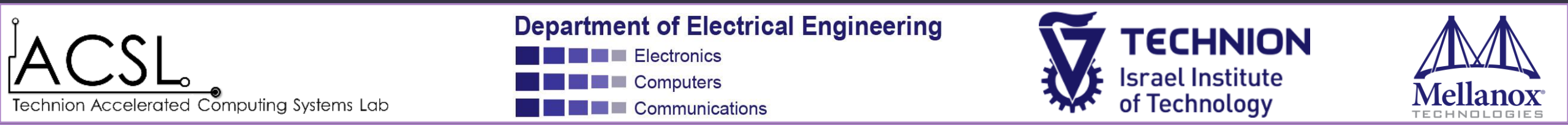
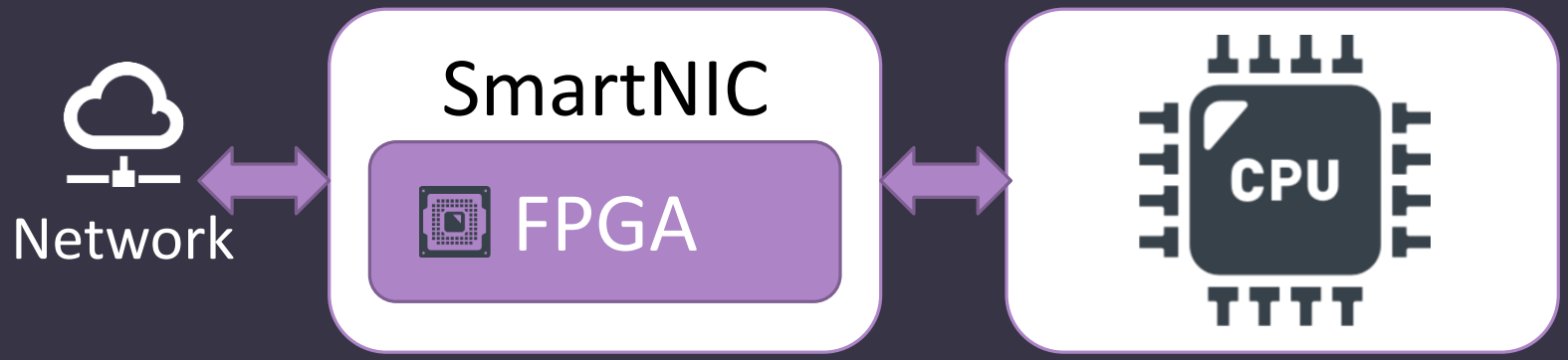
NICA: An Infrastructure for Inline Acceleration of Network Applications

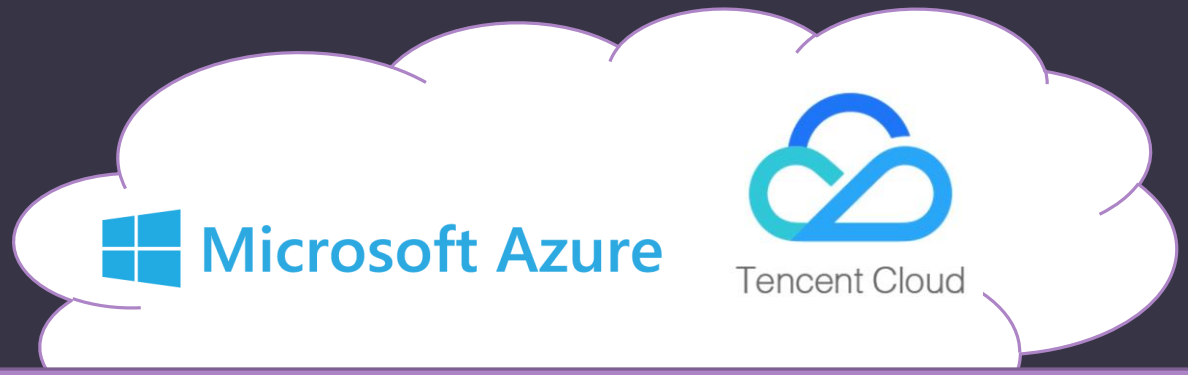
HAGGAI ERAN[†#], LIOR ZENO[†], MAROUN TORK[†], GABI MALKA[†], MARK SILBERSTEIN[†]

[†]TECHNION – ISRAEL INSTITUTE OF TECHNOLOGY [#]MELLANOX TECHNOLOGIES



FPGA-Based SmartNICs





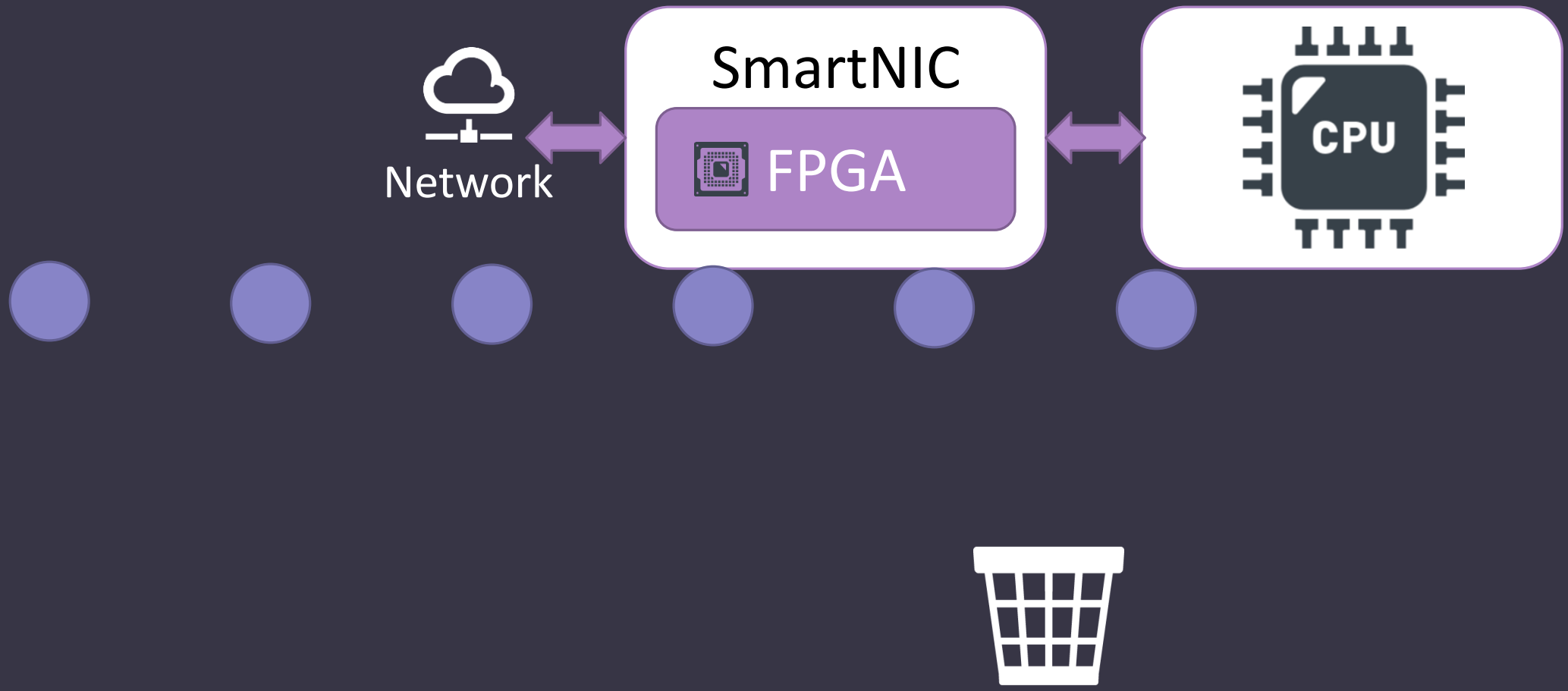
Azure SmartNICs implementing AccelNet have been deployed on all new Azure servers since late 2015 in a fleet of >1M hosts. [NSDI'18]

