Arrakis:
The Operating System is the Control Plane

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Building an OS for the Data Center

- Server I/O performance matters
  - Key-value stores, web & file servers, lock managers, …
- **Can we deliver performance close to hardware?**

- Example system: Dell PowerEdge R520

Intel X520
10G NIC
2 us / 1KB packet

+

Intel RS3 RAID
1GB flash-backed cache
25 us / 1KB write

+

Sandy Bridge CPU
6 cores, 2.2 GHz

= **$1,200**

Building an OS for the Data Center

- Server I/O performance matters
  - Key-value stores, web & file servers, lock managers, …
- **Can we [illegible]re?**
- Example:

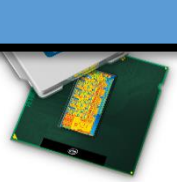
Today's I/O devices are fast

Intel X520
10G NIC
2 us / 1KB packet

+

Intel RS3 RAID
1GB flash-backed cache
25 us / 1KB write

+

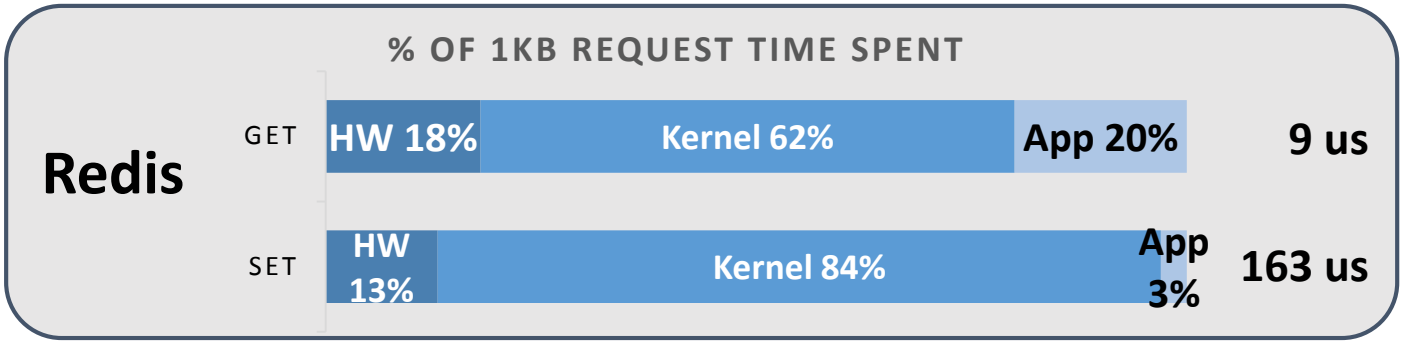


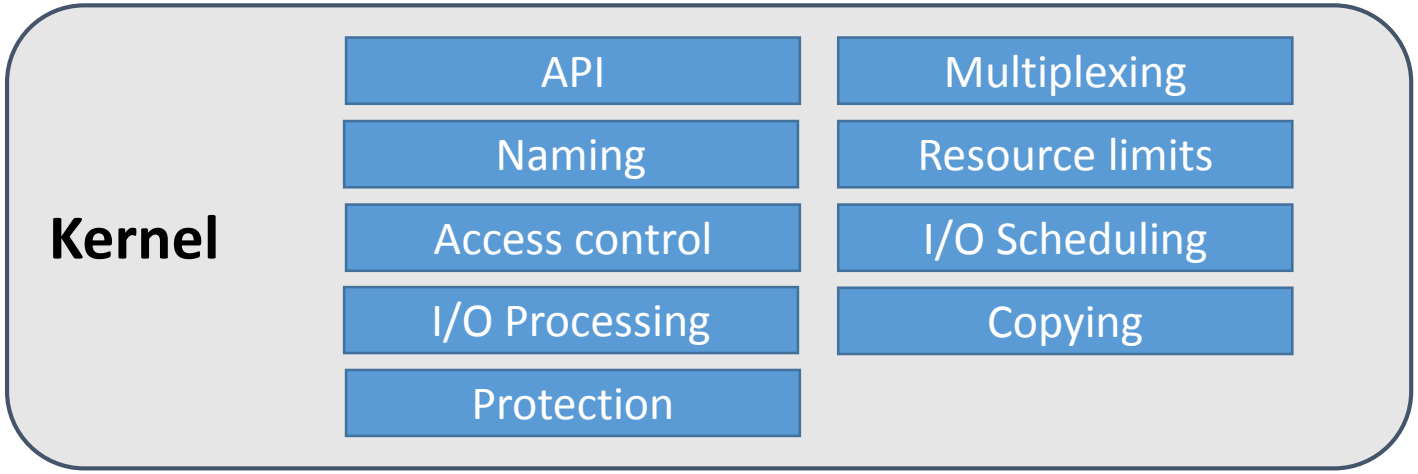
Sandy Bridge CPU
6 cores, 2.2 GHz

= **$1,200**

Can’t we just use Linux?

