Computer Networks COL 334/672

Software Defined Networking

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Slides adapted from KR

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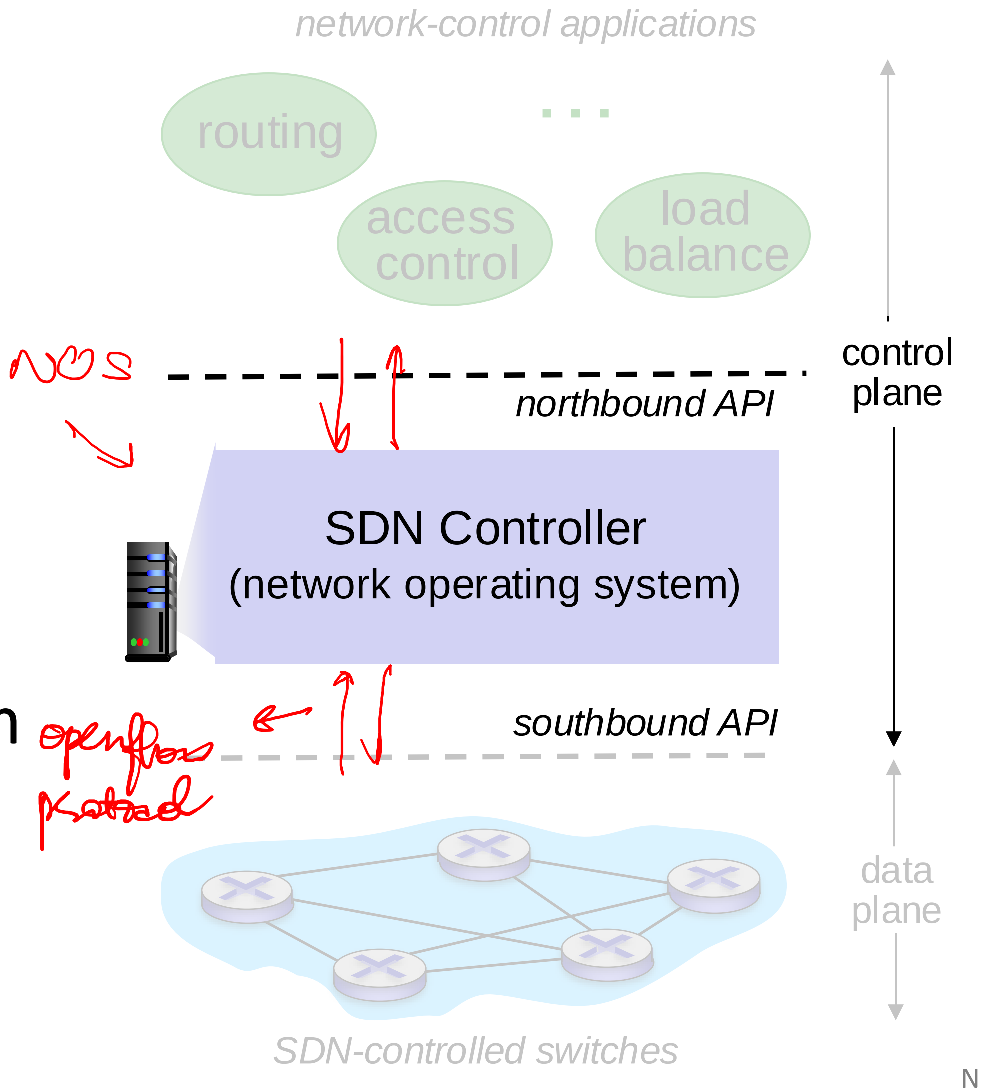
Recap: SDN Controller