Inline Acceleration (Analogy)

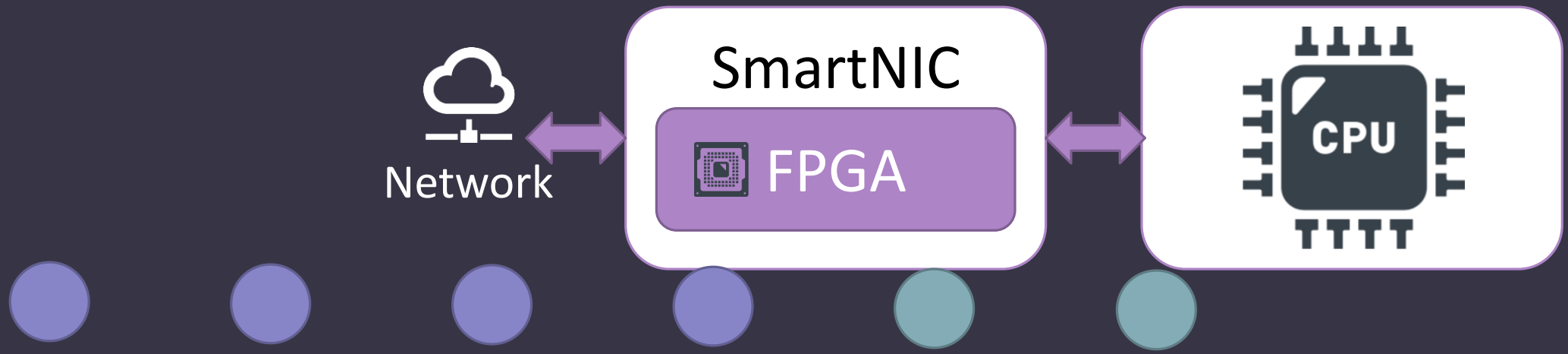
https://www.pinterest.com/pin/334603447314940566/