Linux I/O Performance





Data Path

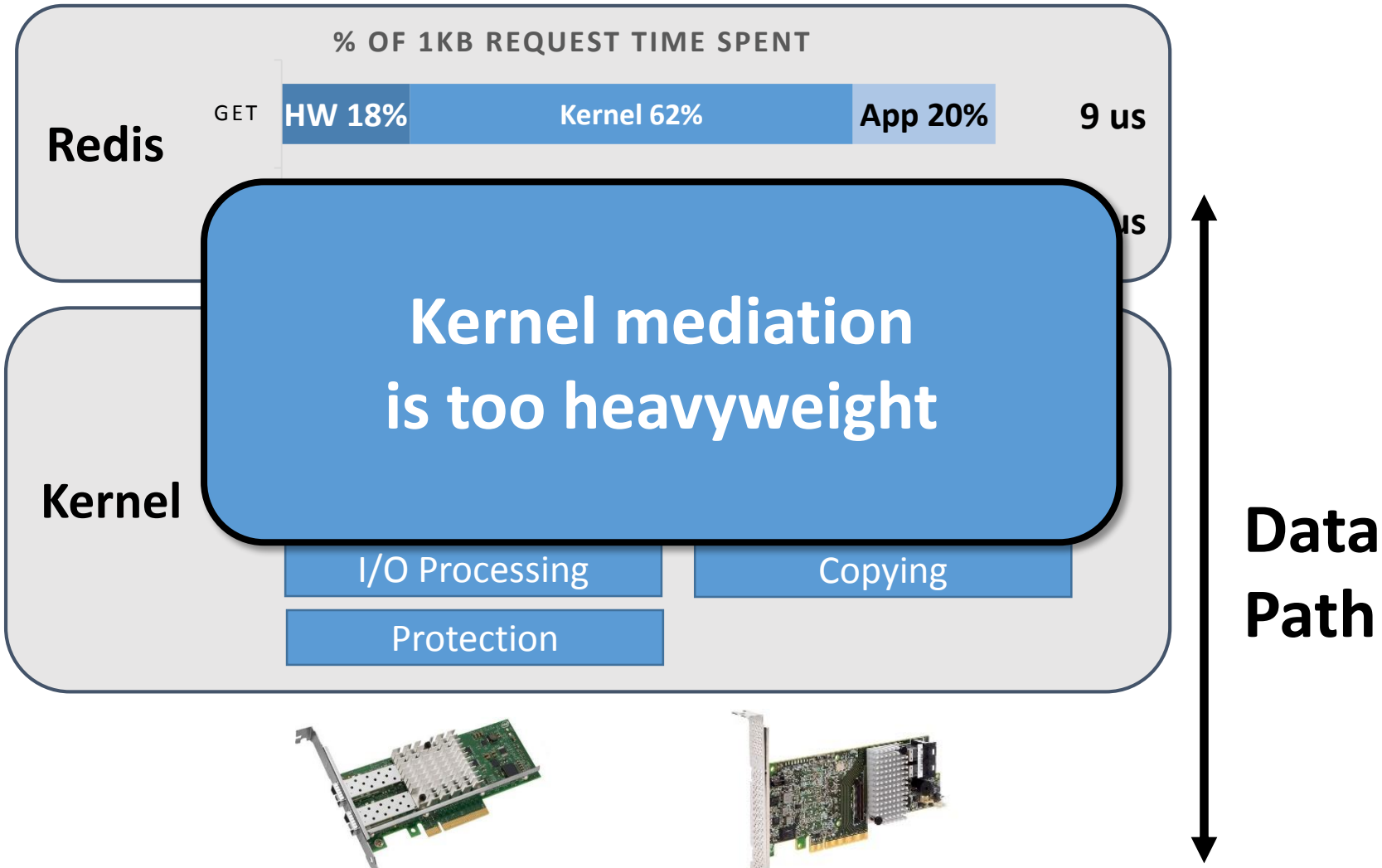
10G NIC

2 us / 1KB packet

RAID Storage

25 us / 1KB write

Linux I/O Performance

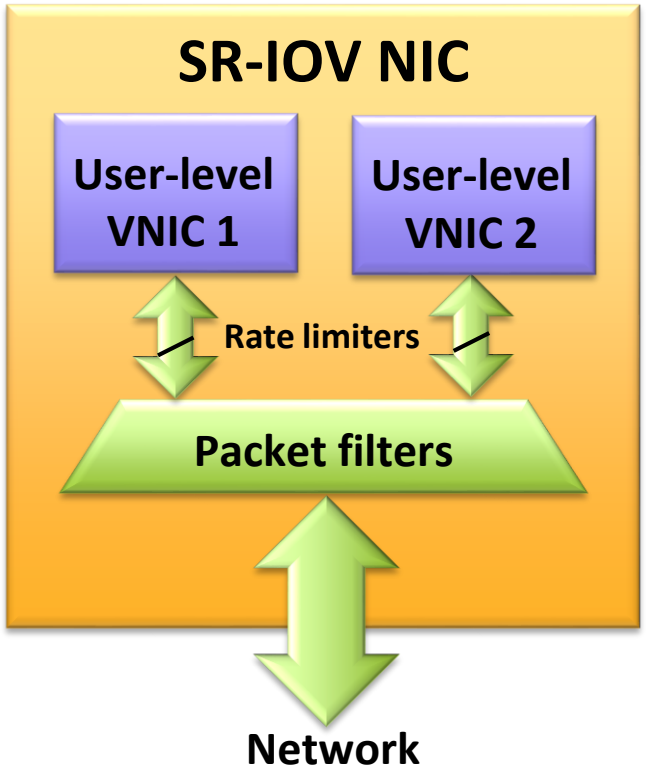


Arrakis Goals

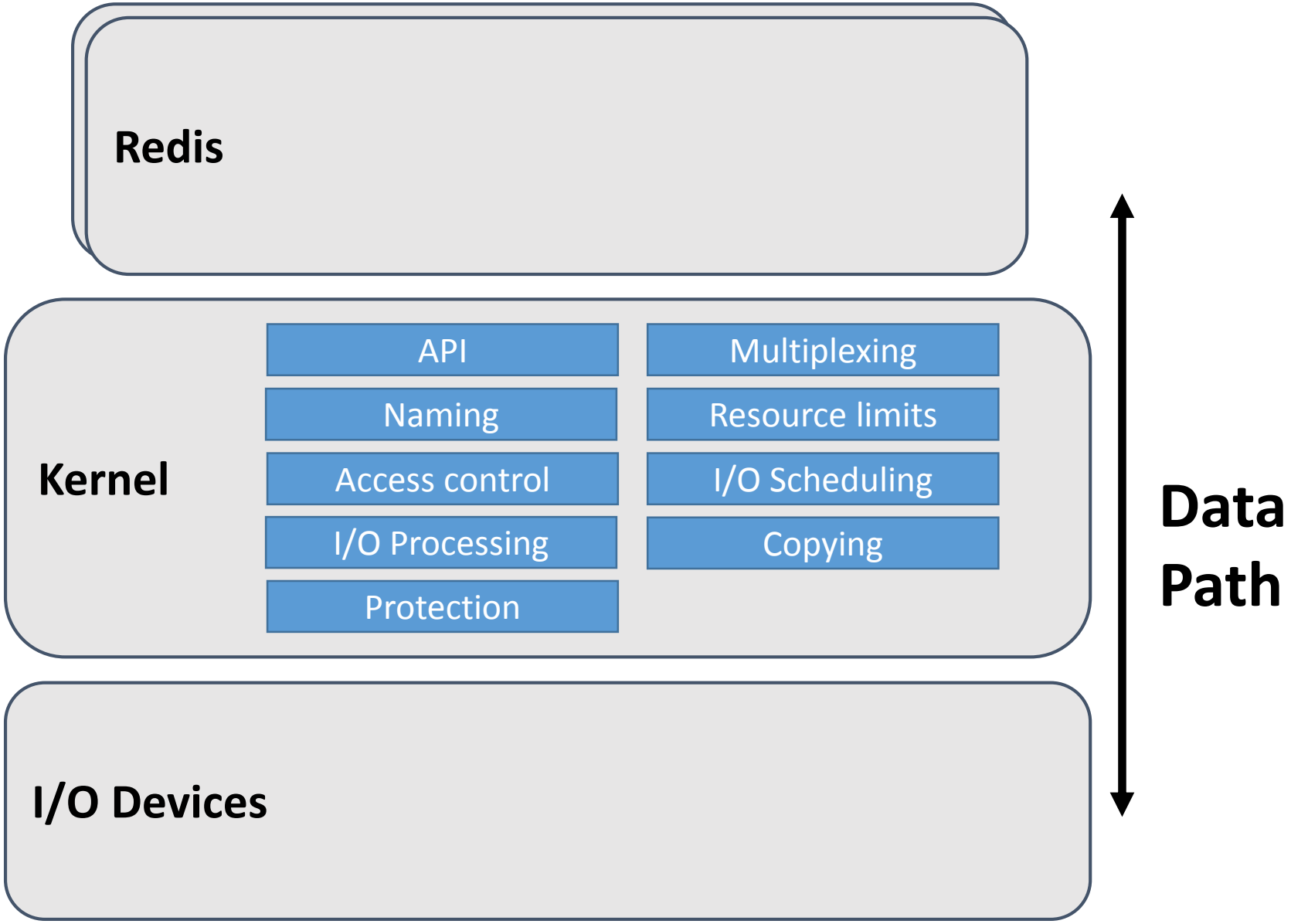
- Skip kernel & deliver I/O directly to applications
  - Reduce OS overhead
- Keep classical server OS features
  - Process protection
  - Resource limits
  - I/O protocol flexibility
  - Global naming
- The hardware can help us…

Hardware I/O Virtualization

- Standard on NIC, emerging on RAID
- Multiplexing
  - **SR-IOV**: Virtual PCI devices w/ own registers, queues, INTs
- Protection
  - **IOMMU**: Devices use app virtual memory
  - **Packet filters**, **logical disks**: Only allow eligible I/O
- I/O Scheduling
  - NIC **rate limiter**, **packet schedulers**



How to skip the kernel?



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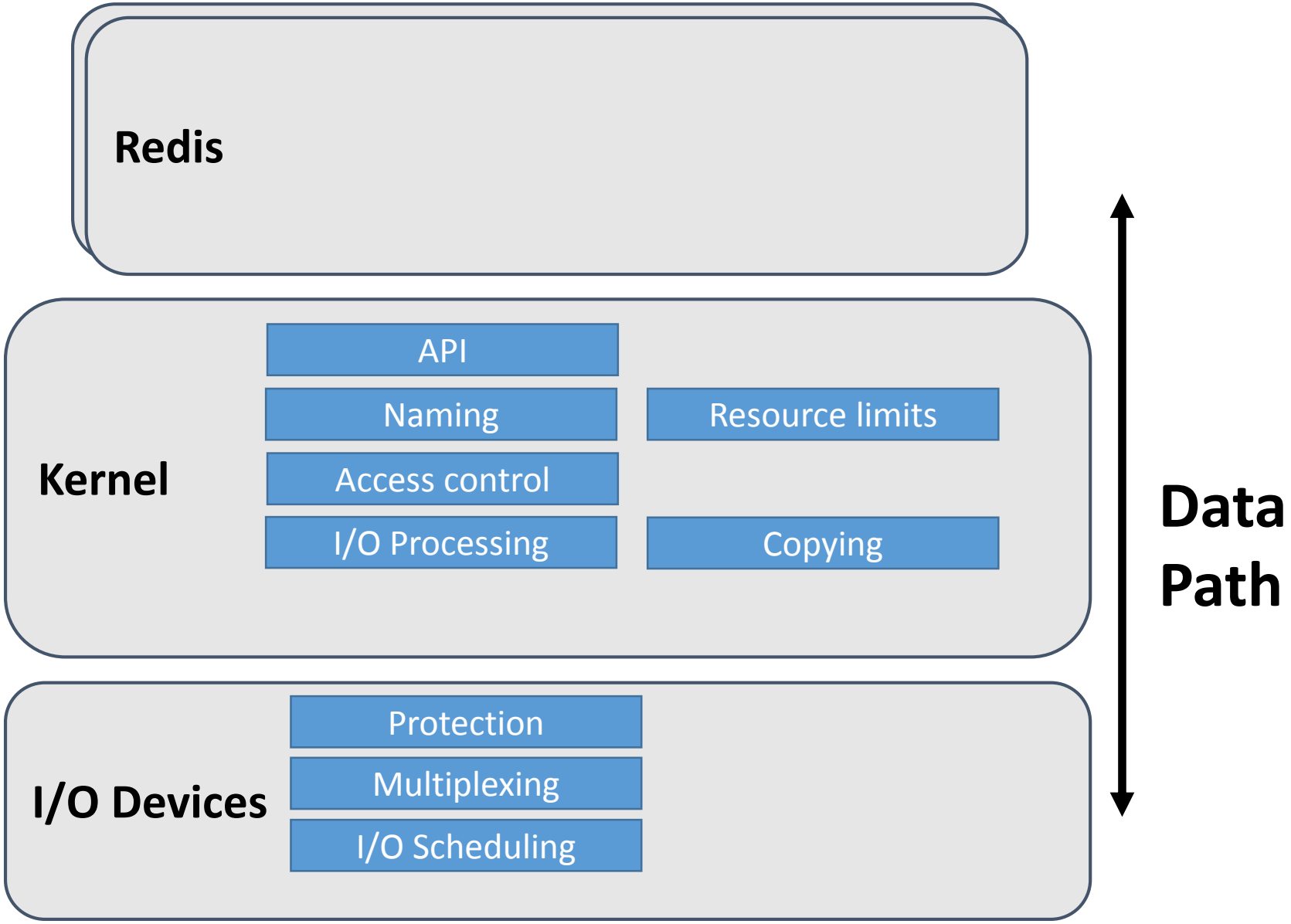

