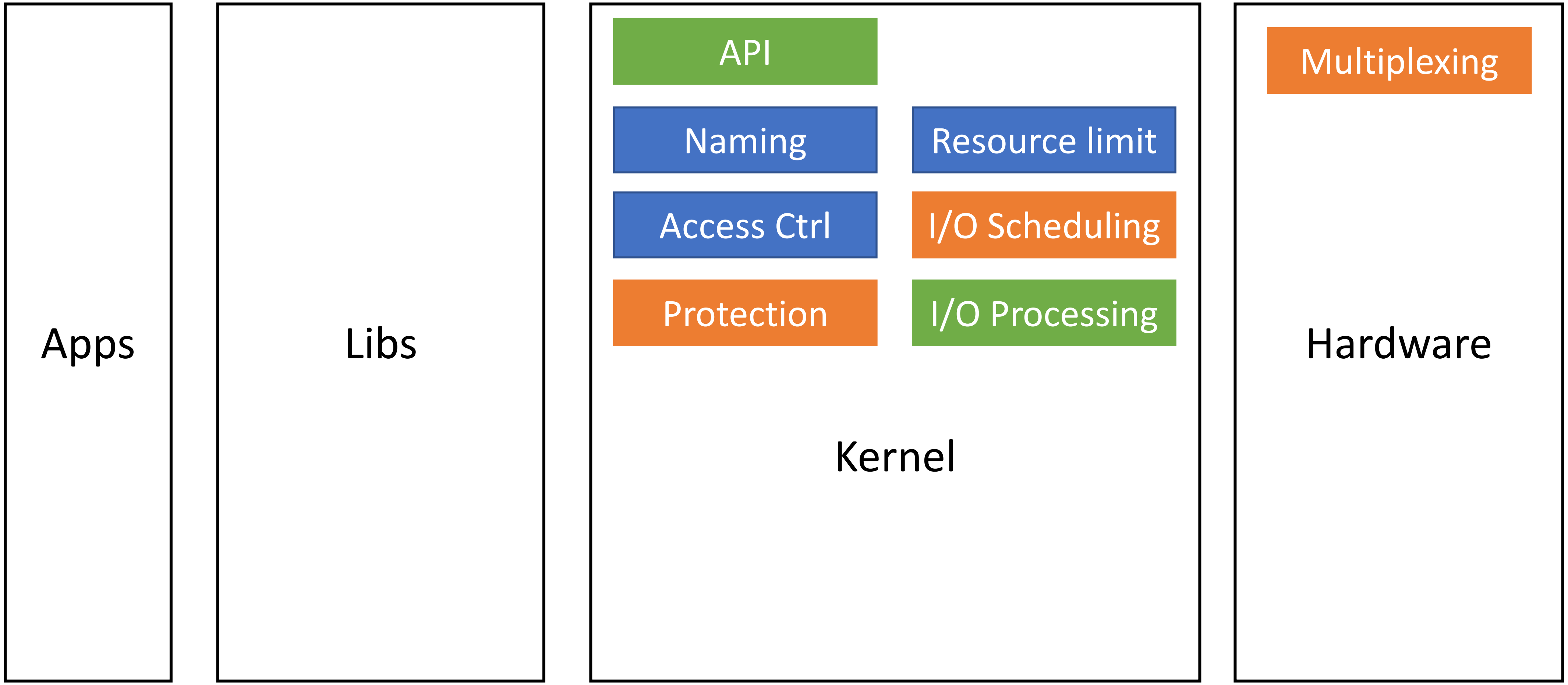
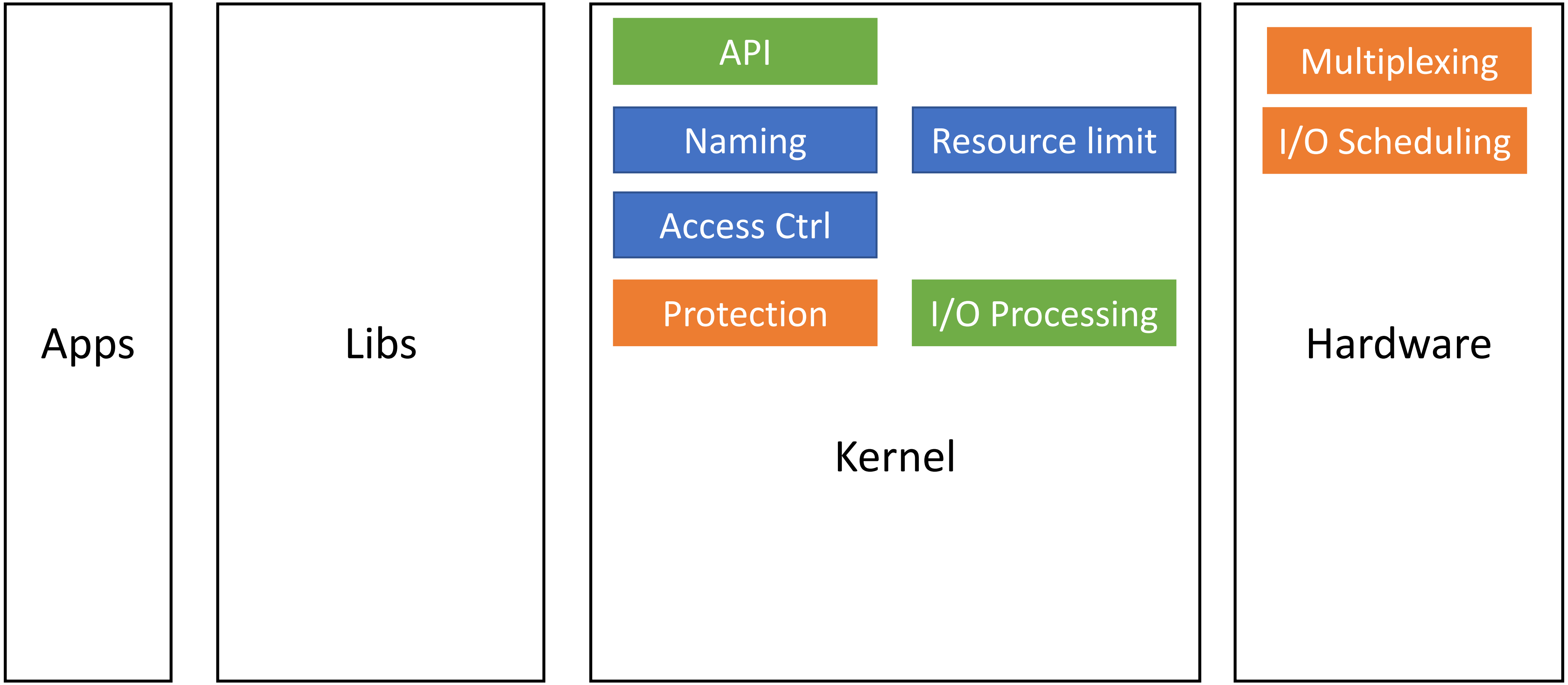