https://www.amazon.com/WolVol-Friction-Powered-Garbage-Lights/dp/B00WH4Y9SG

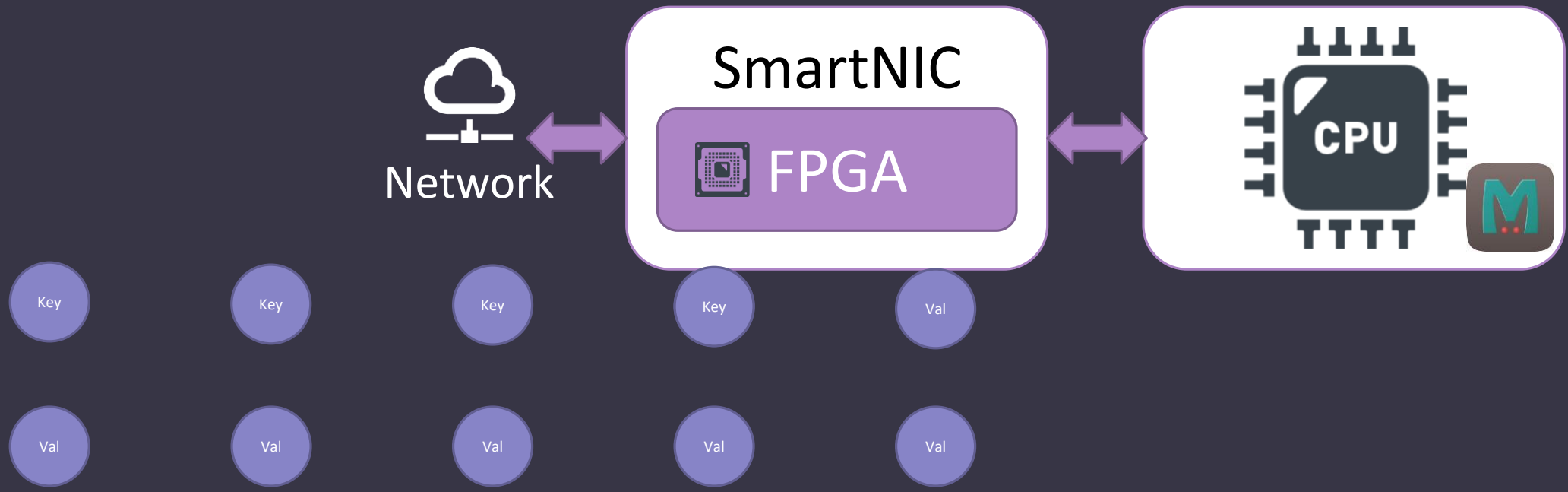
Inline Processing - Filtering



Inline Processing - Transformation

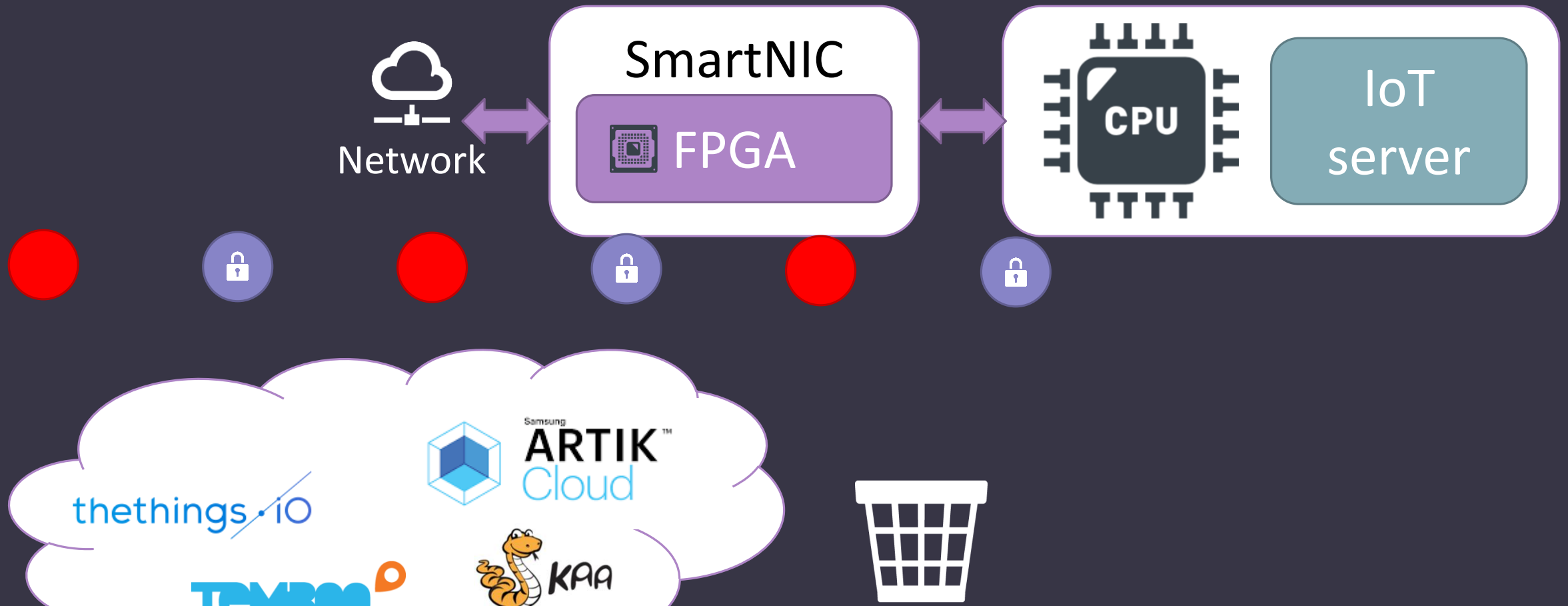


A Key-Value Store Cache



Previous work: KV-Direct [SOSP'17], Floem [OSDI'18], LaKe [ReConFig'18]

CoAP Cryptographic Authentication



Challenges for Cloud Inline Accelerators

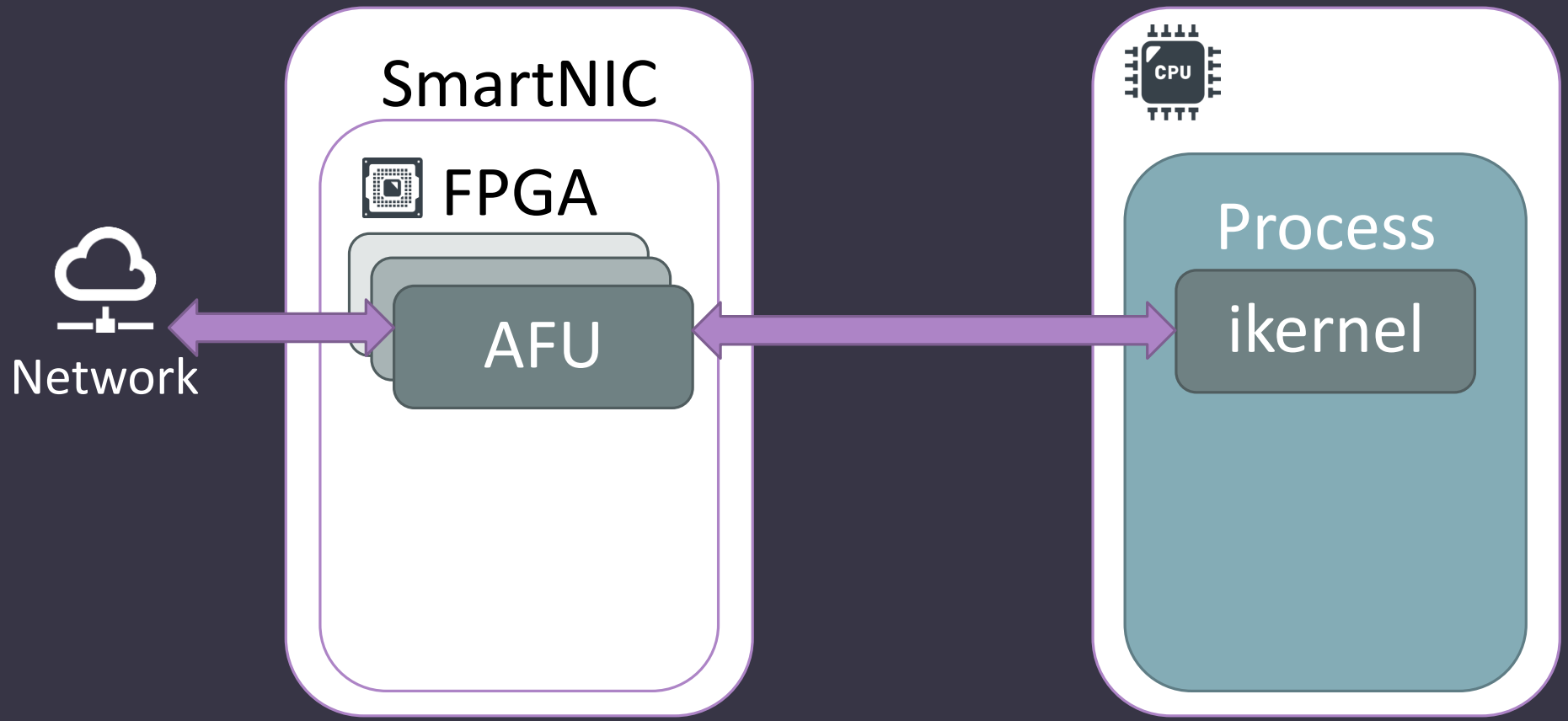
- No operating system abstractions
- No virtualization support:
  - performance & state isolation

The NICA infrastructure fulfills these requirements for arbitrary inline accelerators.

NICA – Contributions

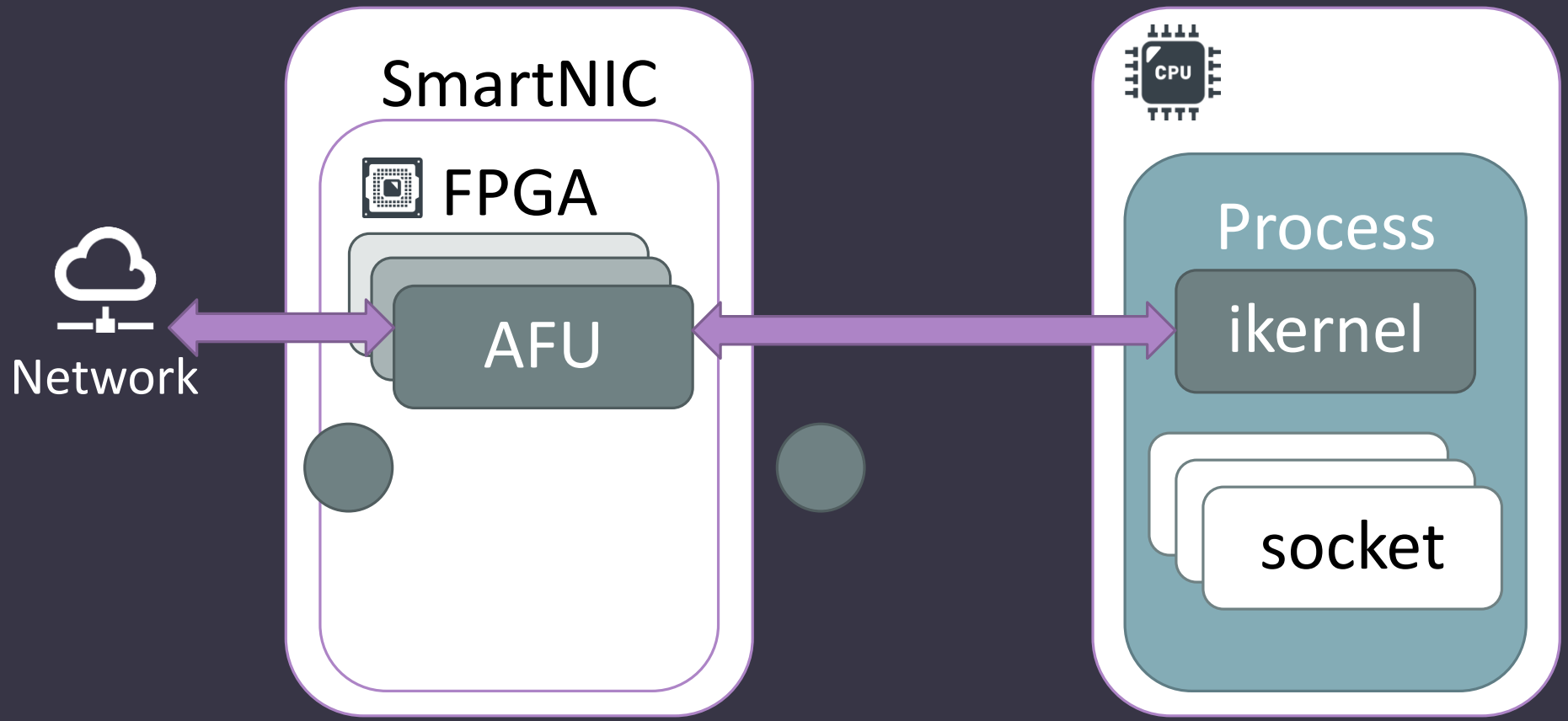
- ikernel OS abstraction for inline application acceleration
- SmartNIC virtualization:
  Fine-grain time sharing & strict performance isolation