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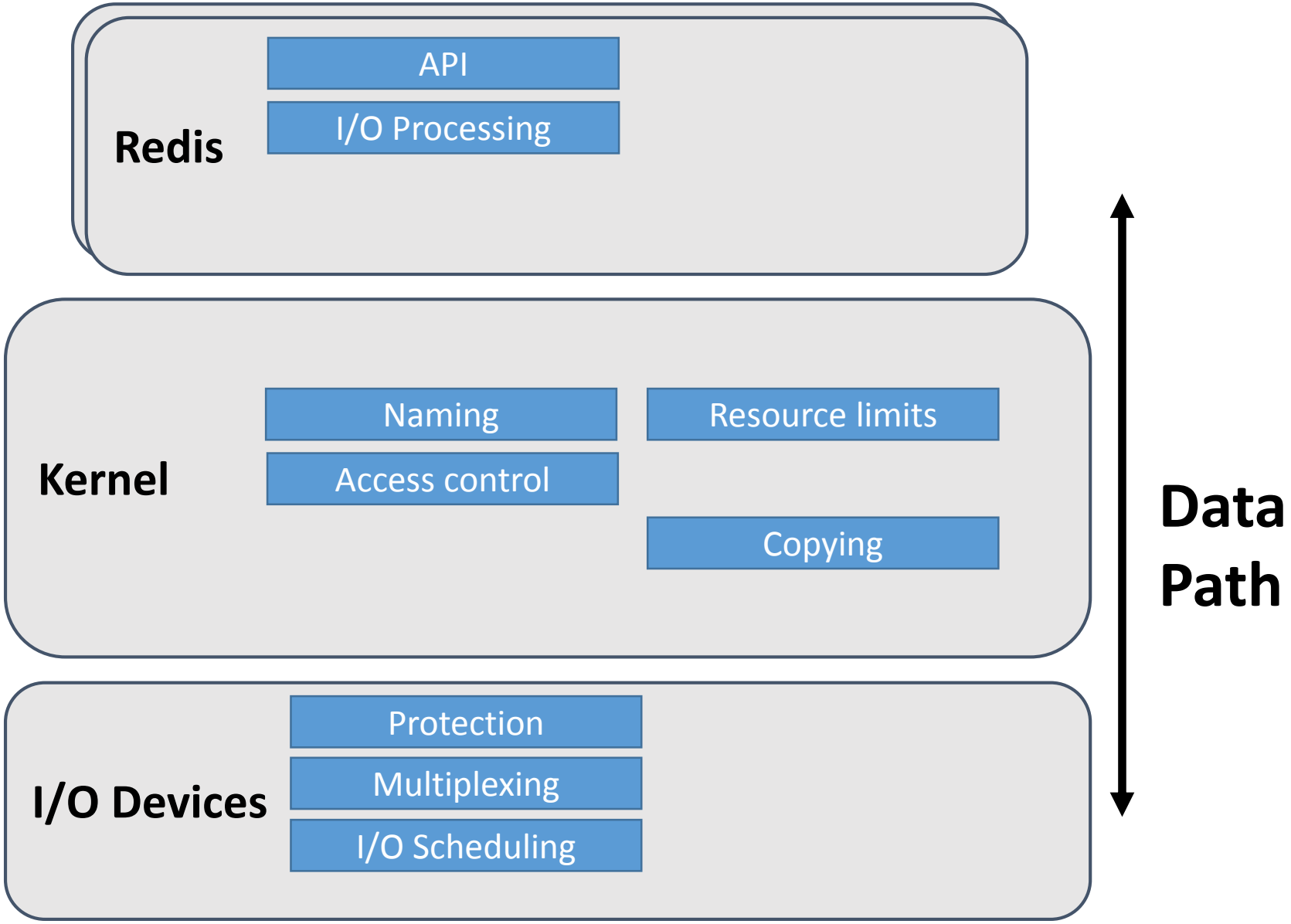

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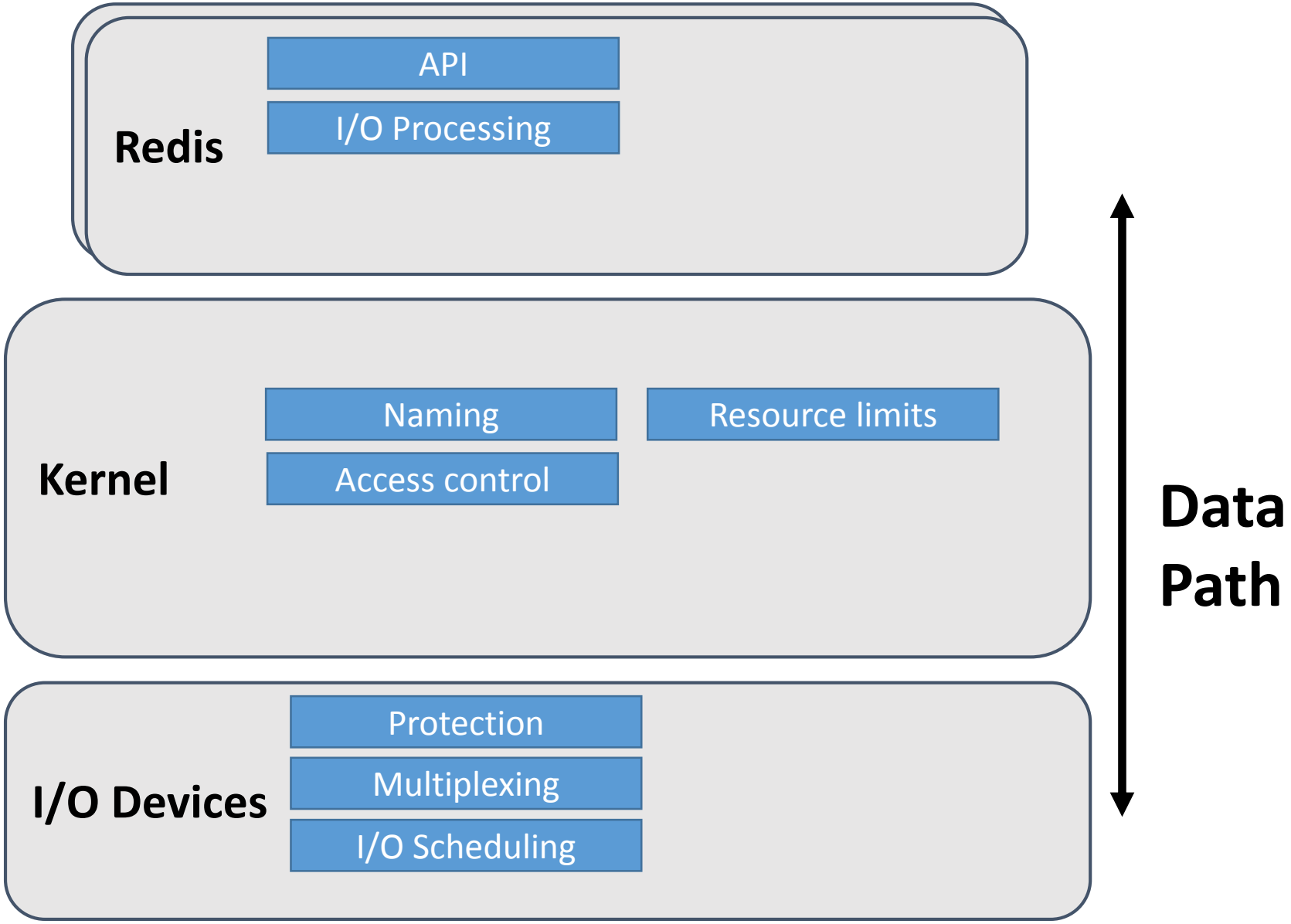
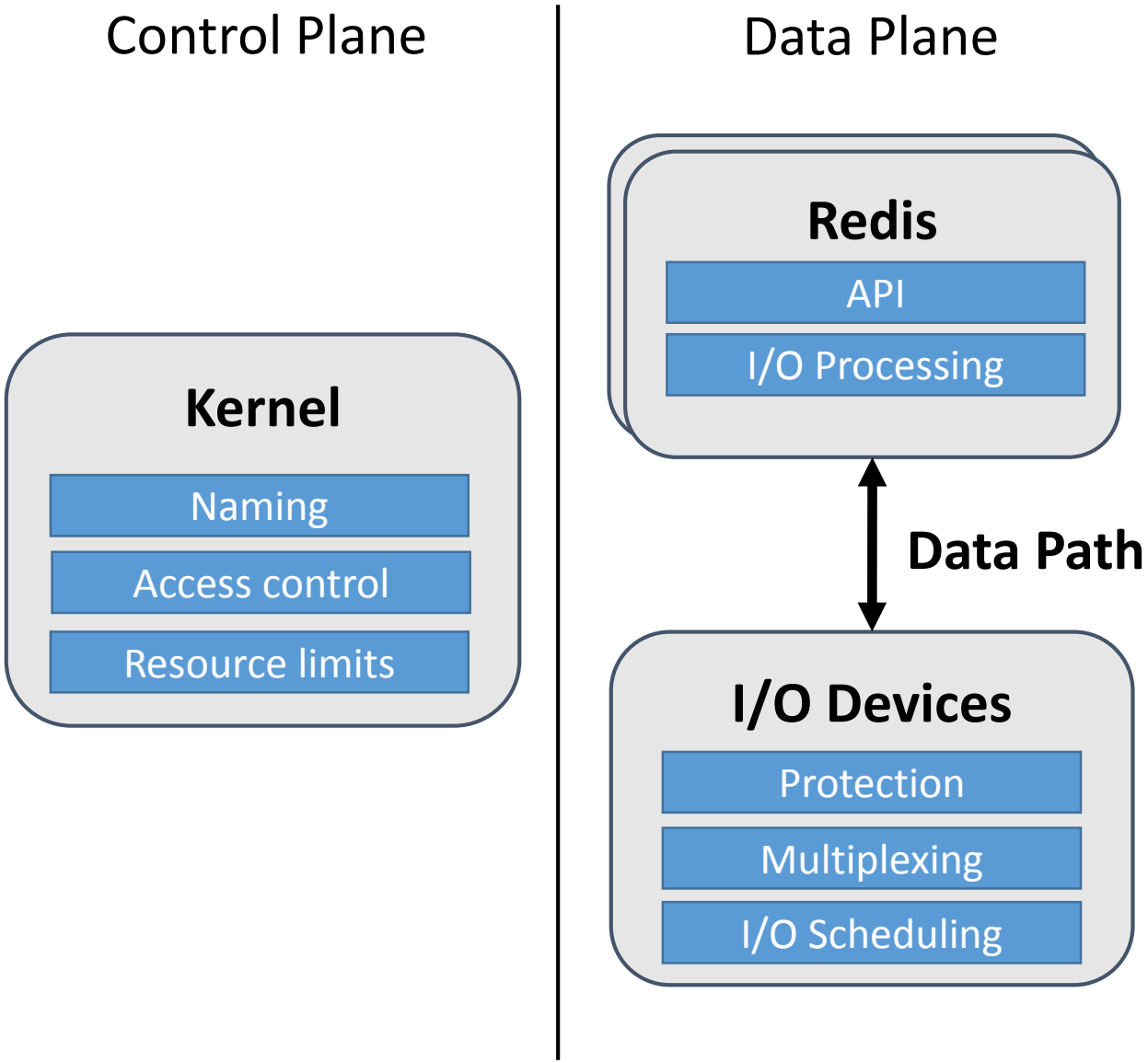