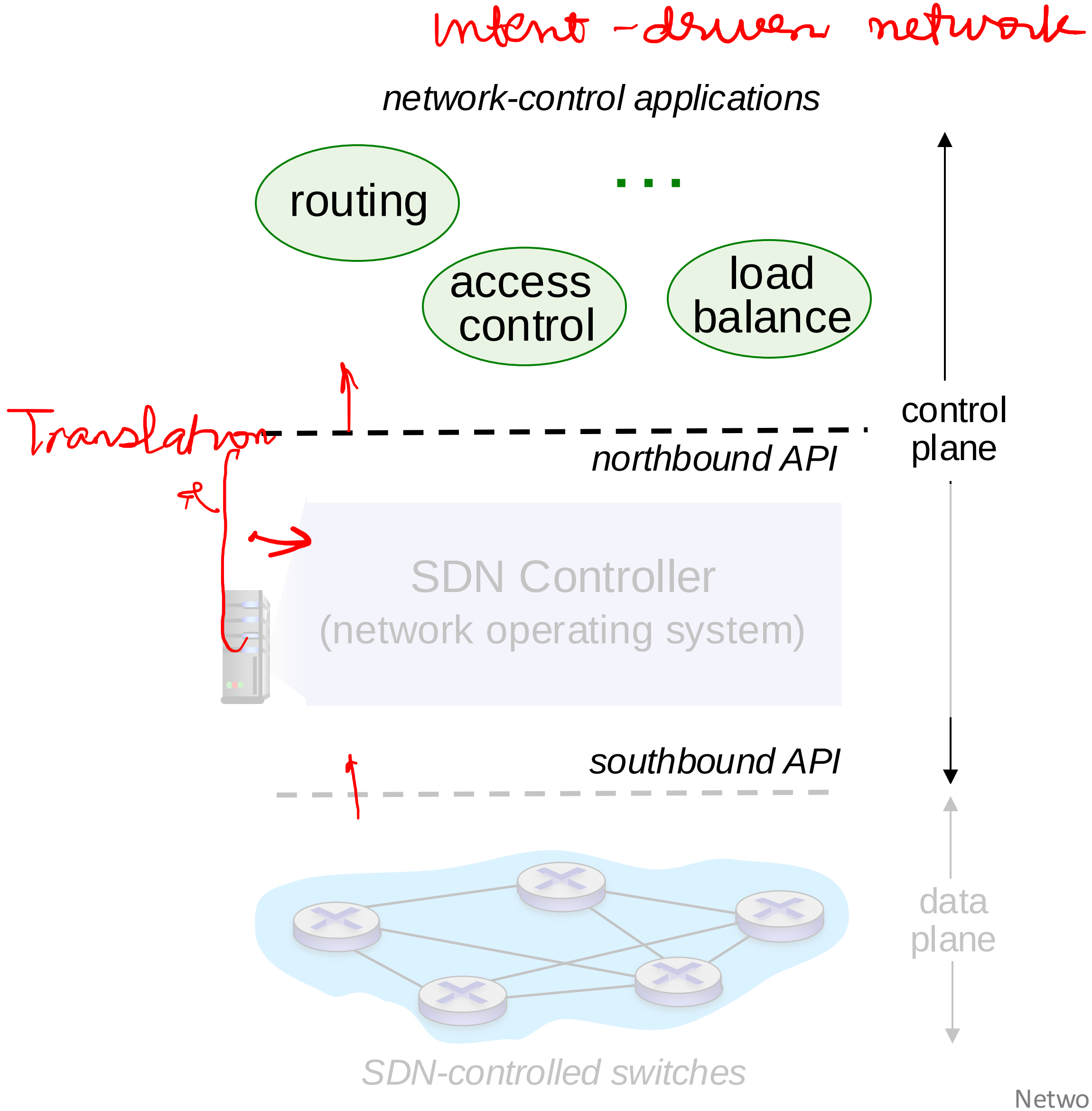
- maintains network state information
- interacts with network control applications "above" via northbound API
- interacts with network switches "below" via southbound API
- implemented as distributed system for performance, scalability, fault-tolerance, robustness