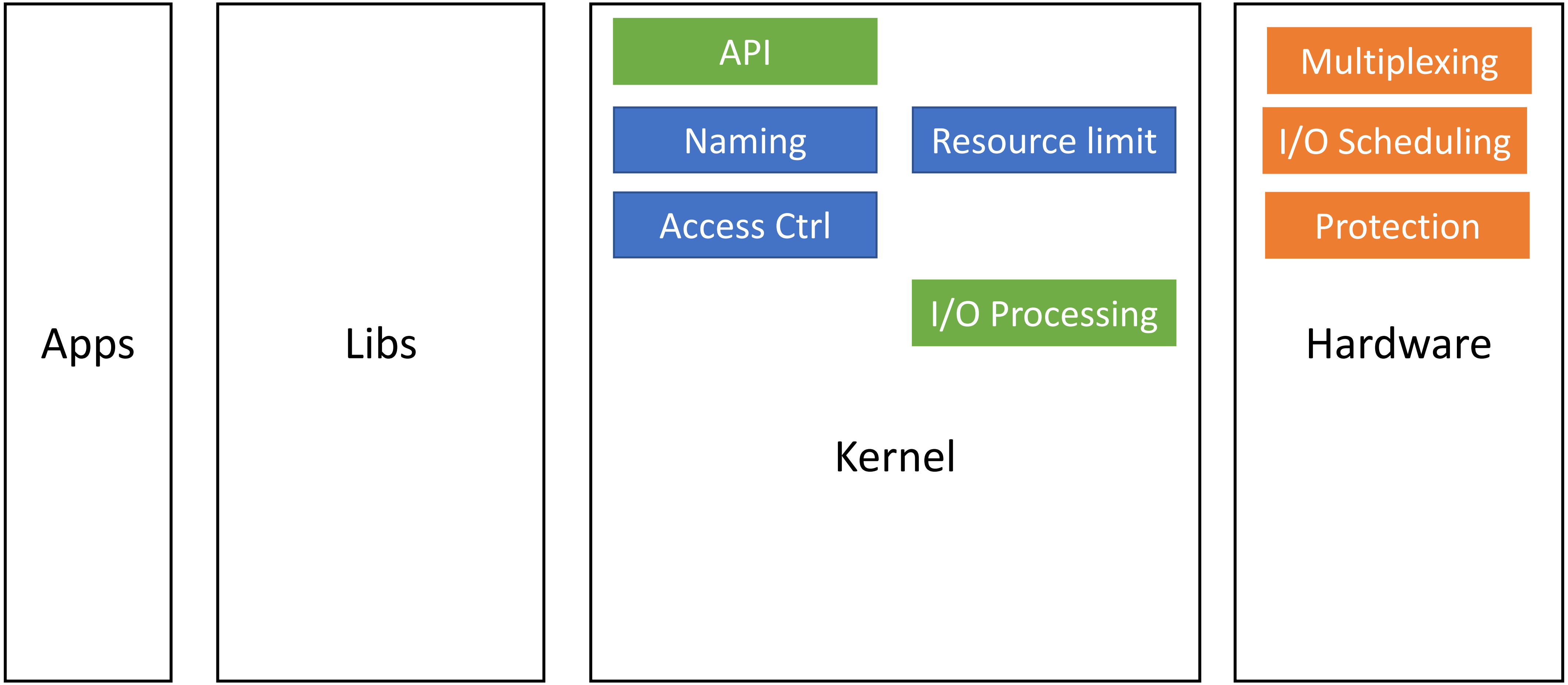
Kernel bypass



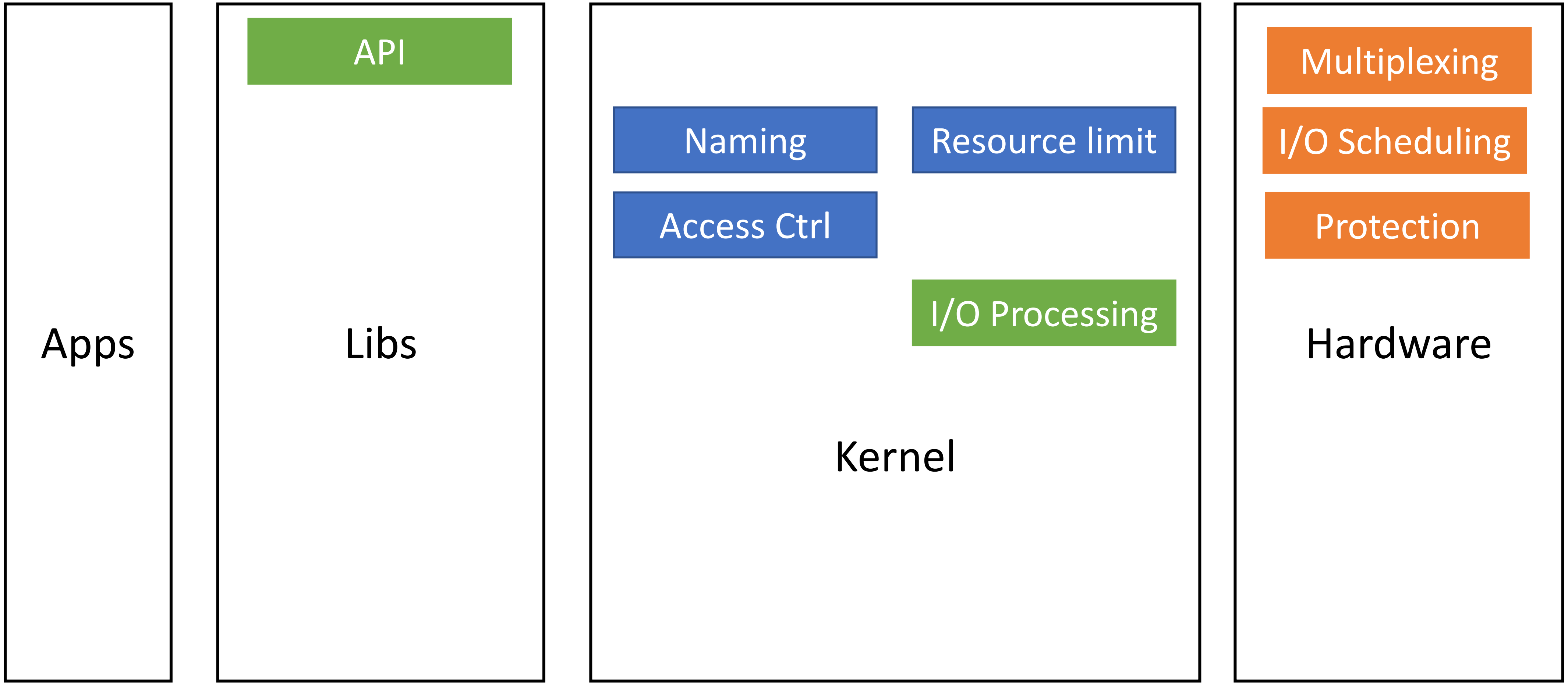
Kernel bypass