Arrakis I/O Architecture



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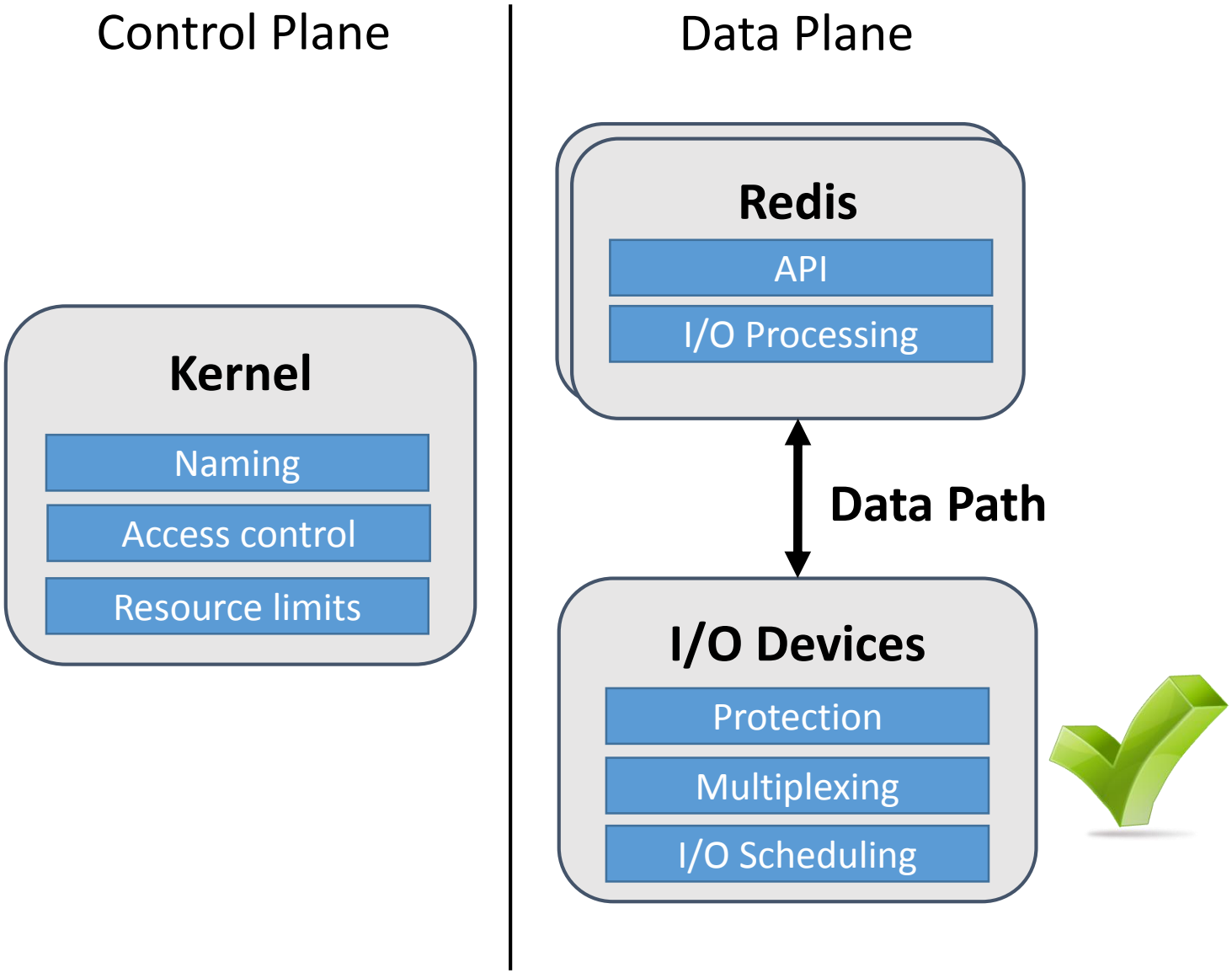
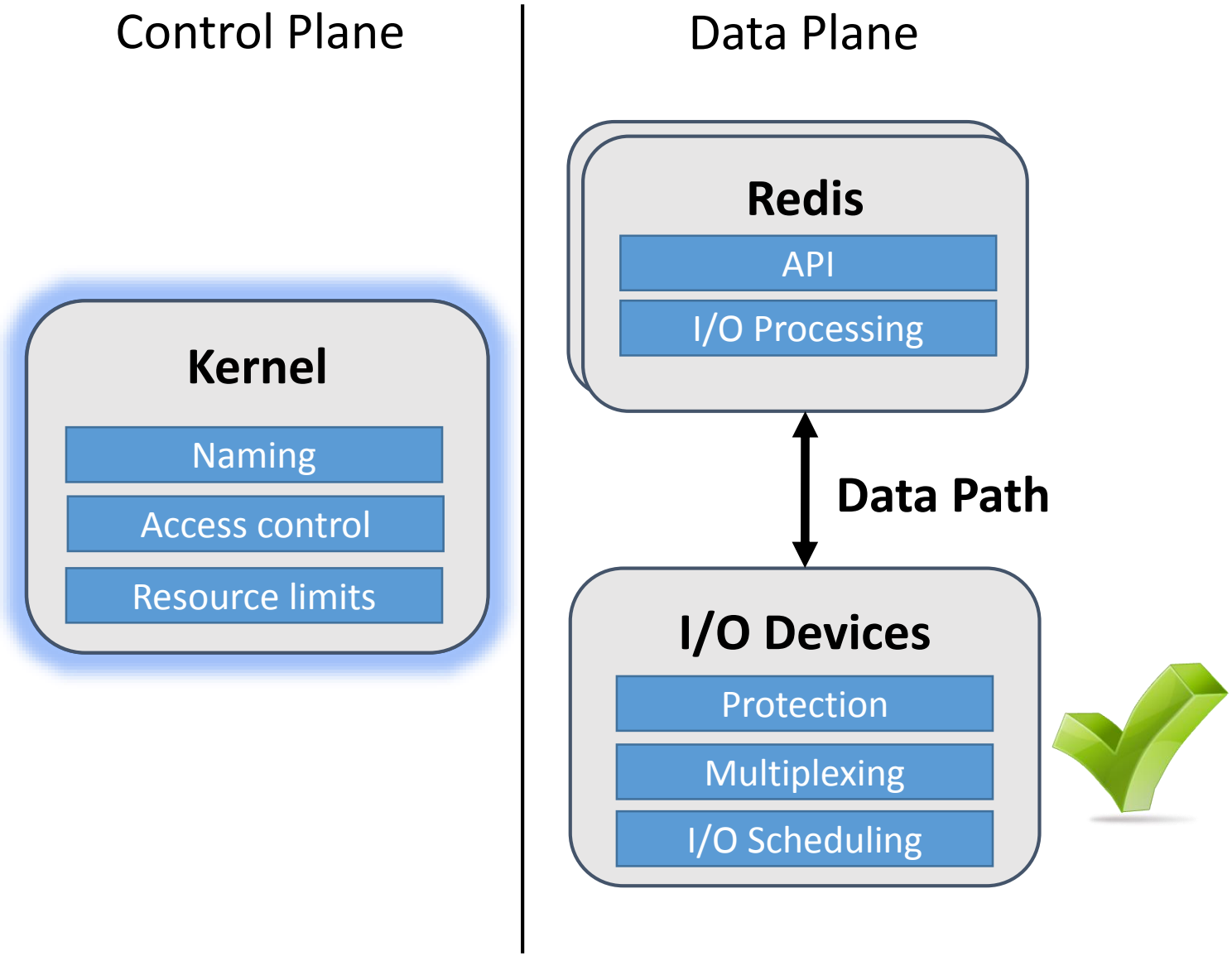
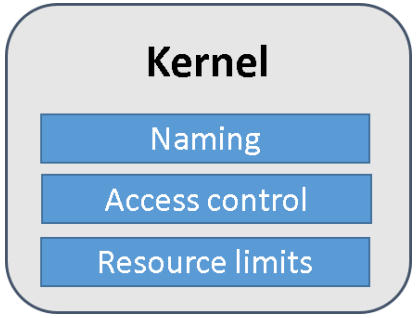