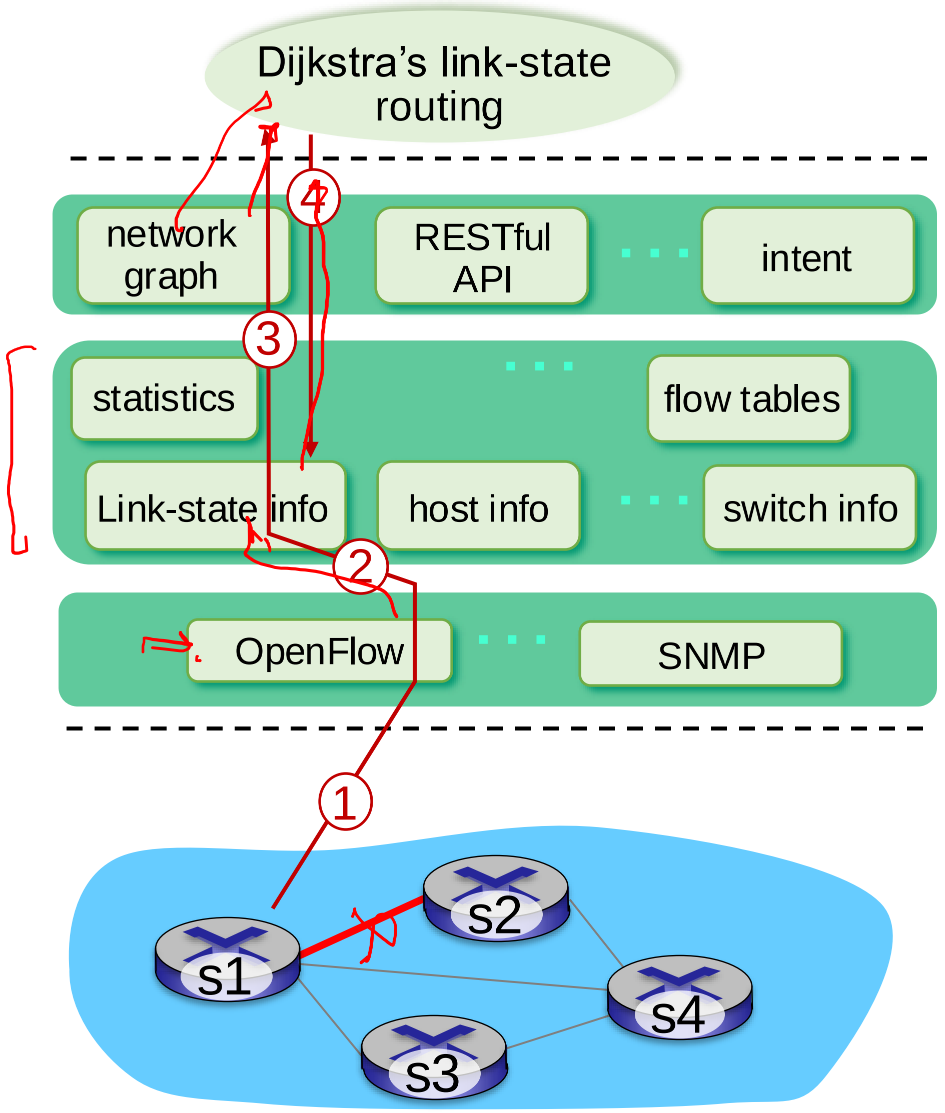
protocol → application

Software defined networking (SDN)

- operators don't "program" switches by creating/sending OpenFlow messages directly.
- Instead use higher-level abstraction at controller
- "brains" of control: implement control functions using lower-level services, API provided by SDN controller
- *unbundled:* can be provided by 3rd party: distinct from routing vendor, or SDN controller



SDN: control/data plane interaction example



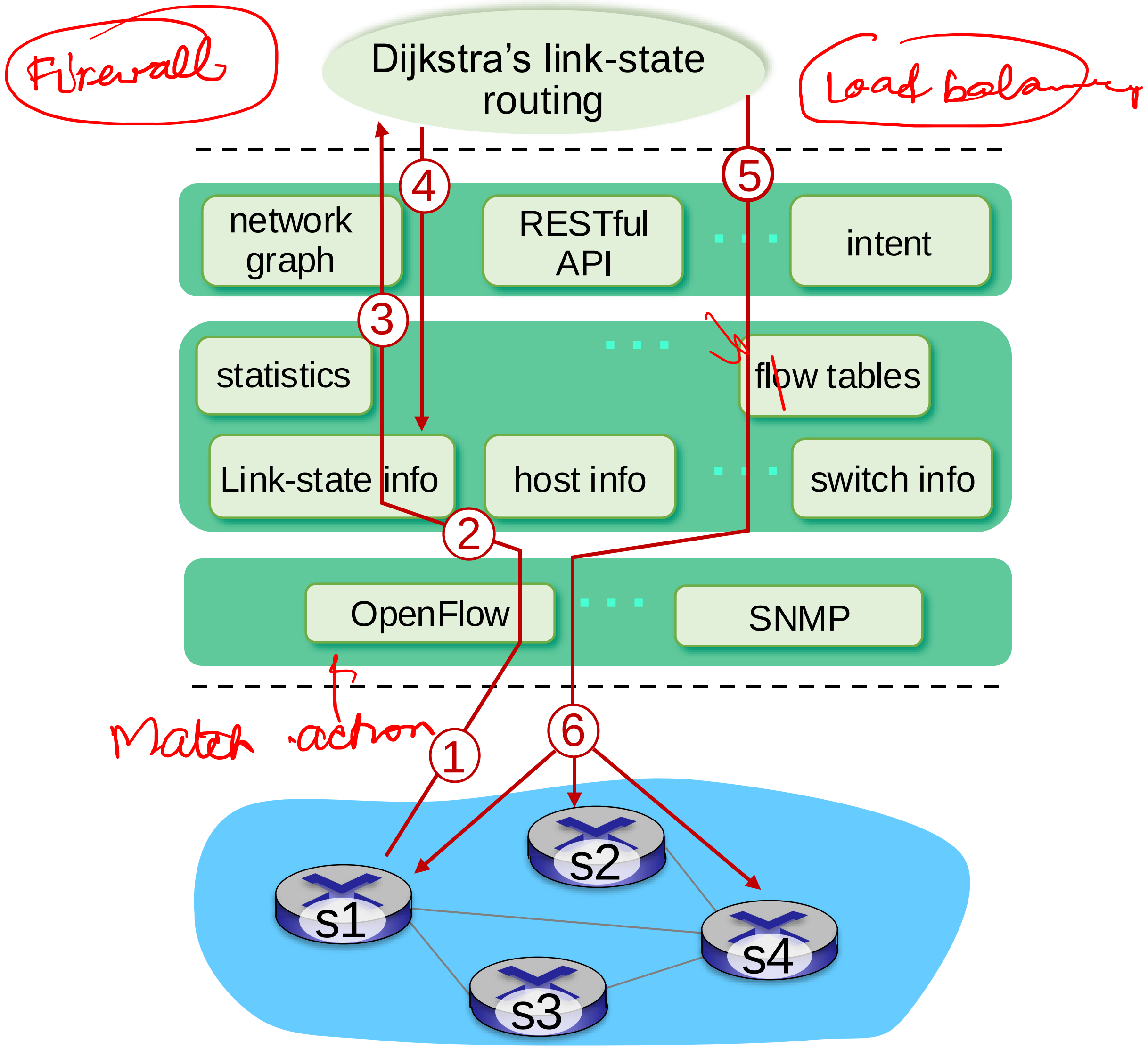
1. S1, experiencing link failure uses OpenFlow port status message to notify controller

2. SDN controller receives OpenFlow message, updates link status info

3. Dijkstra's routing algorithm application has previously registered to be called when ever link status changes. It is called.