The ikernel Abstraction



AFU – Accelerator Functional Unit

Attaching an ikernel



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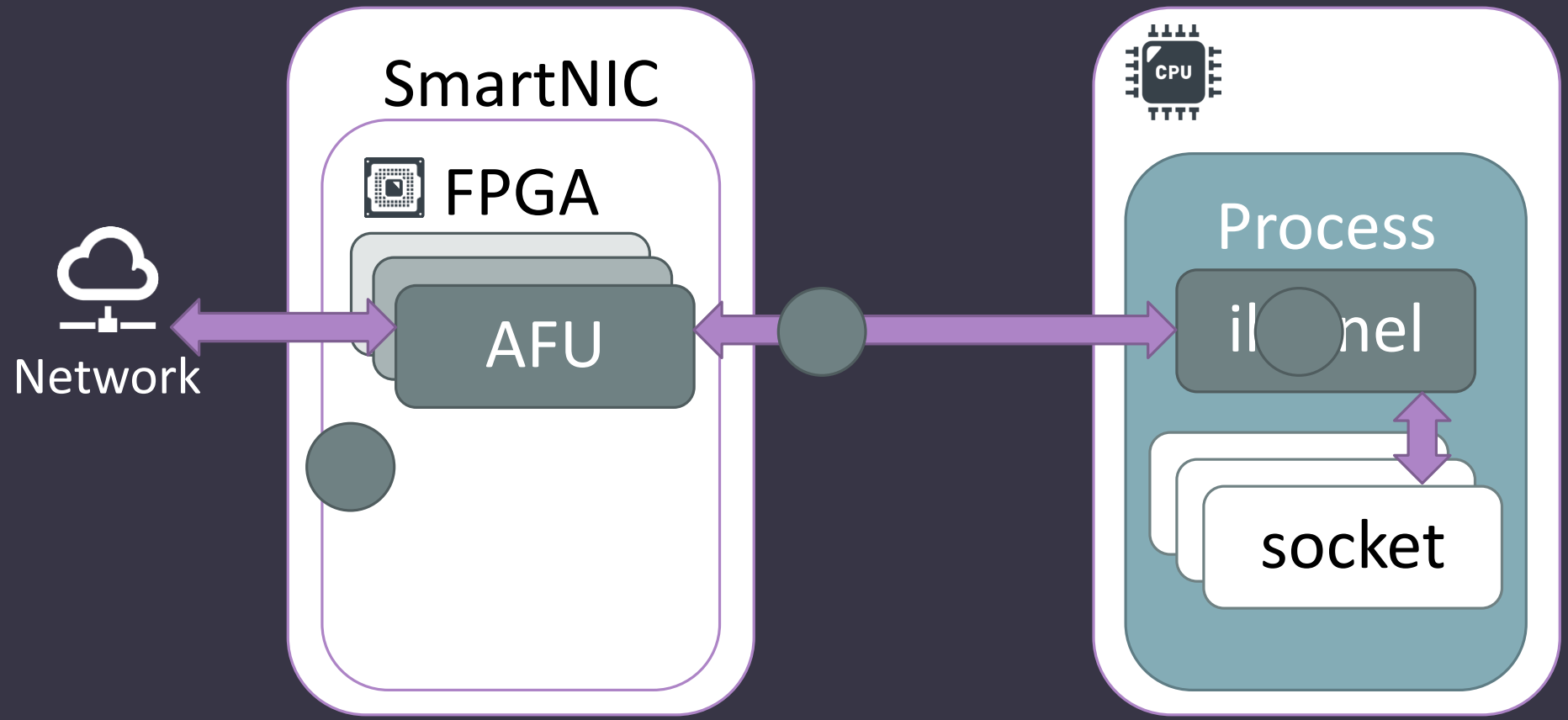
Attaching an ikernel

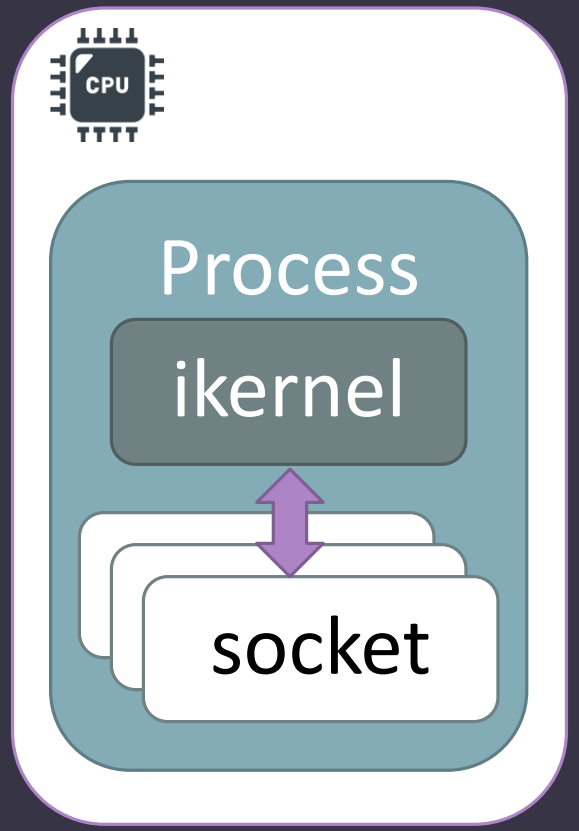


AFU – Accelerator Functional Unit

Interfaces of an ikernel

- Attach to sockets
  - Use POSIX API for data
- Custom ring – direct producer-consumer interface
  - Bypass the host network stack
- RPC – access AFU state
  - E.g. configure cryptographic keys, read counters