Arrakis I/O Architecture

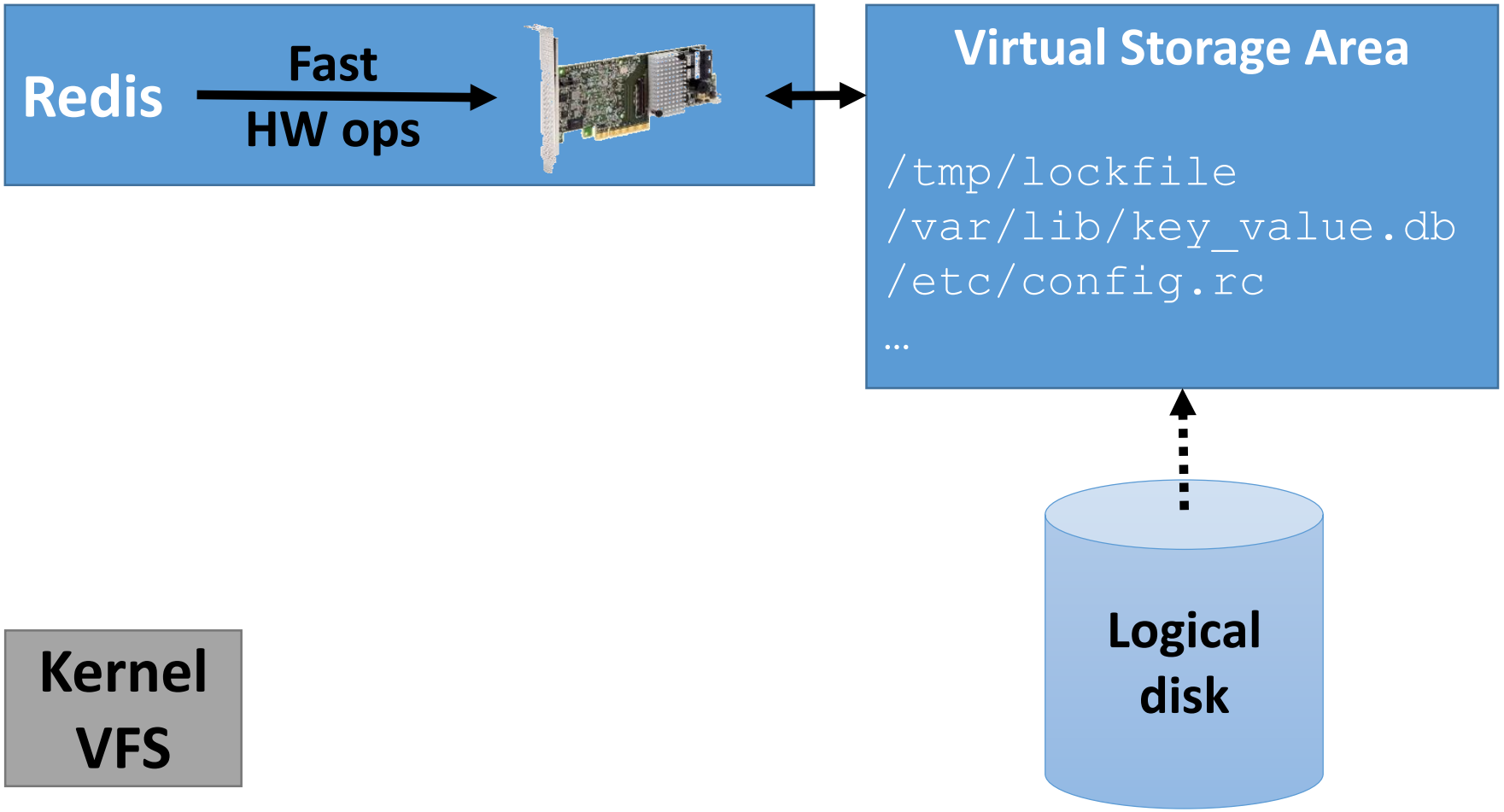


Arrakis Control Plane



- Access control
  - Do once when configuring data plane
  - Enforced via NIC filters, logical disks
- Resource limits
  - Program hardware I/O schedulers
- Global naming
  - Virtual file system still in kernel
  - Storage implementation in applications

Global Naming



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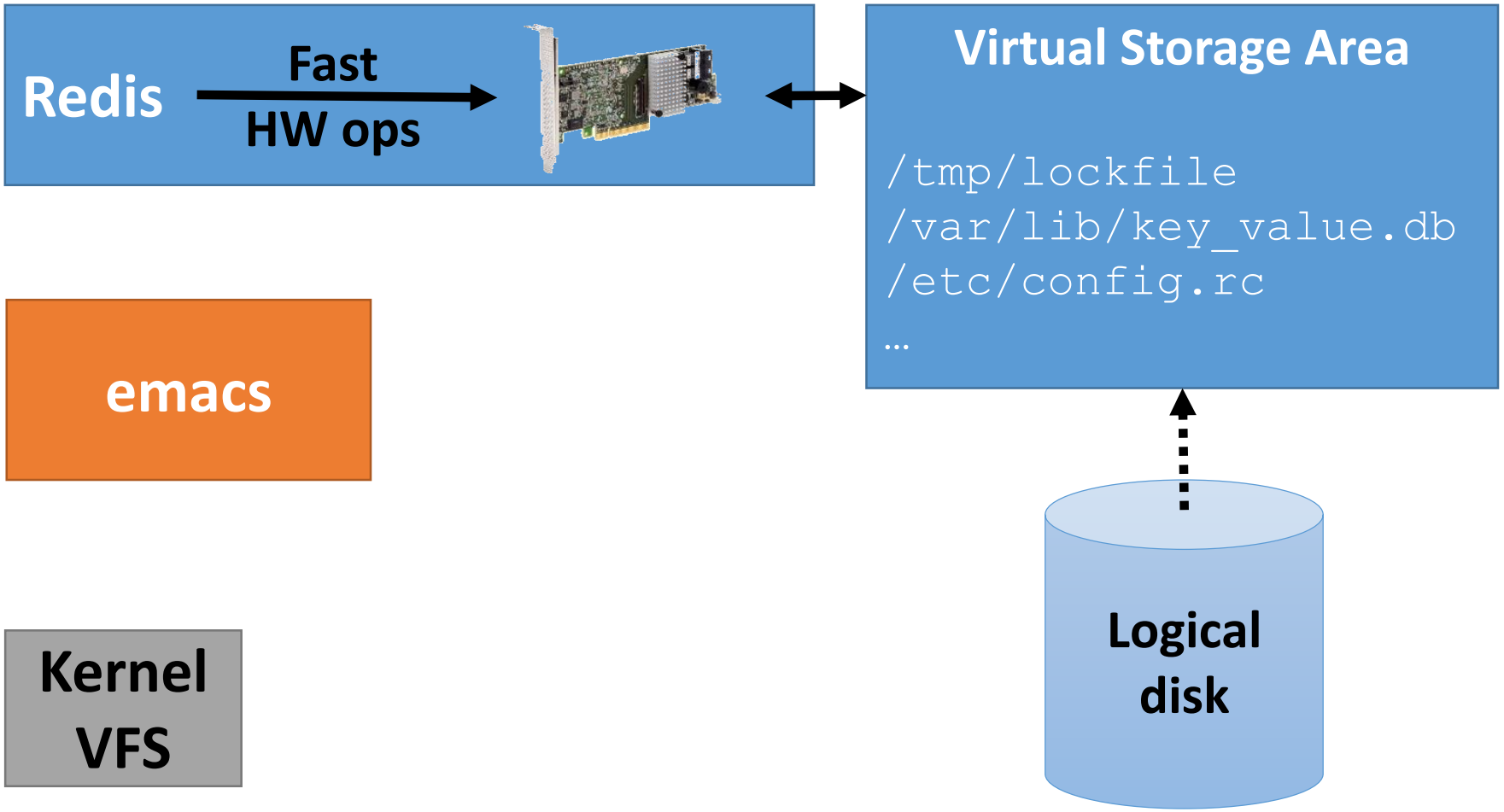

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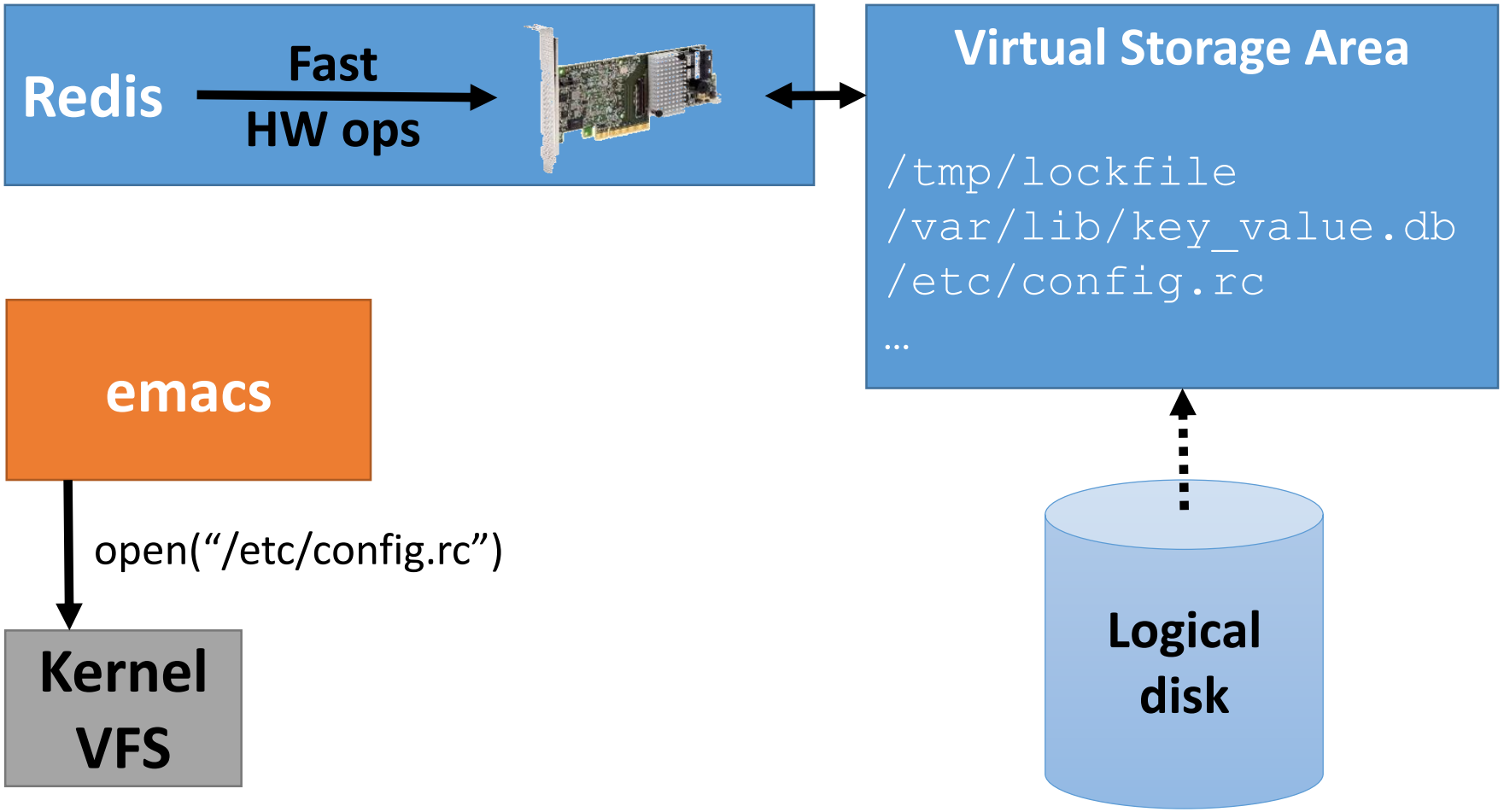