Kernel bypass



Kernel bypass



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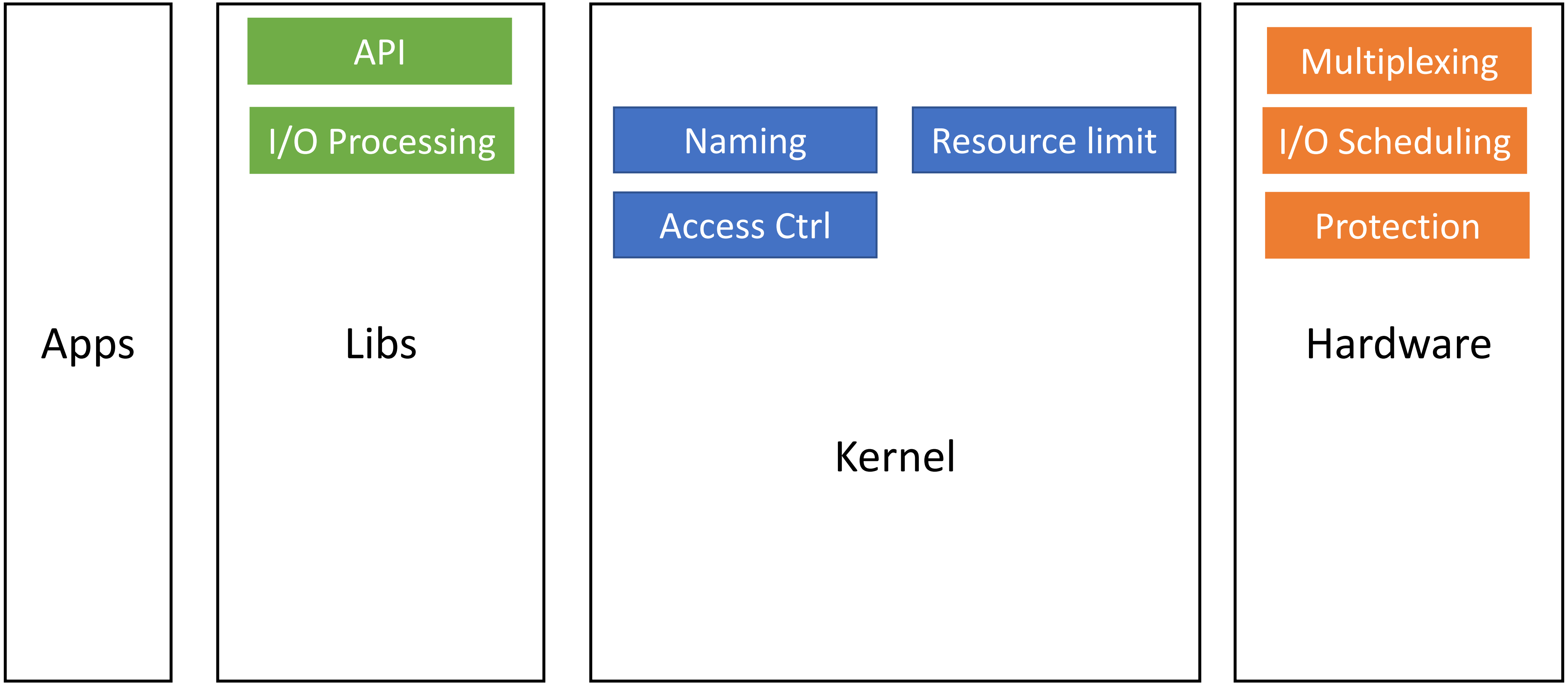
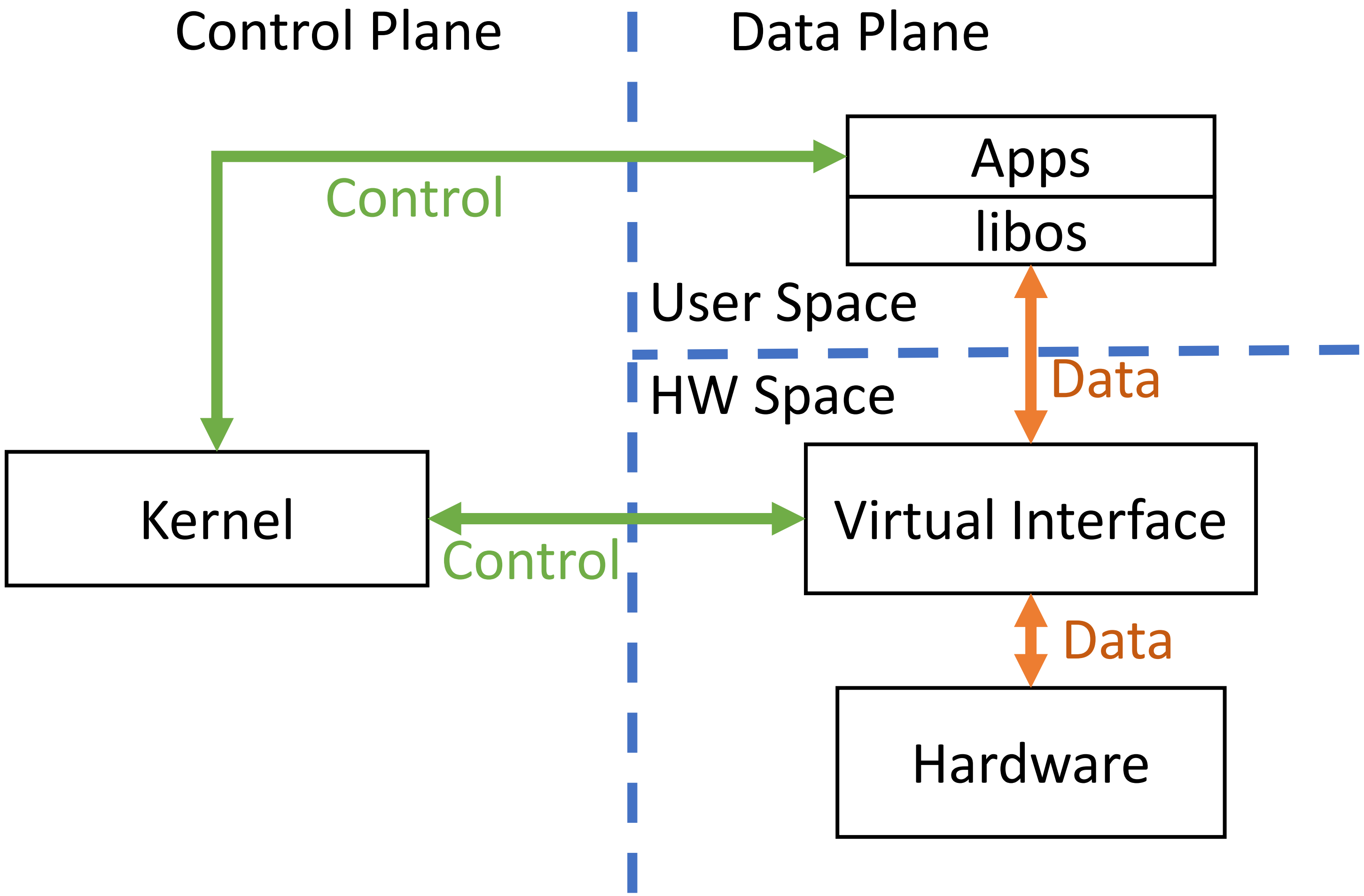


Kernel bypass. The OS is the control plane.