4. Dijkstra's routing algorithm access network graph info, link state info in controller, computes new routes

SDN: control/data plane interaction example



⑤ link state routing app interacts with flow-table-computation component in SDN controller, which computes new flow tables needed

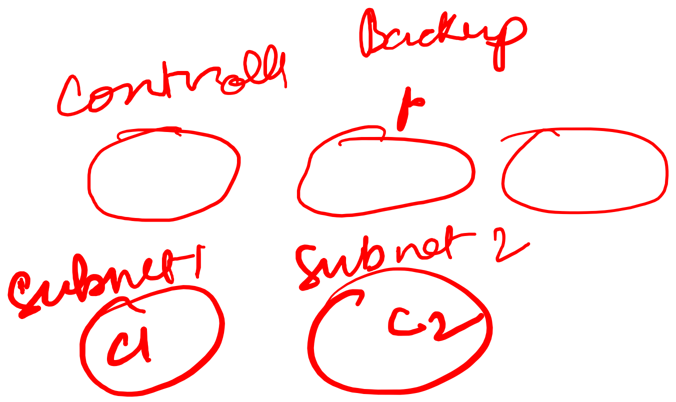
⑥ controller uses OpenFlow to install new tables in switches that need updating

SDN: Key Challenges

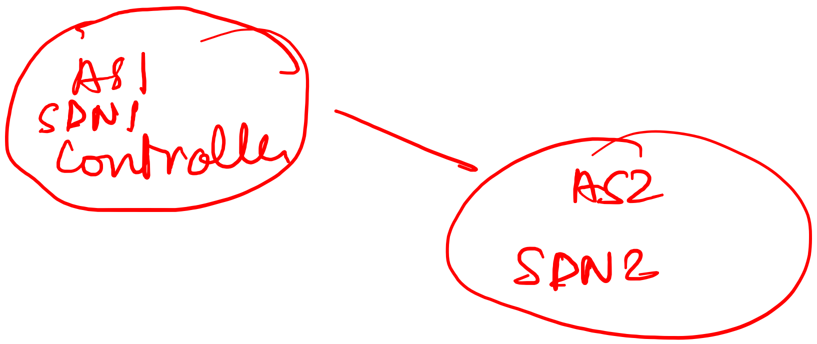
- Hardening the control plane
  - Scalability
  - Reliability
  - Consistency
  - Security

→ Real-time → logically centralize

→ Distributed systems



- Internet-scaling: beyond a single AS (?)

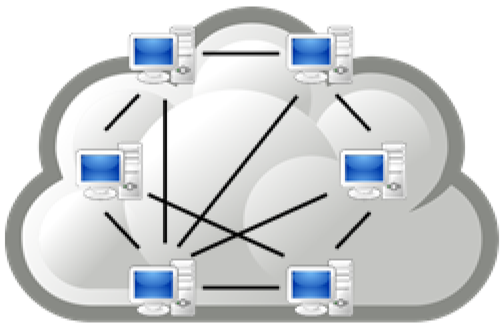


What else is programmable in the network?

- Programmable data plane
- Network function virtualization (NFV)