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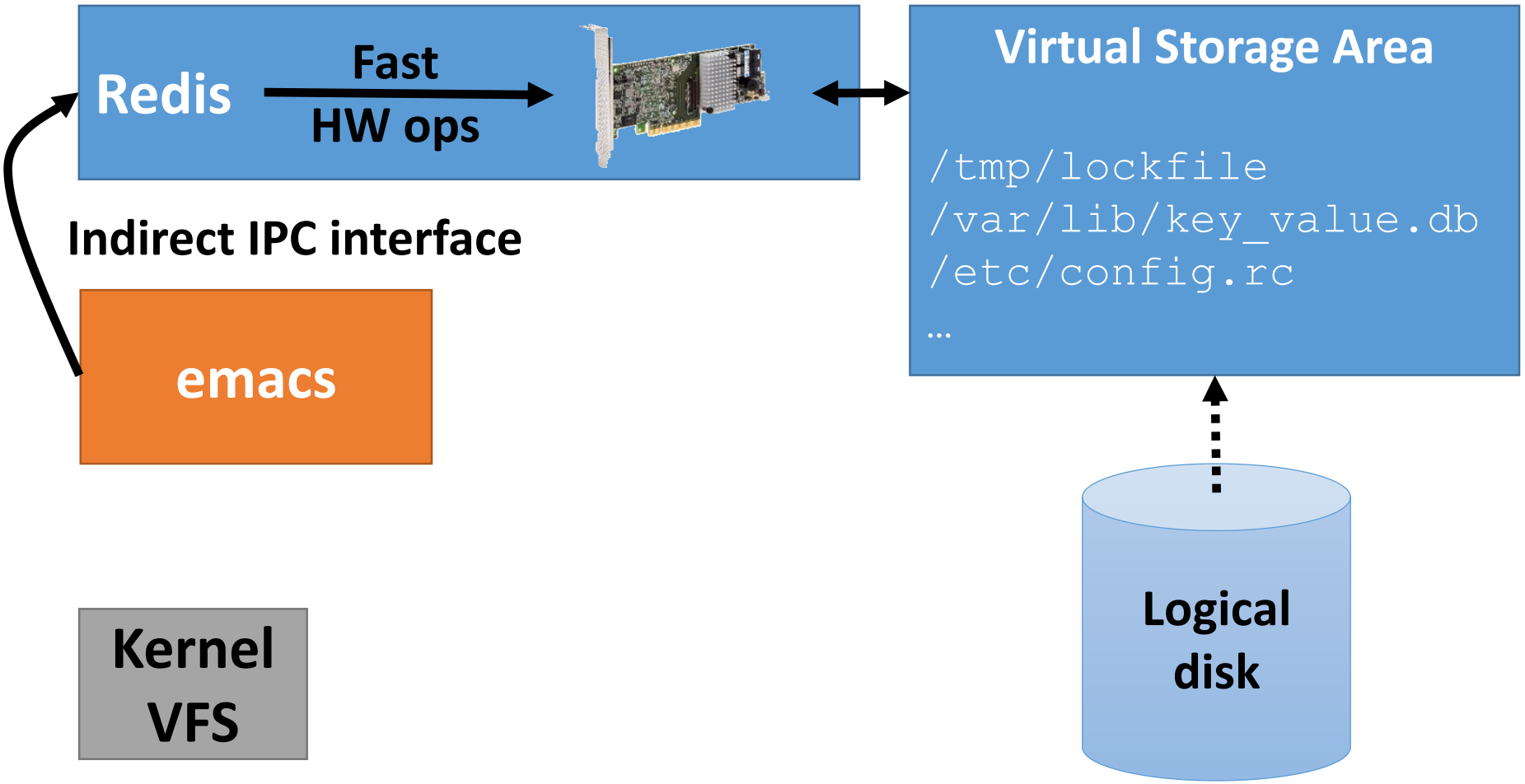

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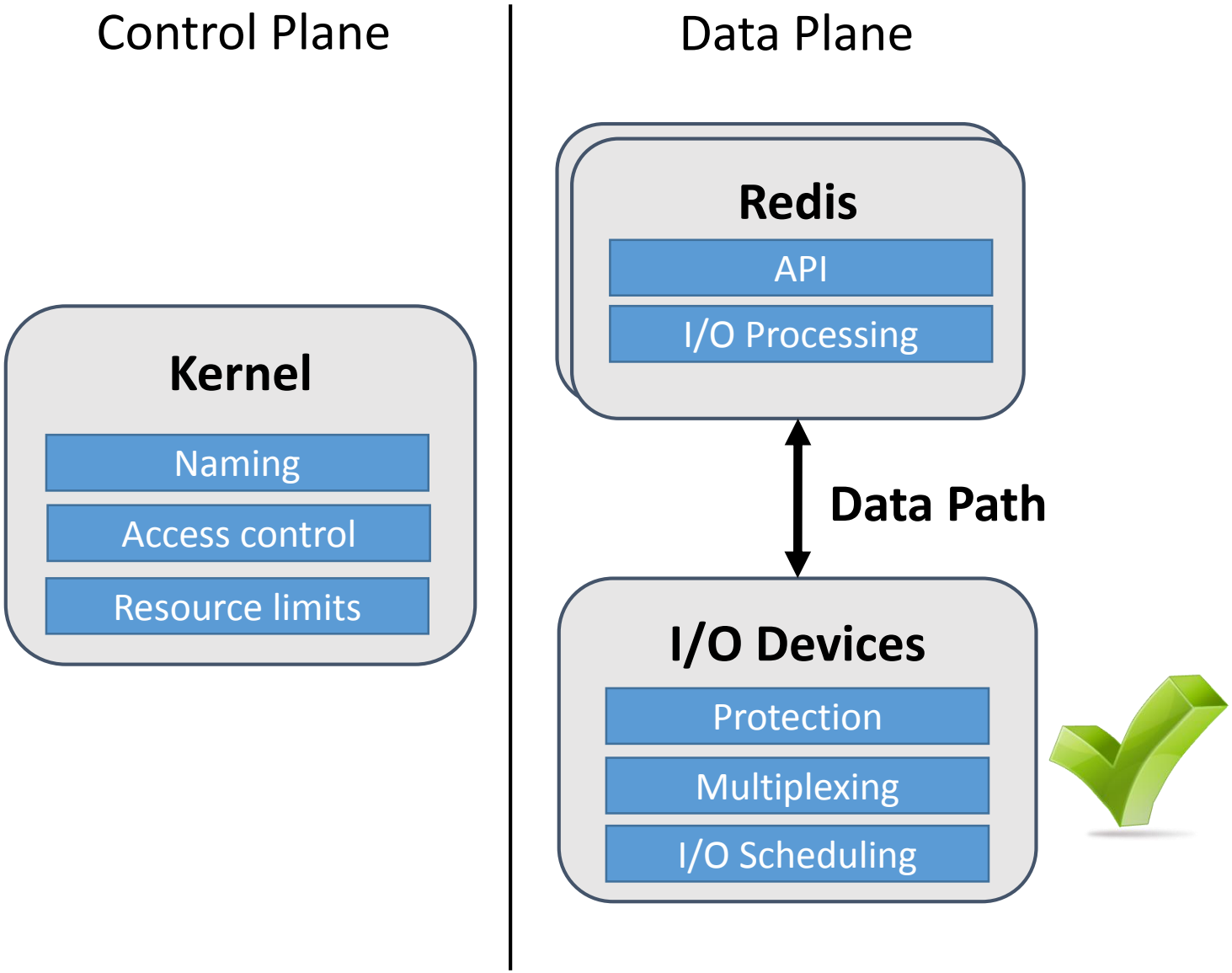