Hardware Model

- NICs (Multiplexing, Protection, Scheduling)

- Storage
  - VSIC (Virtual Storage Interface Controller)
    - each w/ queues etc.
  - VSA (Virtual Storage Areas)
    - mapped to physical devices
    - associated with VSICs
    - VSA & VSIC : many-to-many mapping

Control Plane Interface

- VIC (Virtual Interface Card)
  - Apps can create/delete VICs, associate them to doorbells
- doorbells (like interrupt?)
  - associated with events on VICs
- filter creation
  - e.g. create_filter(rx,*,tcp.port == 80)

Control Plane Features

- Access control
  - enforced by filters
  - infrequently invoked (during set-up etc.)
  - Can export an entire VSA
- Resource limiting
  - send commands to hardware I/O schedulers
- Naming
  - VFS in kernel
  - actual storage implemented in apps
  - "By default, the Arrakis application library managing the VSA exports a file server interface; other applications can use normal POSIX API calls via user-level RPC to the embedded library file server. This library can also run as a standalone process to provide access when the original application is not active" What does this sound like?

Network Data Interface

- Apps send/receive directly through sets of queues
- filters applied for multiplexing
- doorbell used for asynchronous notification (e.g. packet arrival)
- both native (w/ zero-copy) and POSIX are implemented

Storage Data Interface

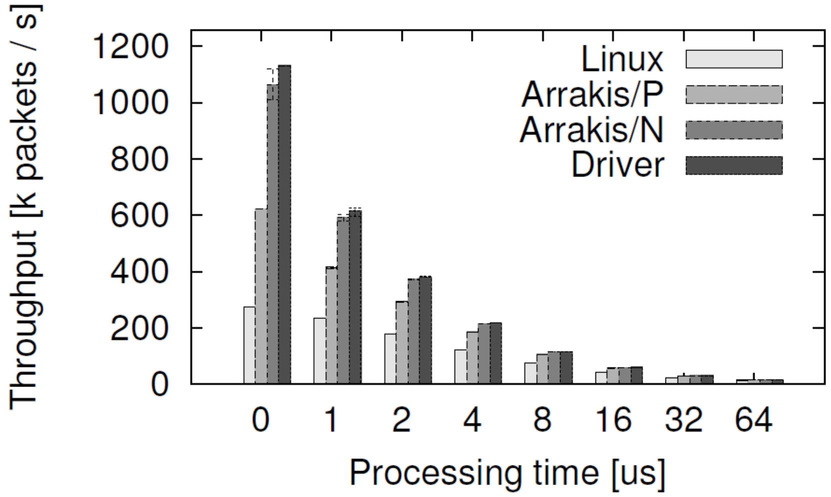
- VSA supports `read`, `write`, `flush`

- persistent data structure (log, queue)
  - modified Redis by 109 LOC
  - operations immediately persistent on disk
  - eliminate marshaling (layout in memory = in disk)
  - data structure specific caching & early allocation

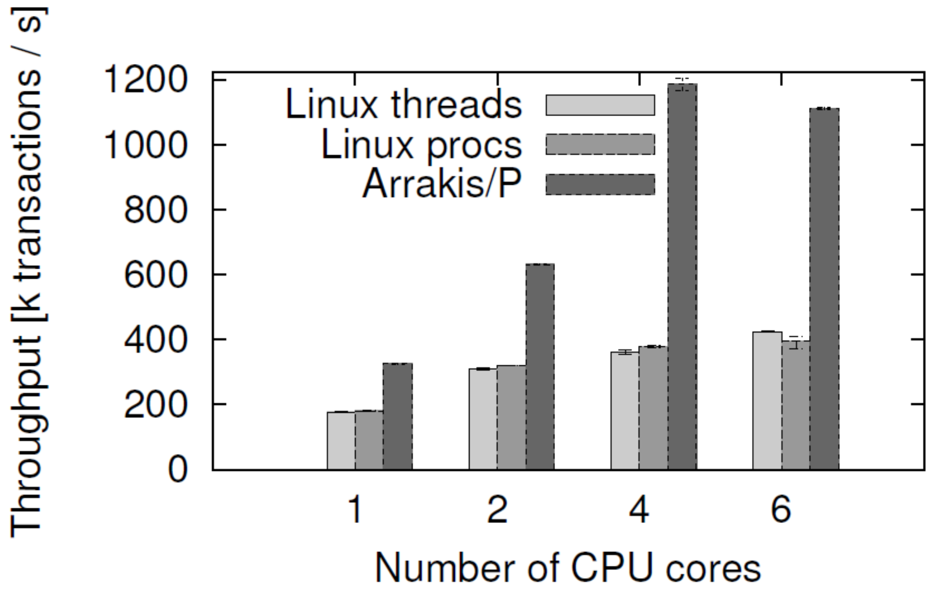
Evaluation

1. UDP echo server
2. Memcached key-value store
3. Redis NoSQL store
4. HTTP load balancer (haproxy)
5. IP-layer middle box
6. Performance isolation (rate limiting)