The ikernel Abstraction




```
// Create handle
k = ik_create(MEMCACHED_AFU);
ik_command(k, CONFIGURE, ...);
// Init a socket.
s = socket(...); bind(s, ...);
// Activate the ikernel
ik_attach(k, s);
// Use POSIX APIs to receive
while (recvmsg(s, buf, ...))
  ...
```

107 lines of code for memcached integration

Virtualization Support

- Computation
- I/O

How FPGAs Are Shared [Background]

- **Space sharing**
- Coarse grain time sharing
- Fine grain time sharing

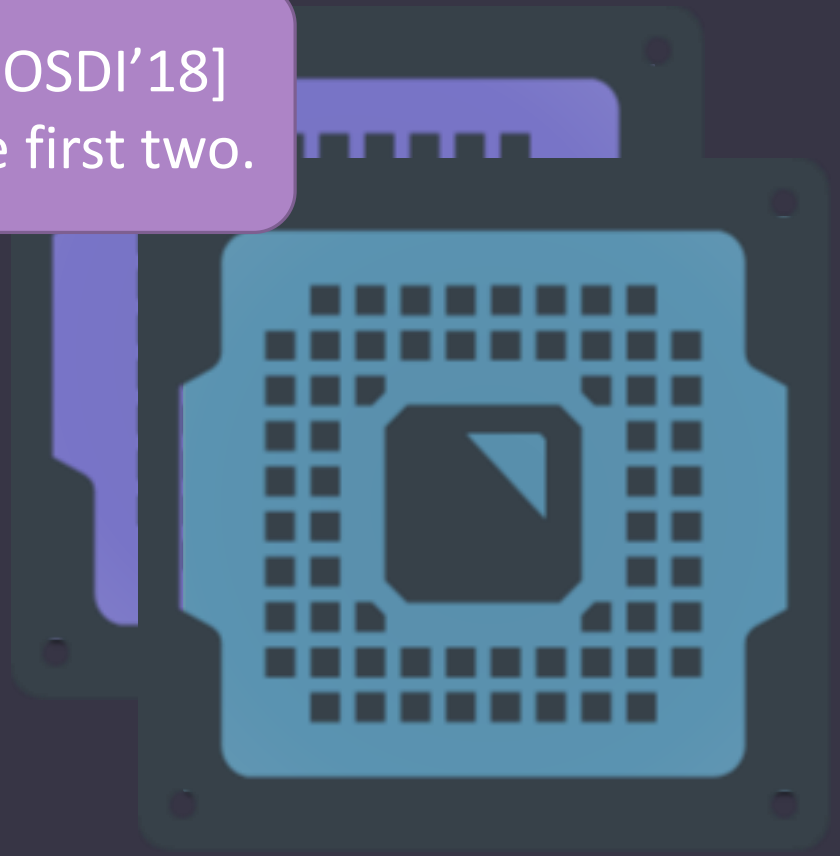
-Limited utilization

How FPGAs Are Shared [Background]

- Space sharing
- **Coarse-grain time sharing**
- Fine-grain time sharing

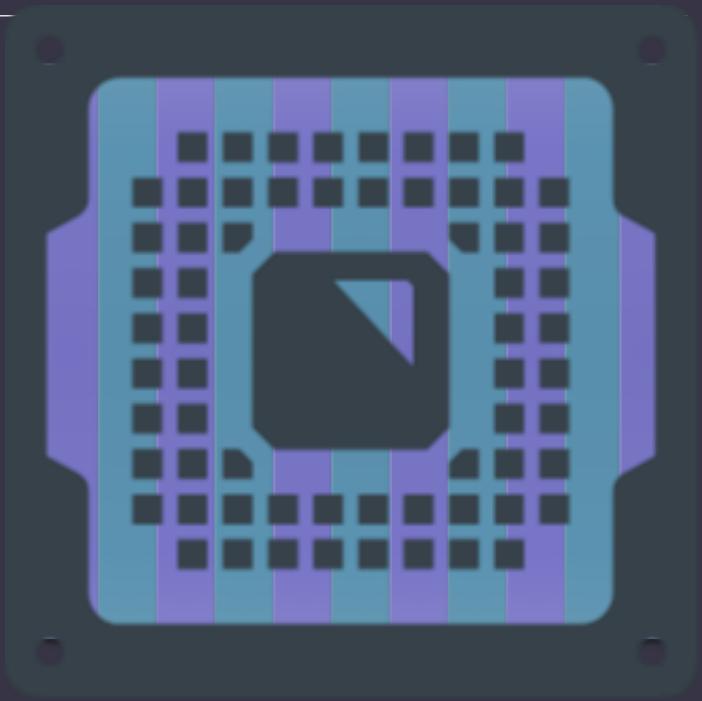
-Long context switch

AmorphOS [OSDI'18] combines the first two.



How FPGAs Are Shared [Background]

- Space sharing
- Coarse-grain time sharing
- **Fine-grain time sharing**



Multiple tenants share the same AFU.

+Low latency – hardware context switch (packet granularity)