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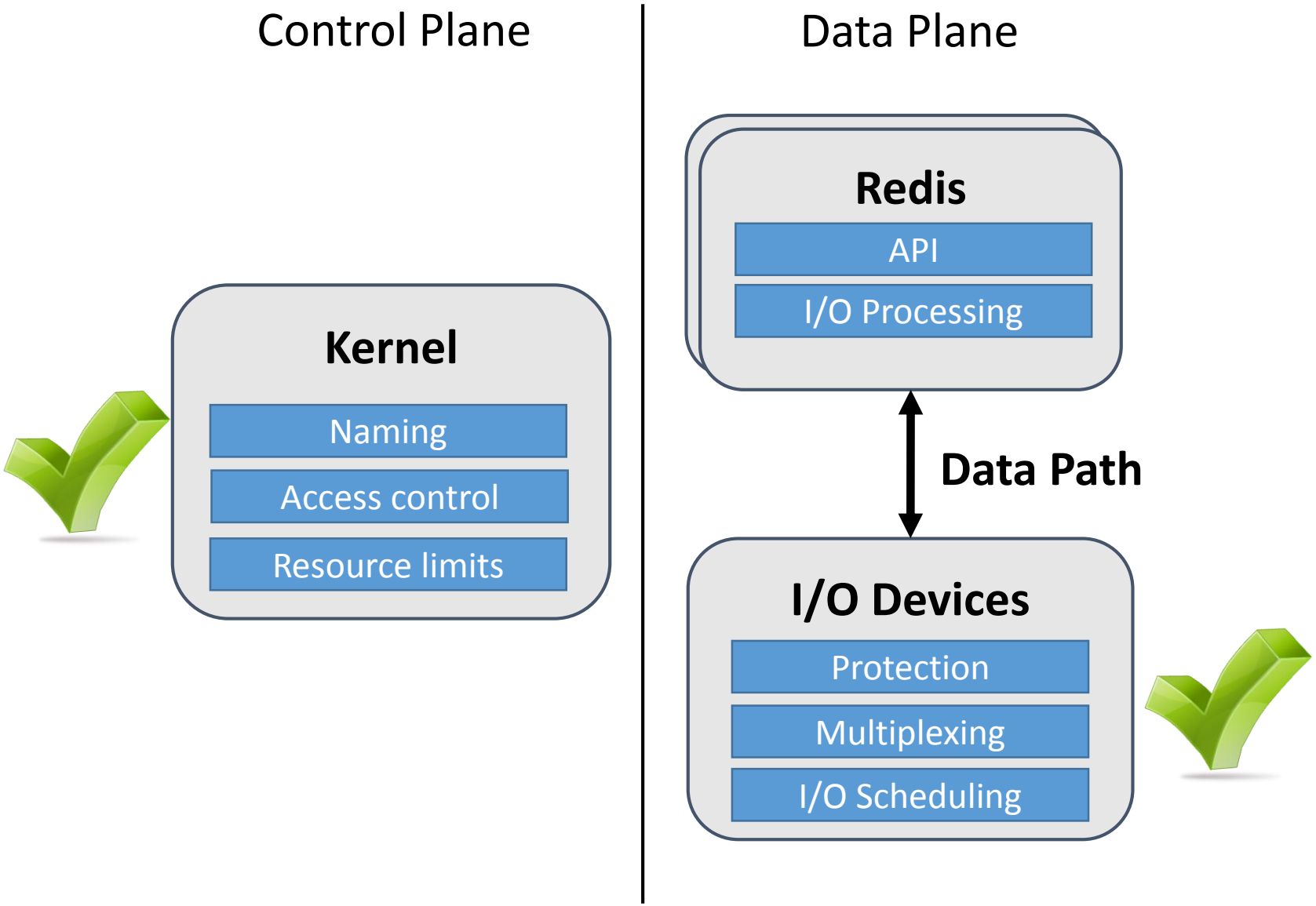

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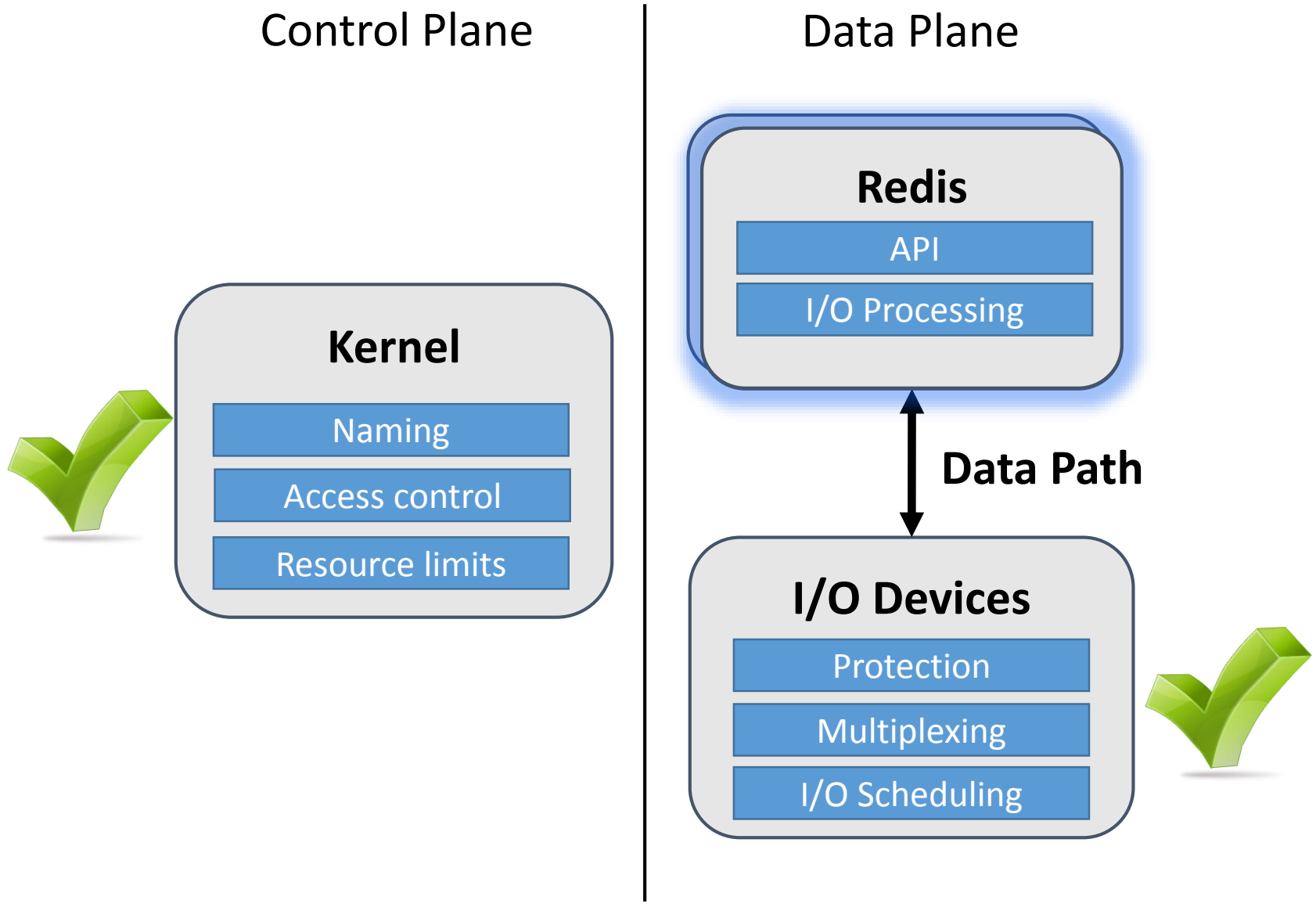
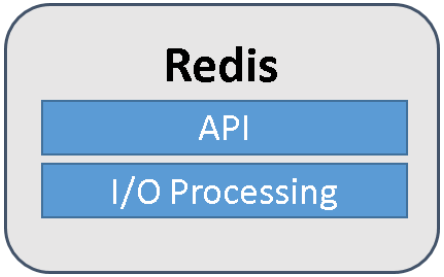


Storage Data Plane: Persistent Data Structures



- Examples: **log, queue**
- Operations immediately persistent on disk

Benefits:

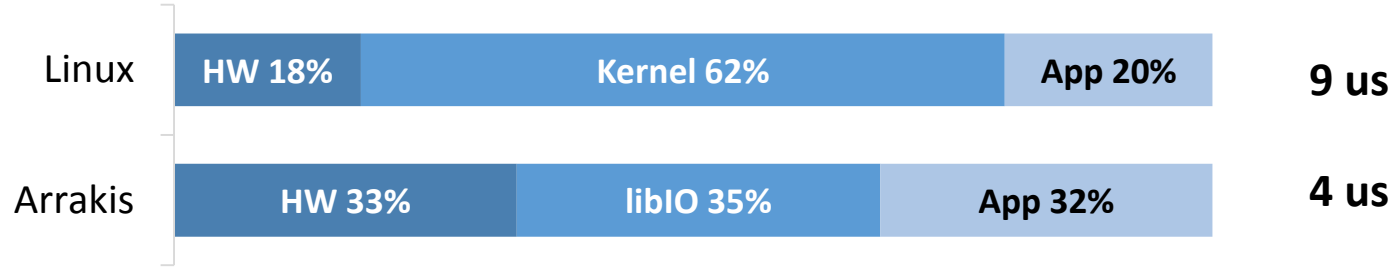
- In-memory = on-disk layout
  - Eliminates marshaling
- Metadata in data structure
  - Early allocation
  - Spatial locality
- Data structure specific caching/prefetching