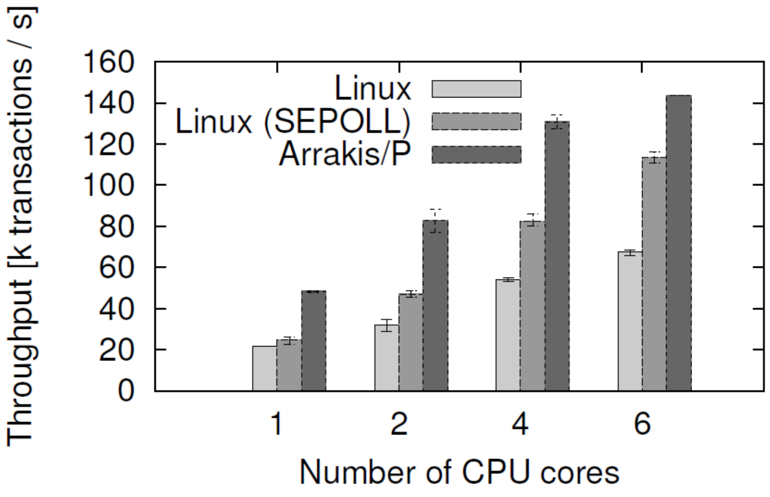
Performance



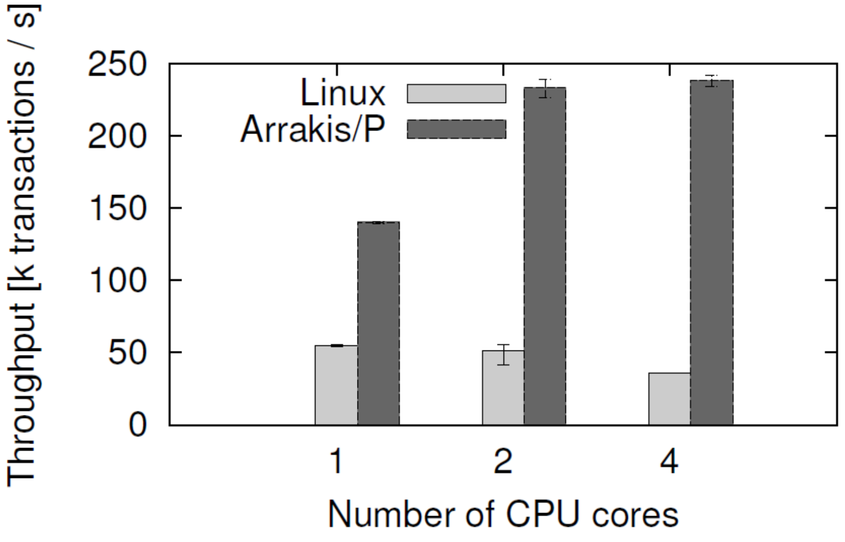
UDP Echo



memcached

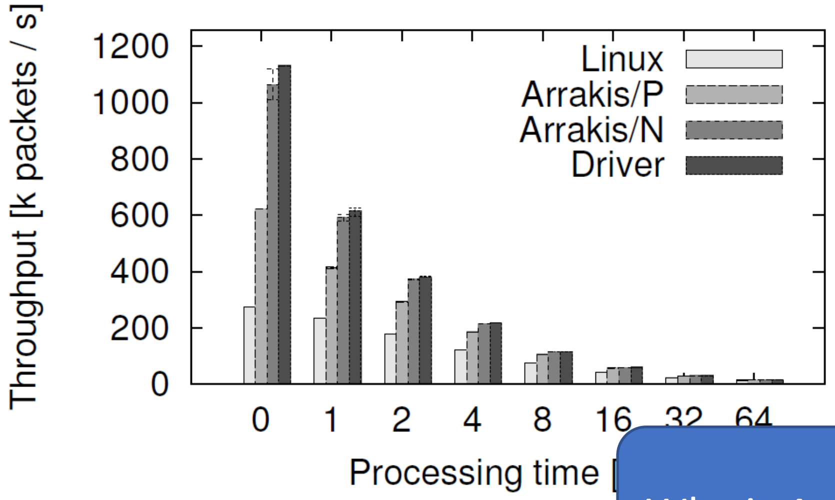


Load balancer

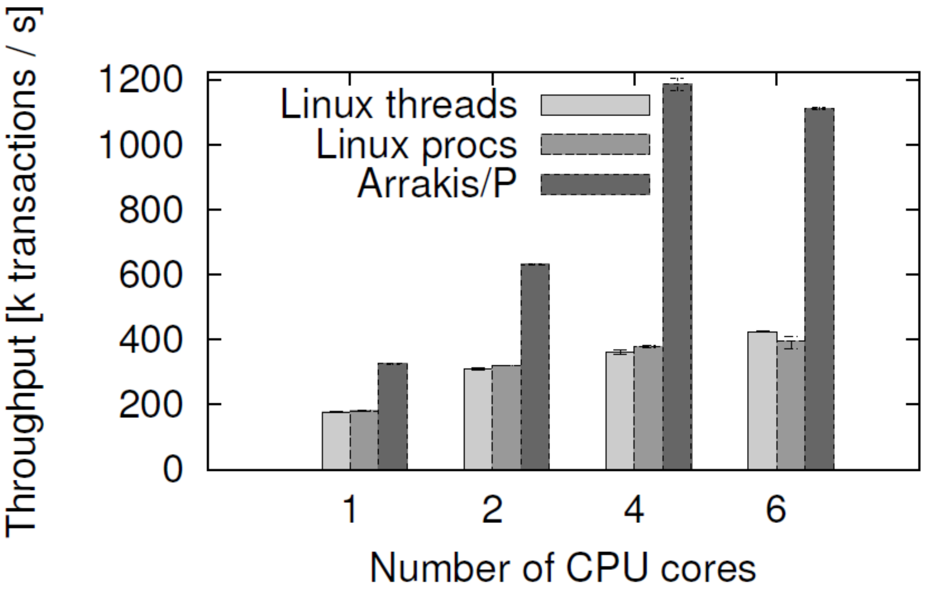


IP middlebox

Performance

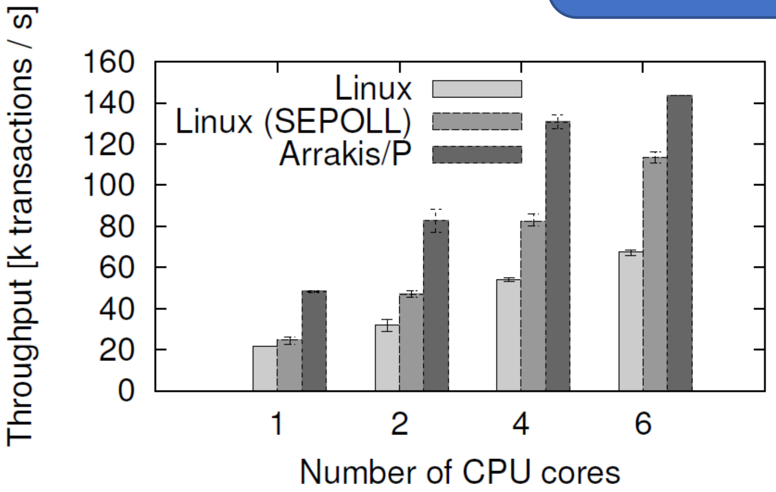


UDP Echo



memcached

Why is Arrakis/N faster than Arrakis/P?