NICA applies these techniques to SmartNIC AFUs

Cloud Deployment Model

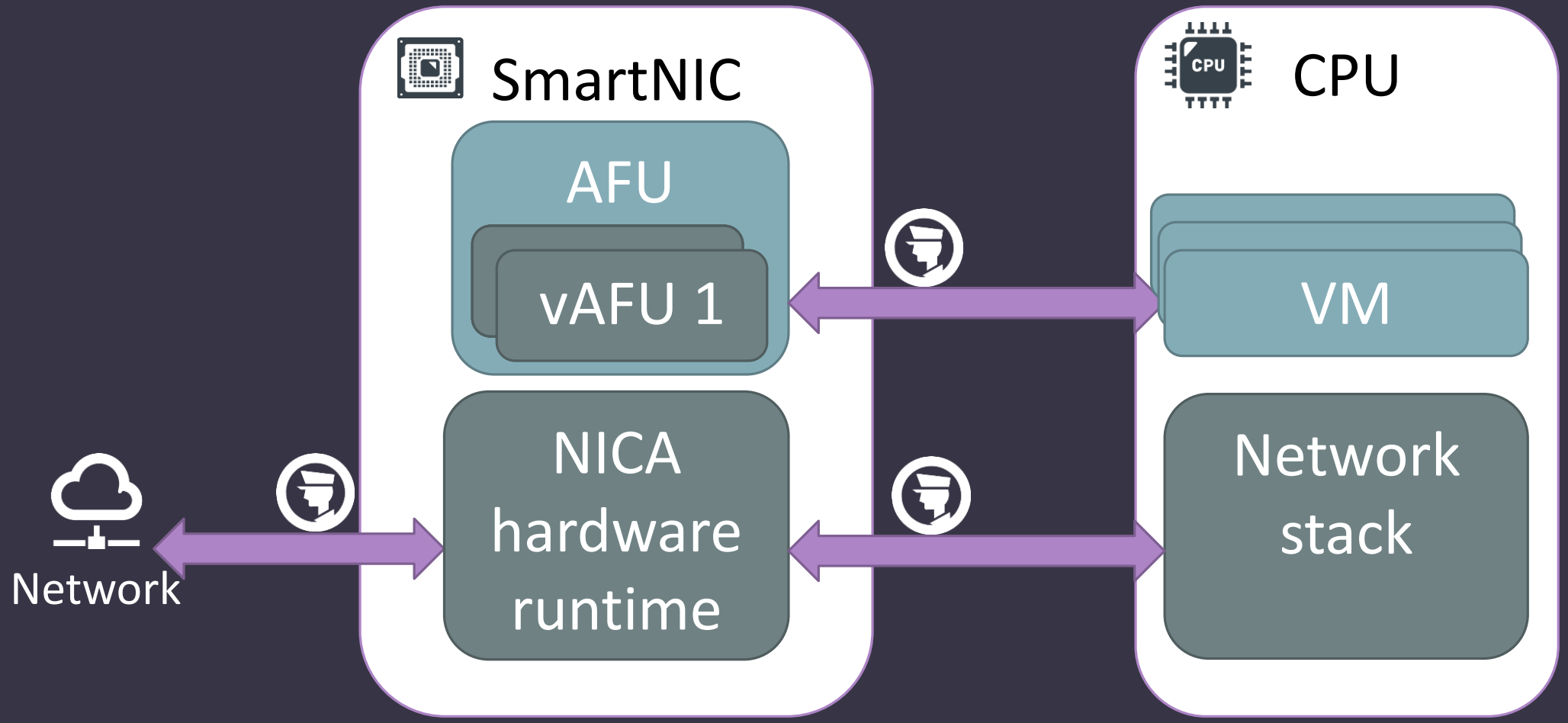
FPGA-as-a-Service

- Customers bring their own design
- Coarse-grain sharing

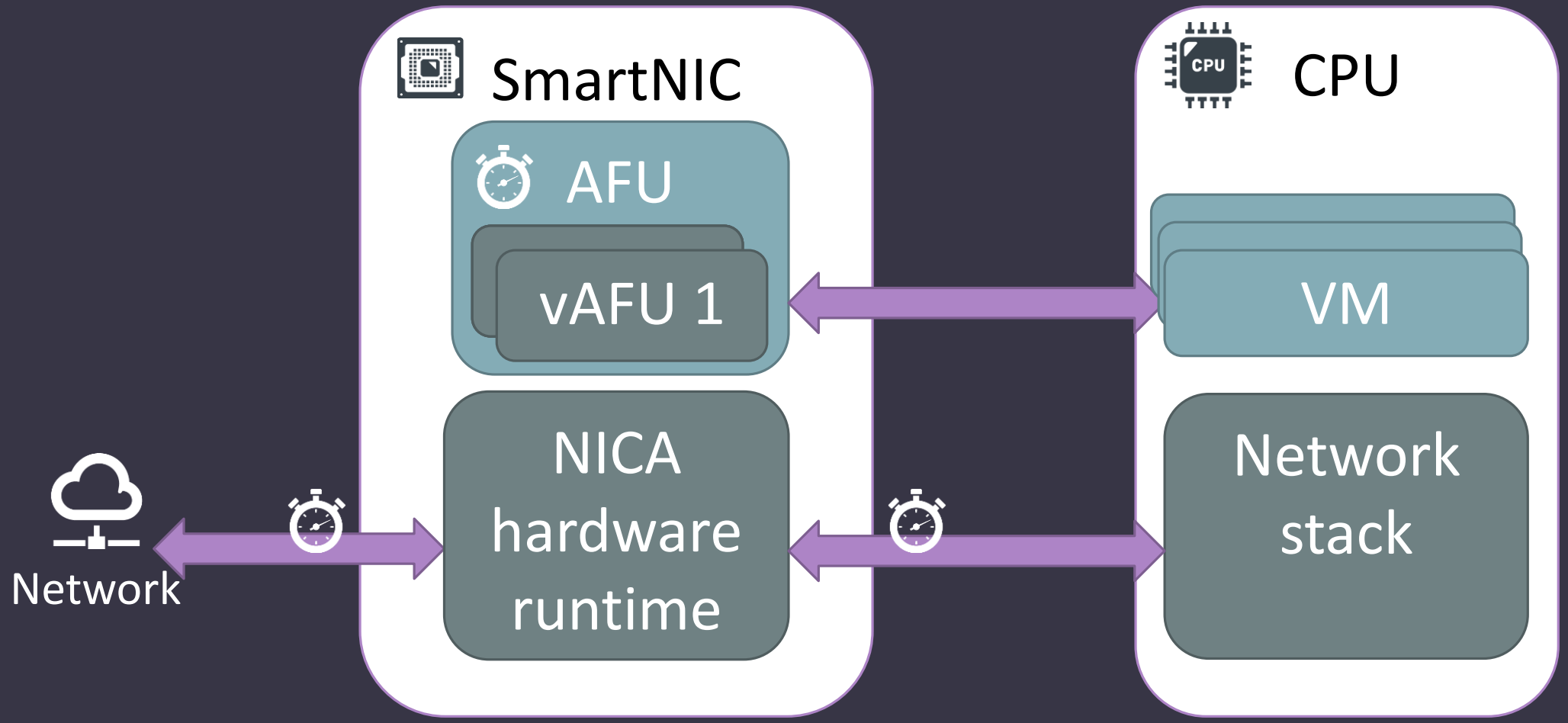
AFU Marketplace

- Cloud provider develops/audits AFUs
- AFUs trusted to implement fine-grain virtualization

NICA I/O Virtualization



Performance Isolation



In the Paper

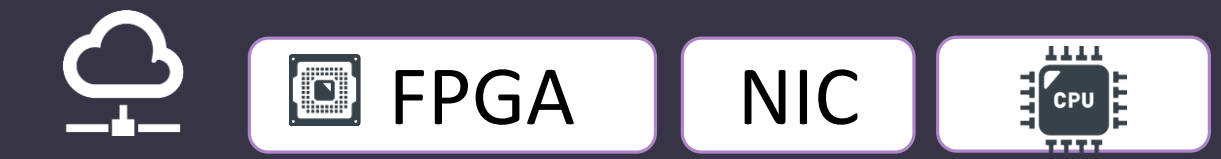
- NICA hardware runtime
- Network stack integration and TCP support
- Custom ring implementation using RDMA
- SR-IOV and para-virtual interfaces
- Implementation details

Evaluation

40 Gbps bump-in-the-wire SmartNIC:

- Mellanox Innova Flex
  - ConnectX 4 Lx EN
  - Xilinx Kintex UltraScale FPGA

Similar to Microsoft Catapult.



Evaluation

Baseline:

- VMA user-space networking stack

Microbenchmarks:

- UDP/TCP performance
- Virtualization overheads
- I/O isolation overheads

Applications:

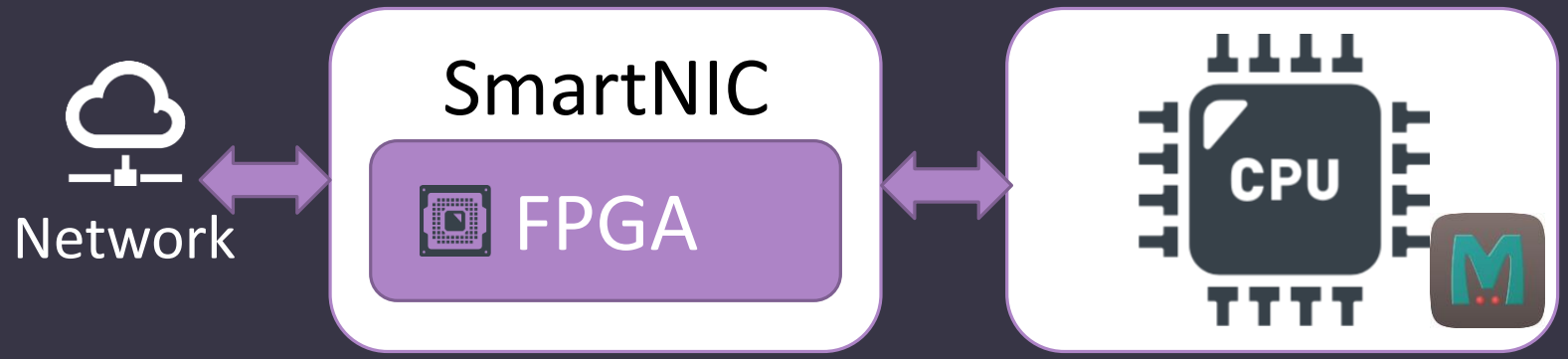
- memcached
  - Comparison with MICA [NSDI'14]; KV-Direct [SOSP'17]
- IoT message authentication
  - Node.js server
  - Integrated with 20 lines of JavaScript

Memcached Cache

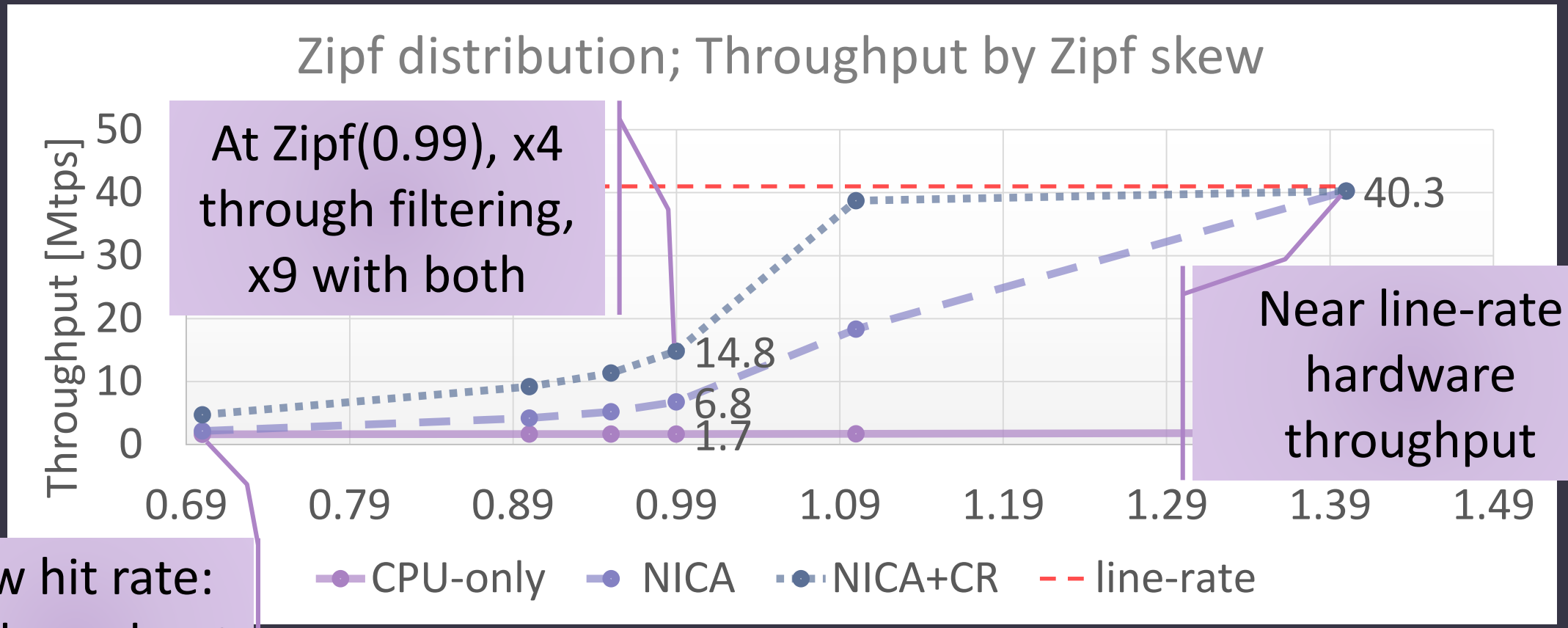
- Host working set: 32M keys
- SmartNIC Cache: 2M keys
- 16 byte keys and values
- Memcached UDP ASCII protocol

Simplicity of host integration:

- POSIX – 107 lines of C code
- Custom ring – 135 lines of code

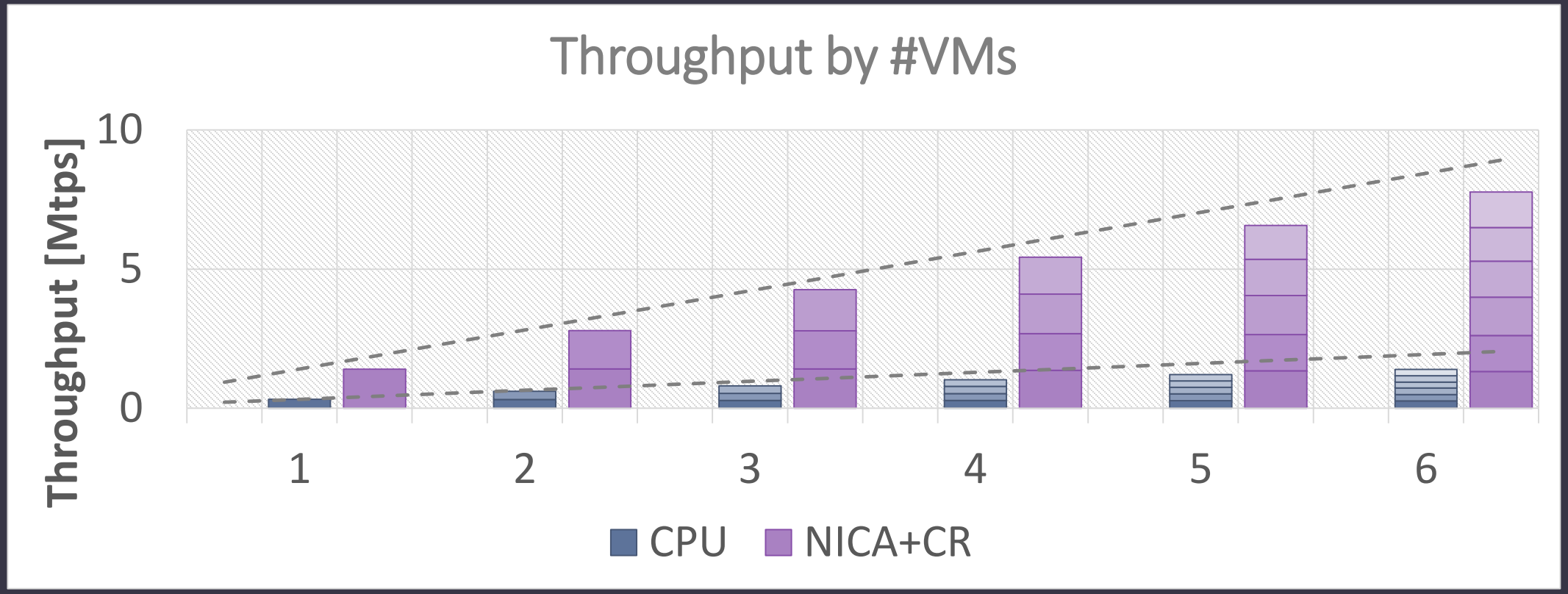


Key-Value Store Cache – Bare Metal R/O



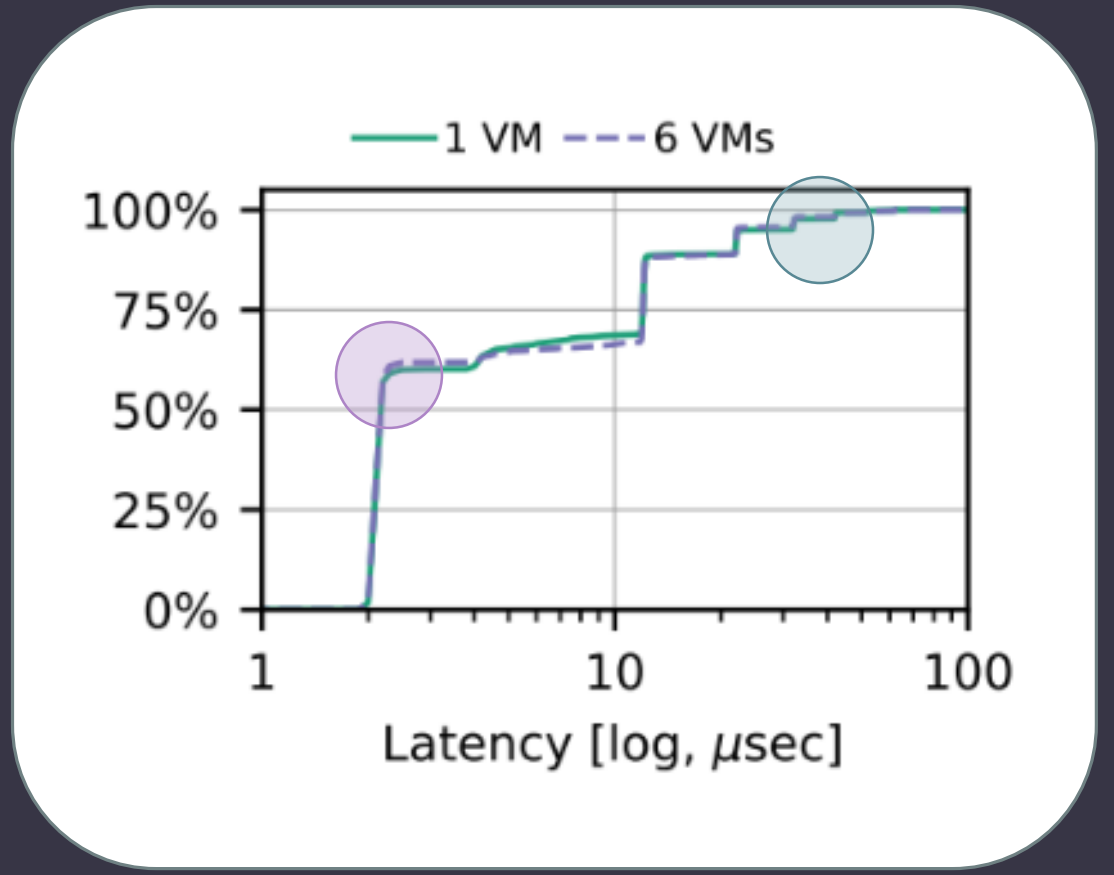
Key-Value Store Cache - Virtualization

- 1 core, 5 GB host RAM, 2M key cache, Zipf(0.9)

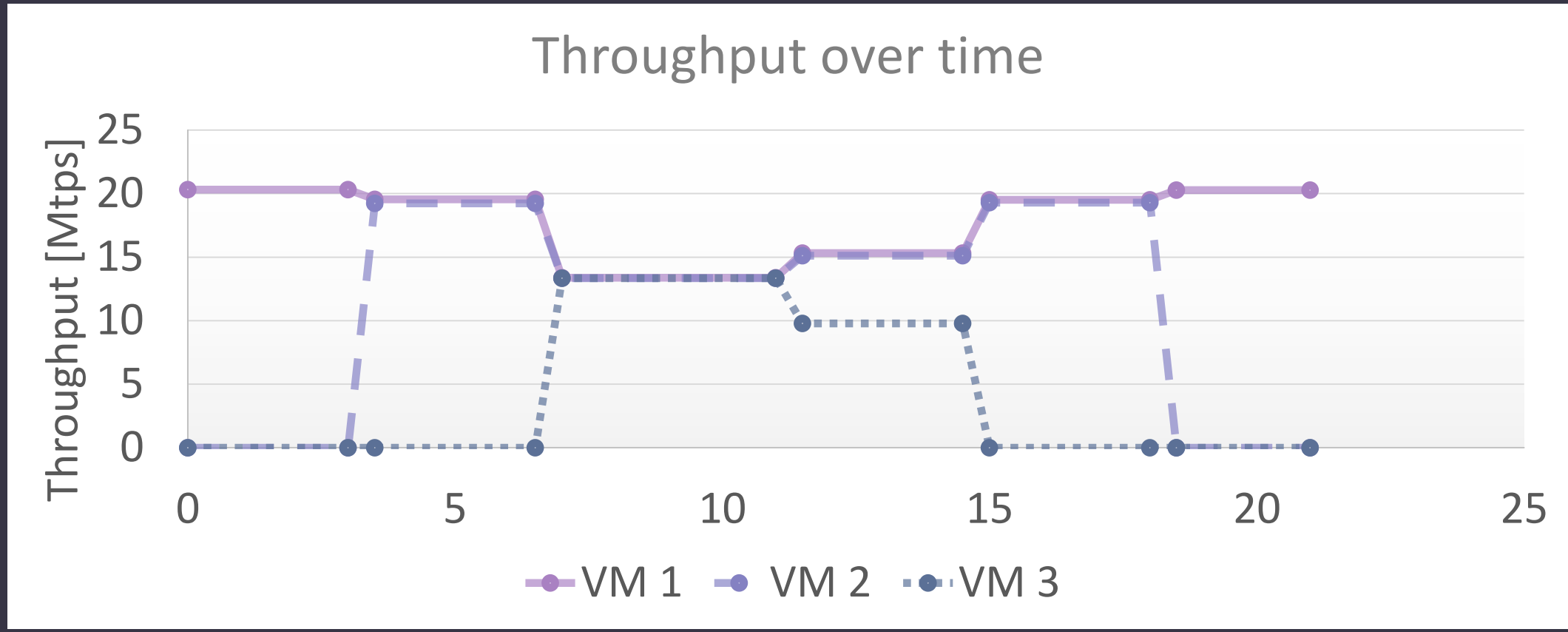


Latency under virtualization

- 60% hit-rate – 2.1 µs
  - same as bare-metal
- Misses on the CPU – 12-62 µs
  - Compared to 6 µs on bare-metal
- Negligible sharing overhead



Key-Value Store – Performance Isolation



Conclusion

- NICA framework enables SmartNIC inline processing in cloud environments.
- Find our code at  https://github.com/acsl-technion/nica

Thank you!

Questions?