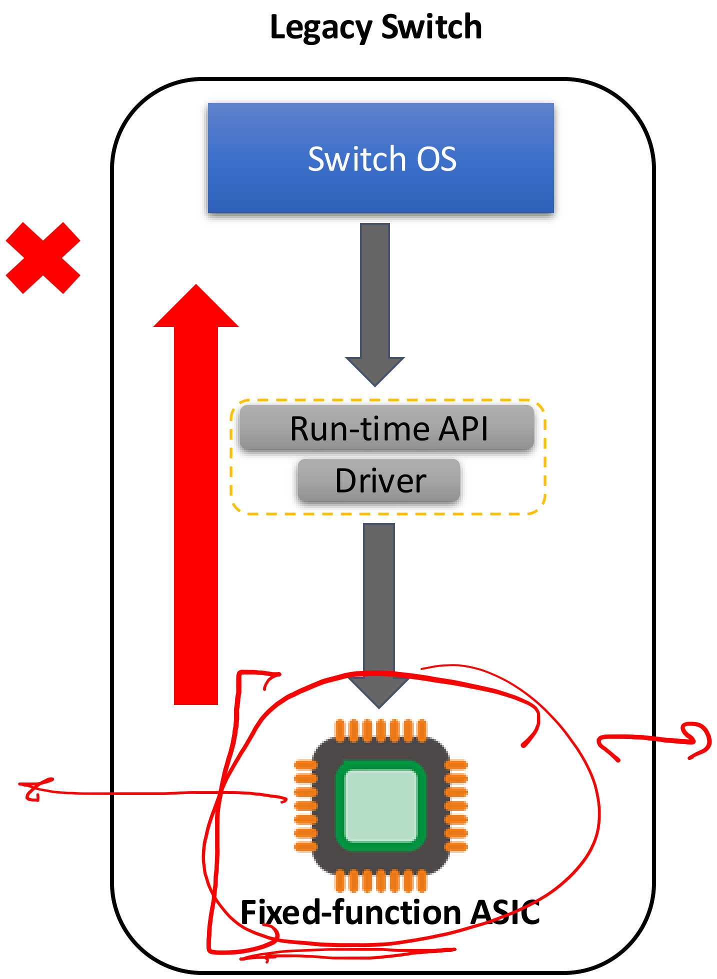
making middleboxes programmable

Status Quo: Bottom-up design



network

Custom requirements



Data plane

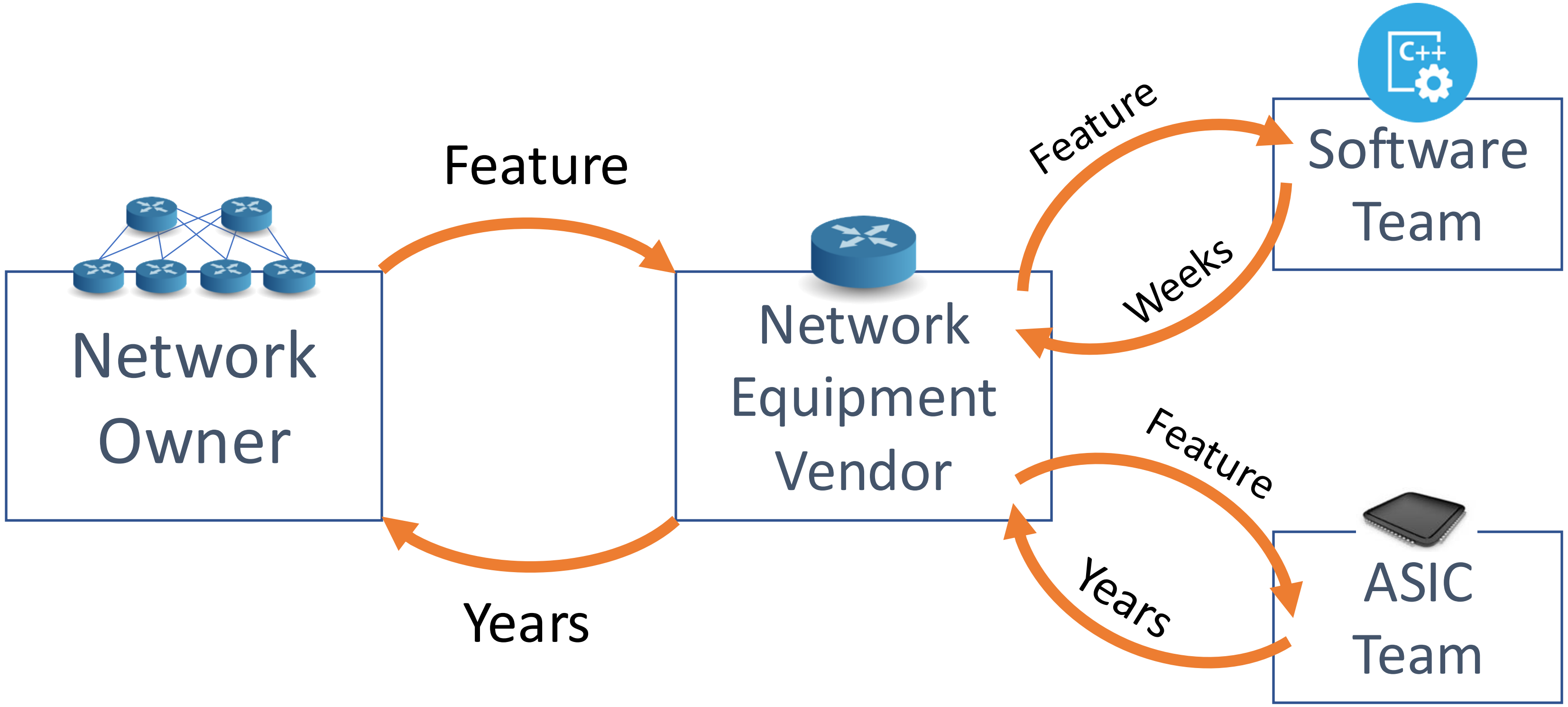
Congestion aware ro

ETH | IP

20 bytes + 40 byte

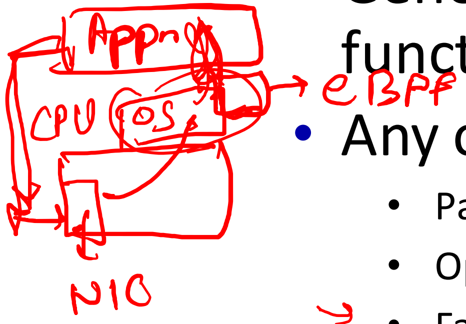
The ASIC datasheet dictates the rules!

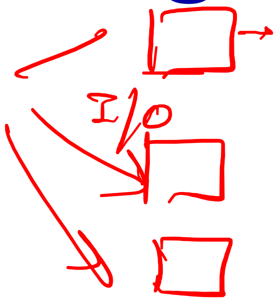
ETH | IP | Tra | App


Feature
Network Owner
Years
Network Equipment Vendor
Feature
Software Team
C++
Weeks
Feature
Years
ASIC Team

How to make Data Plane Programmable?