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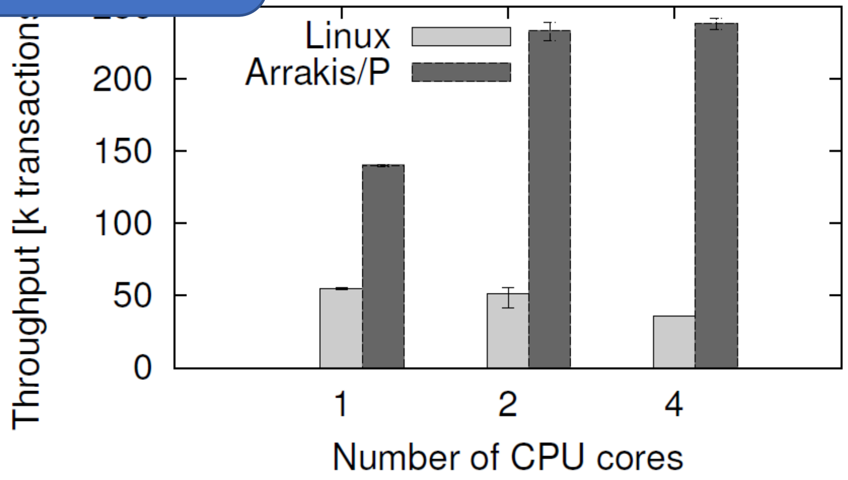
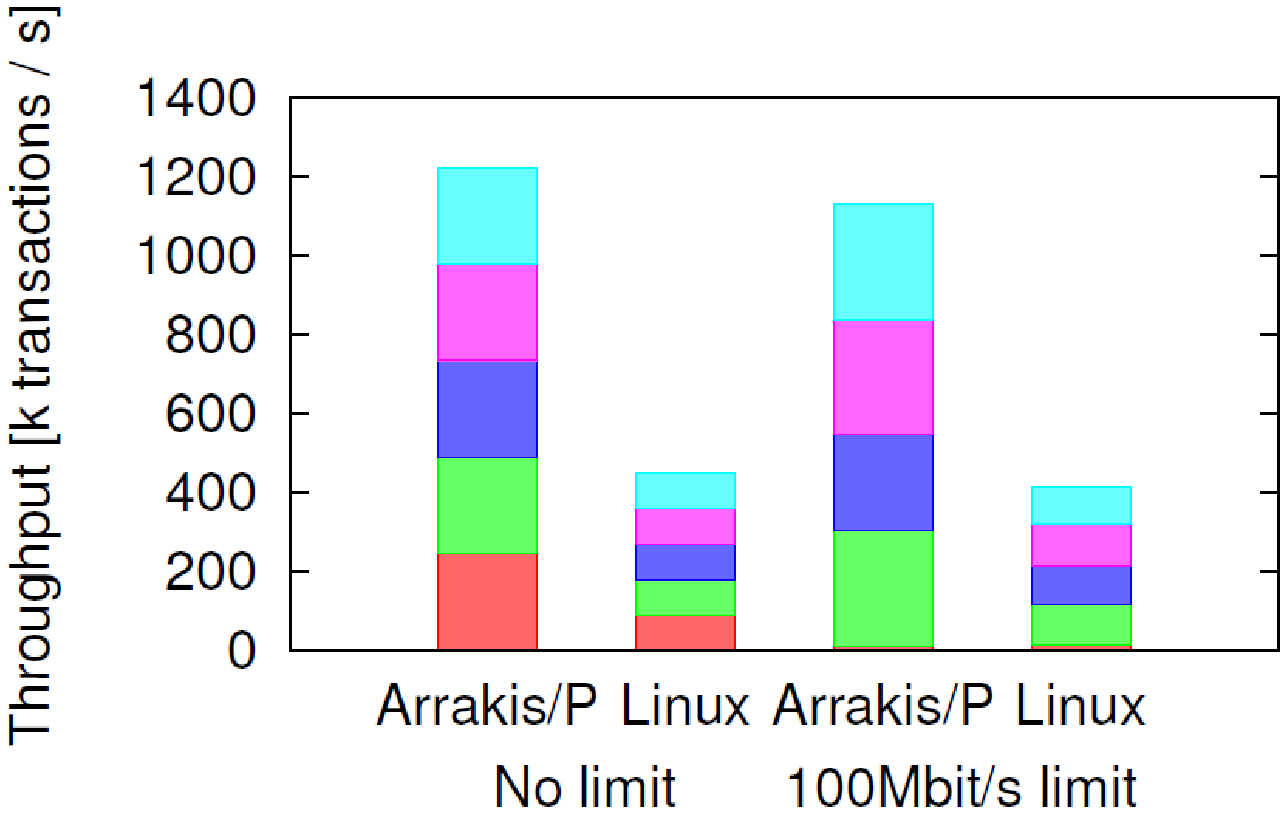
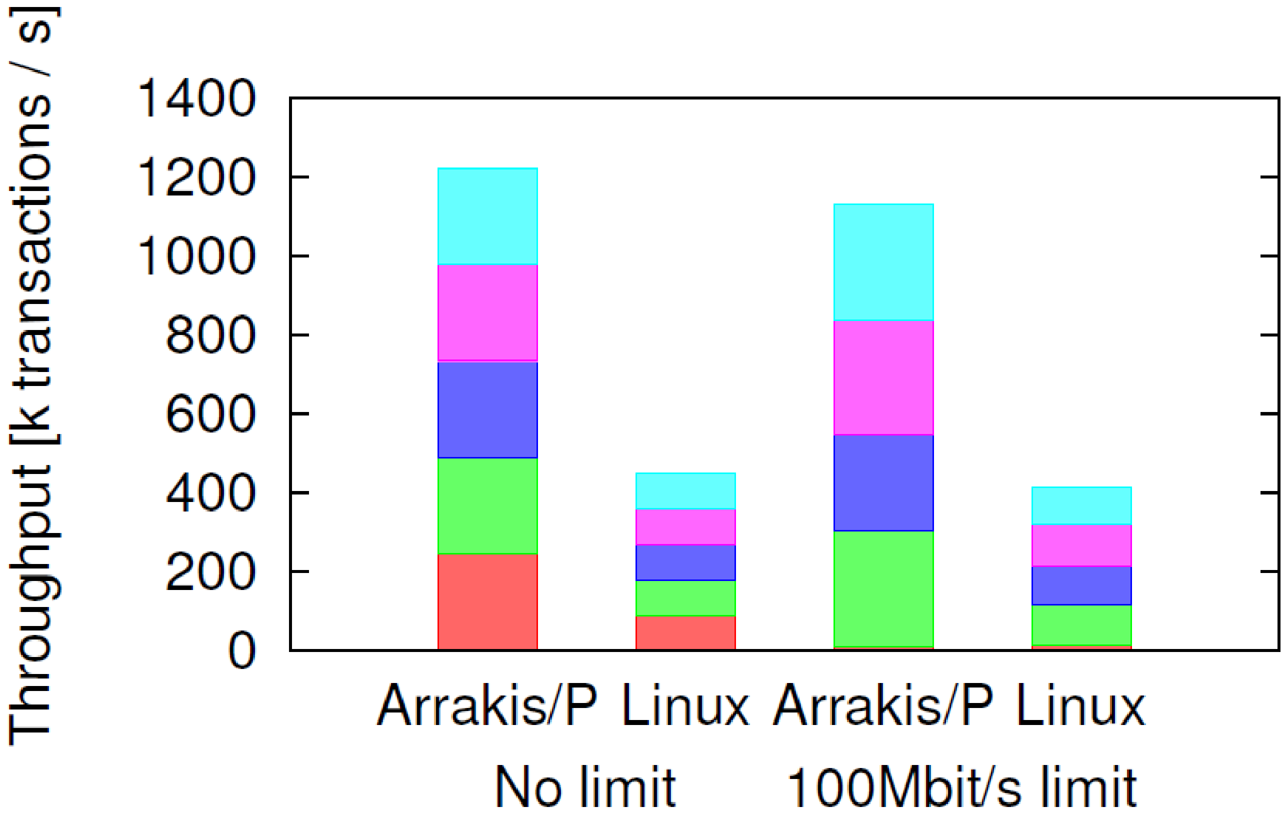


IP middlebox

Case 6: Performance Isolation



Case 6: Performance Isolation



What mechanism(s) enable(s) Arrakis to achieve proportionality?

Discussion

- Pros:
  - much better **raw** performance (for I/O intensive Data Center apps)
    - Redis: up to 9x throughput and 81% speedup
    - Memcached: scales to 3x throughput
- Cons:
  - some features require hardware functionality that is not yet available
    - will other device classes follow suit?
  - requires modification of applications
  - not clear about storage abstractions
  - not easy to track behaviors inside the hardware
- Is Arrakis trading “OS features” for raw performance?

IX, Arrakis, Exokernel, Multikernel

- Arrakis is like Exokernel built on Barrelfish (multikernel)

	IX	Arrakis
Reduce SysCall overhead	Adaptive batching Run to completion	No SysCall in data-plane
Hardware virtualization	No IOMMU No SR-IOV	Expect more than what we have
Enforcement of network I/O policy	Under software control	Rely on hardware