- Modified Redis to use **persistent log**: **109 LOC** changed

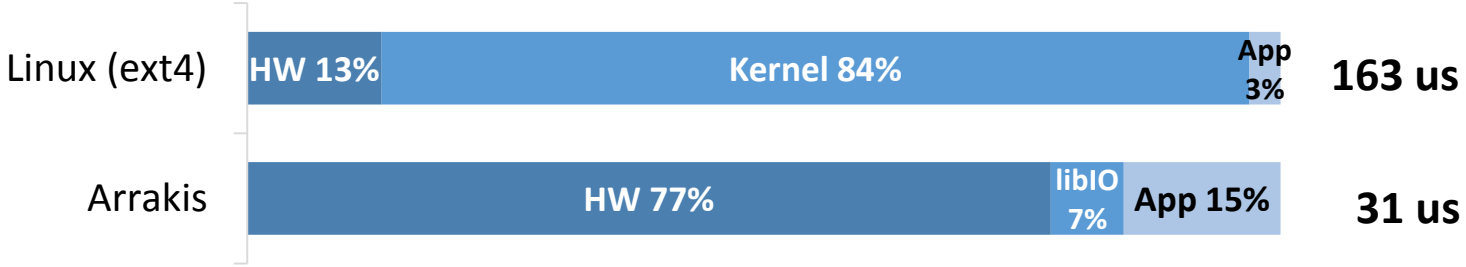
Evaluation

Redis Latency

- Reduced (in-memory) GET latency by **65%**



- Reduced (persistent) SET latency by **81%**

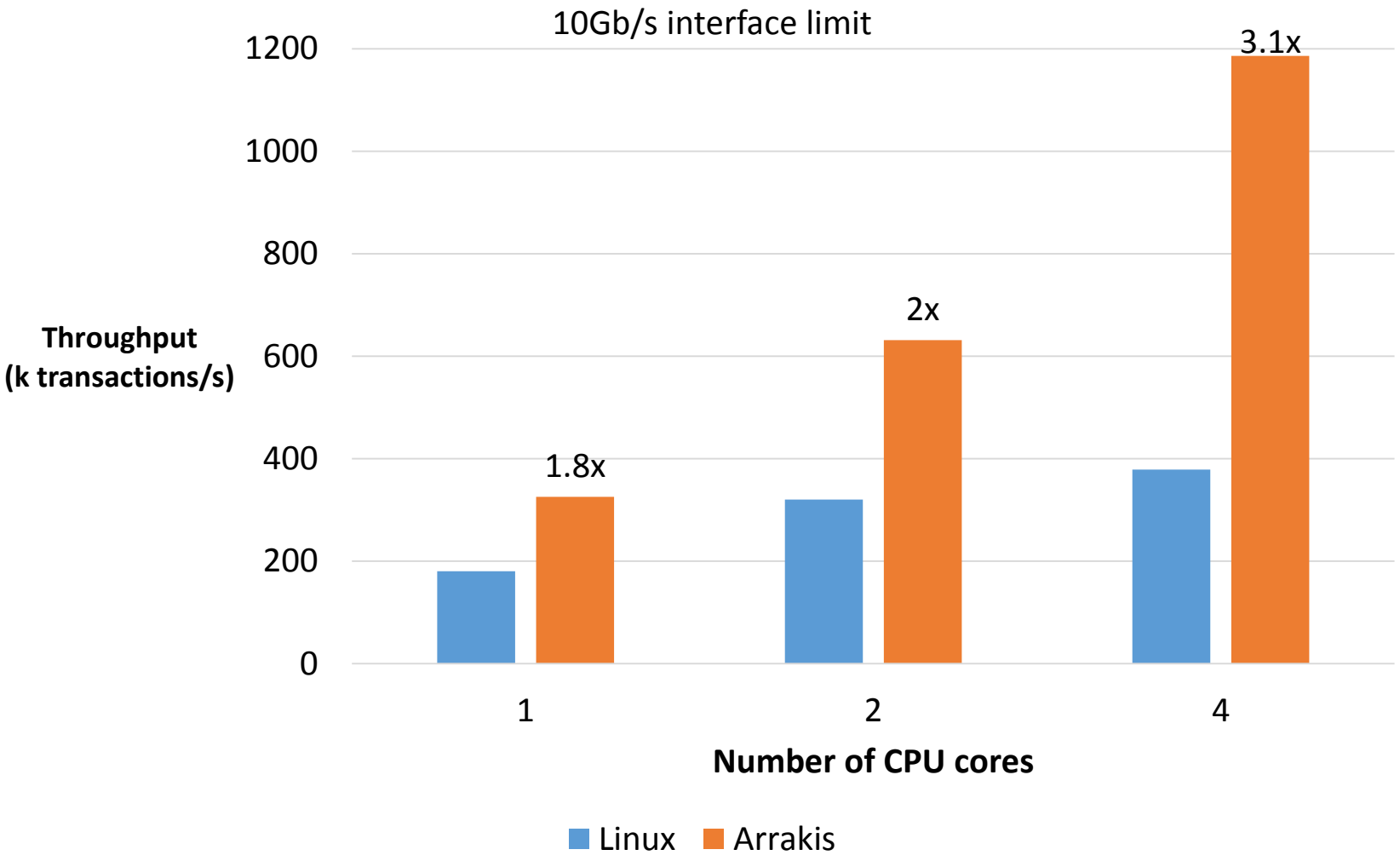


Redis Throughput

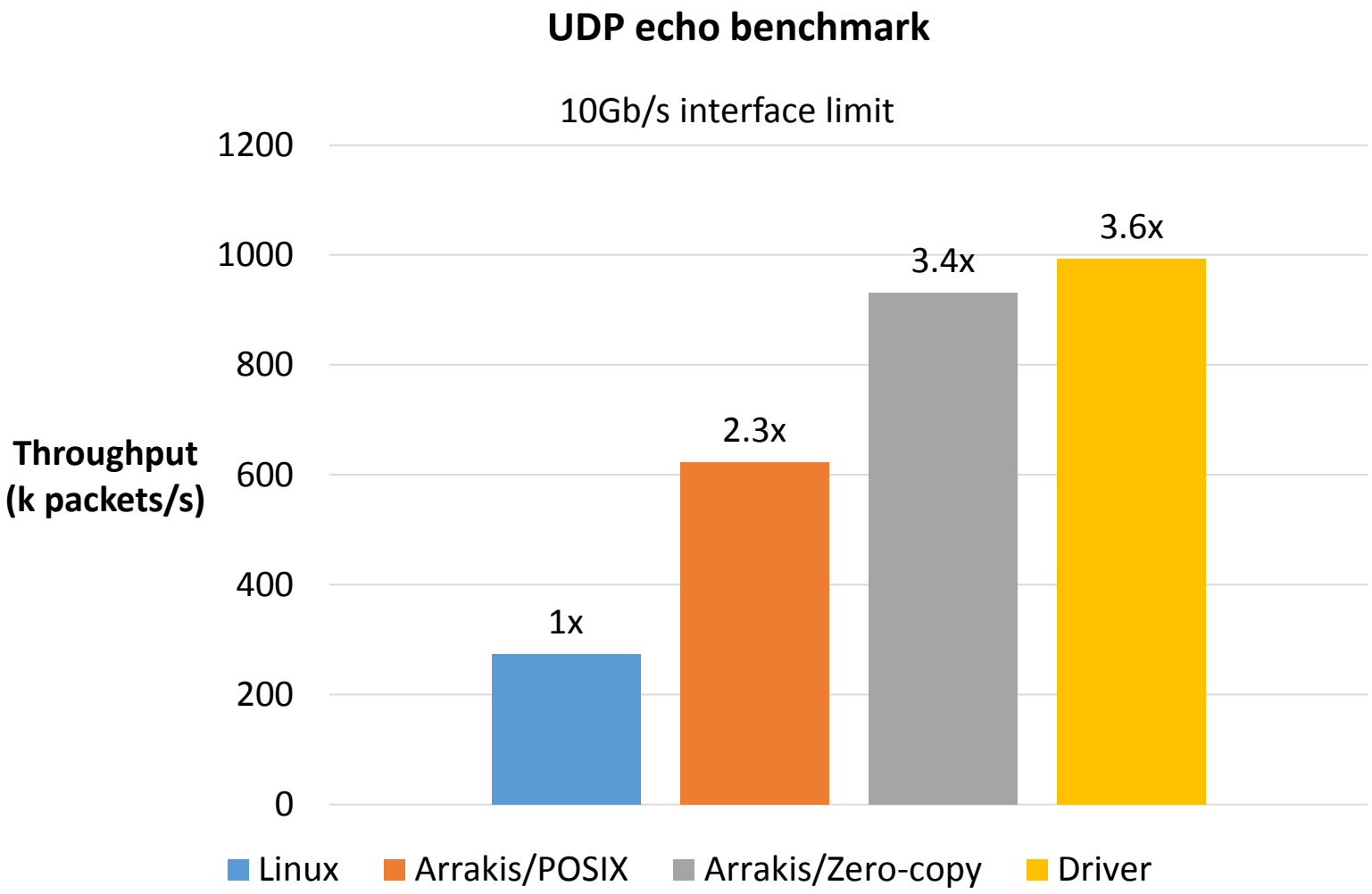
- Improved GET throughput by **1.75x**
  - Linux: **143k** transactions/s
  - Arrakis: **250k** transactions/s

- Improved SET throughput by **9x**
  - Linux: **7k** transactions/s
  - Arrakis: **63k** transactions/s

memcached Scalability



Single-core Performance



Summary

- OS is becoming an I/O bottleneck
  - Globally shared I/O stacks are slow on data path
- **Arrakis:** Split OS into control/data plane
  - Direct application I/O on data path
  - Specialized I/O libaries
- Application-level I/O stacks deliver great performance
  - **Redis:** up to **9x** throughput, **81%** speedup
  - Memcached **scales linearly** to **3x** throughput

Source code: ***http://arrakis.cs.washington.edu***