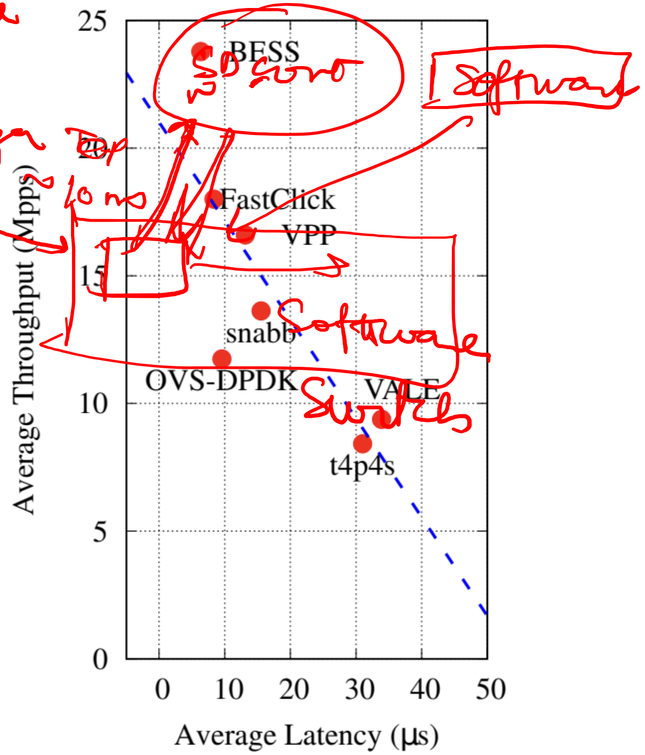
- Move the data plane to software
  - Generally, too slow for data plane functions
  - Any optimization techniques?
    - Parallelism across multiple servers and cores
    - Optimizations in NUMA
    - Fast I/O …



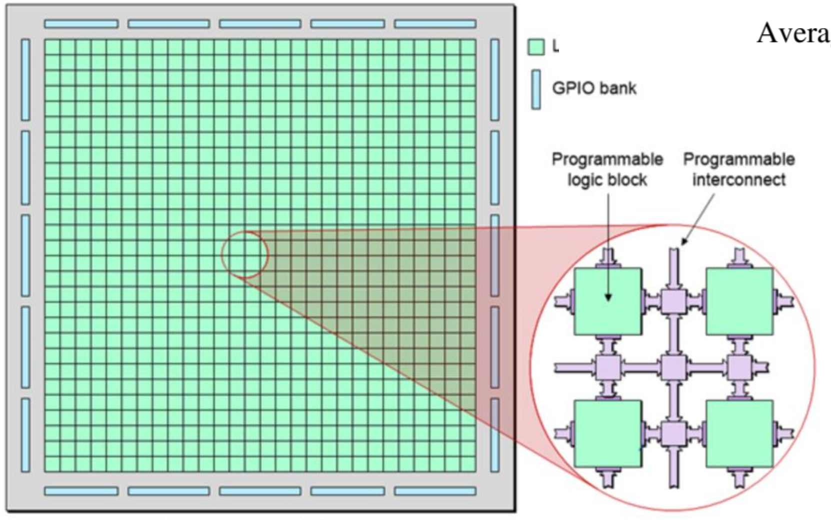


Multiple CPU

Multiple level of storage



- What about programmable hardware?
  - FPGA: but costly, power-hungry, slower



Bird's-eye view of FPGA

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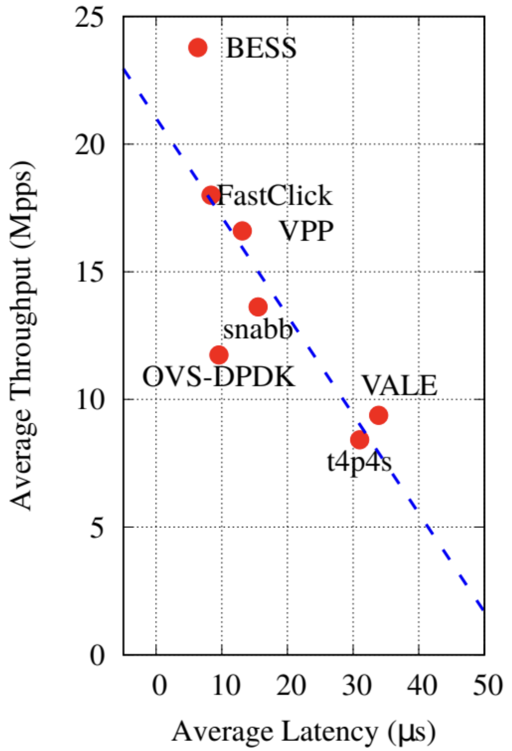

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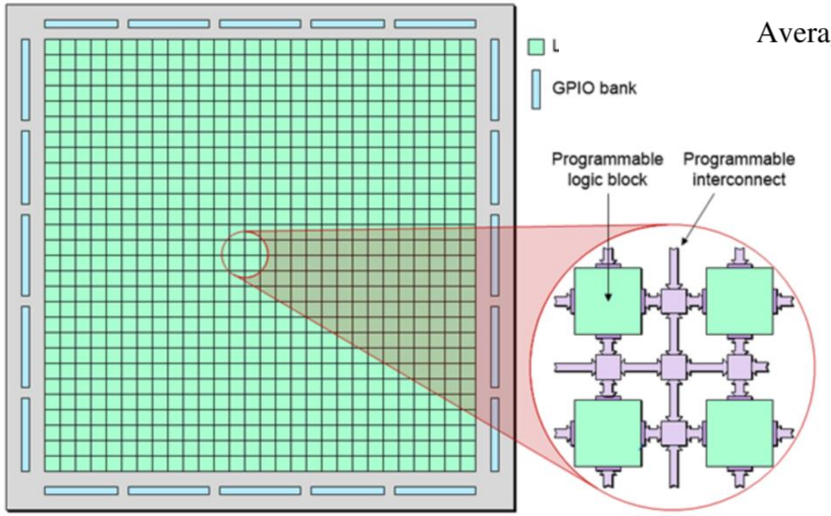


Bird's-eye view of FPGA

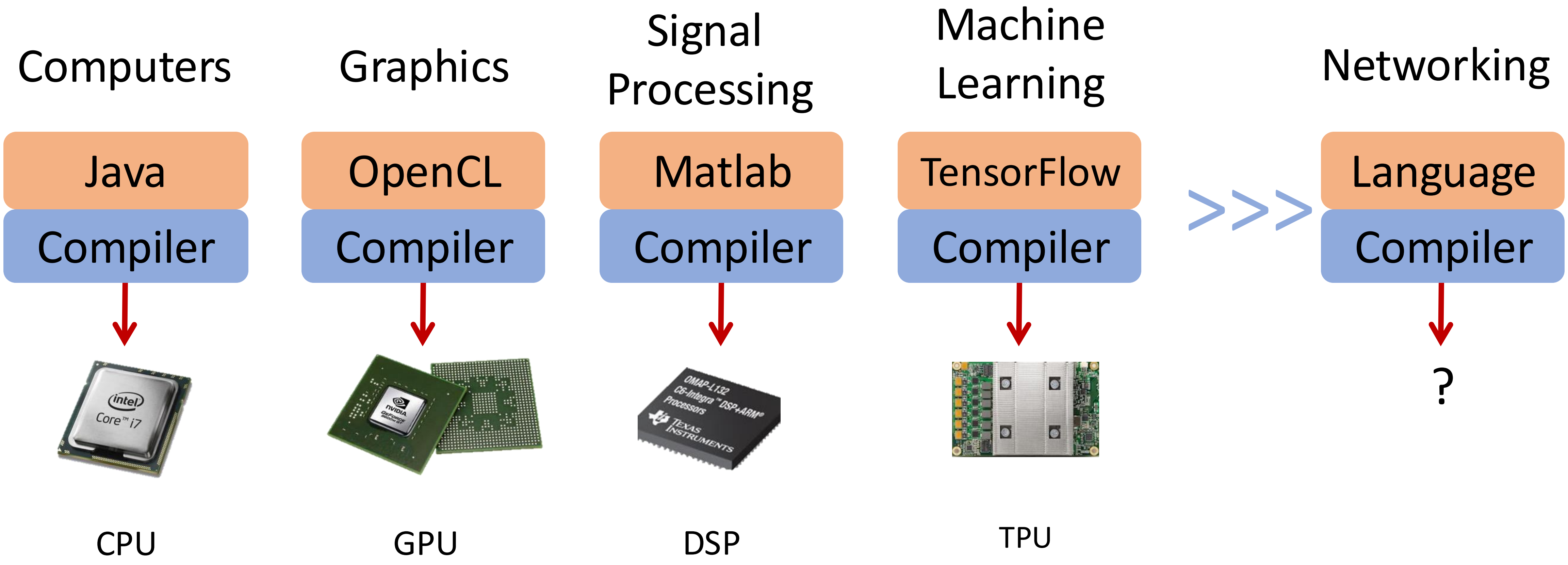
What about Programmable Hardware?

“Programmable swi 10-100x slower than fixe on switches. They are mor sive and consume power.”

nventional wisdom in networking

Not true any more!

Domain Specific Processors



Computers

Java

Compiler

CPU

Graphics

OpenCL

Compiler

GPU

Signal Processing

Matlab

Compiler

DSP

Machine Learning

TensorFlow

Compiler

TPU

>>>

Networking

Language

Compiler

?

Domain Specific Processors

Computers

Java

Compiler

CPU

Graphics

OpenCL

Compiler

GPU

Signal Processing

Matlab

Compiler

DSP

Machine Learning

TensorFlow

Compiler

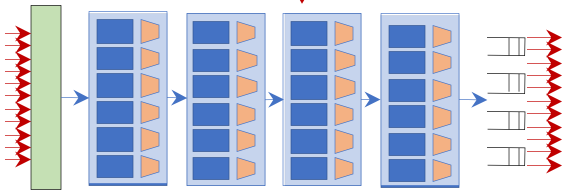
TPU

>>>

Networking

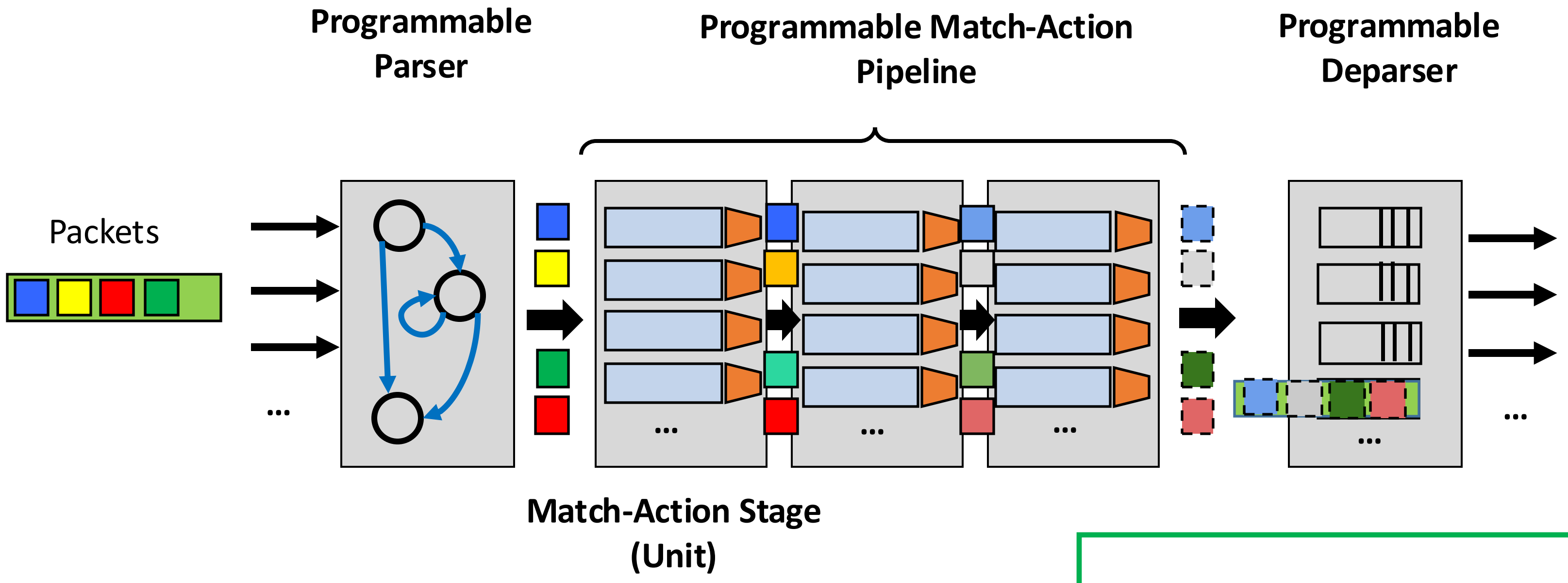
P4

Compiler



PISA

Protocol Independent Switch Architecture



P4 describes PISA's behavior

Reducing complexity

switch.p4
Switch OS

IPv4 and IPv6 routing
- Unicast Routing
  - Routed Ports & SVI
  - VRF
- Unicast RPF
  - Strict and Loose
- ~~Multicast~~
  - ~~PIM-SM/DM & PIM-Bidir~~

Ethernet switching
- ~~VLAN Flooding~~
- MAC Learning & Aging
- STP state
- ~~VLAN Translation~~

Load balancing
- ~~LAG~~
- ECMP & WCMP
- Resilient Hashing
- ~~Flowlet Switching~~

Fast Failover
- LAG & ECMP

Tunneling
- IPv4 and IPv6 Routing & Switching
  - ~~IP in IP (6in4, 4in4)~~
  - VXLAN, NVGRE, GENEVE & GRE
  - ~~Segment Routing, ILA~~

~~**MPLS**~~
- ~~LER and LSR~~
- ~~IPv4/v6 routing (L3VPN)~~
- ~~L2 switching (EoMPLS, VPLS)~~
- ~~MPLS over UDP/GRE~~

ACL
- MAC ACL, IPv4/v6 ACL, RACL
- ~~QoS ACL, System ACL, PBR~~
- Port Range lookups in ACLs

QOS
- QoS Classification & marking
- ~~Drop profiles/WRED~~
- ~~RoCE v2 & FCoE~~
- CoPP (Control plane policing)

~~**NAT and L4 Load Balancing**~~

Security Features
- ~~Storm Control, IP Source Guard~~

Monitoring & Telemetry
- ~~Ingress Mirroring and Egress Mirroring~~
- Negative Mirroring
- ~~Sflow~~
- INT

Counters
- Route Table Entry Counters
- ~~VLAN/Bridge Domain Counters~~
- Port/Interface Counters

Protocol Offload
- BFD, OAM

Multi-chip Fabric Support
- ~~Forwarding, QOS~~

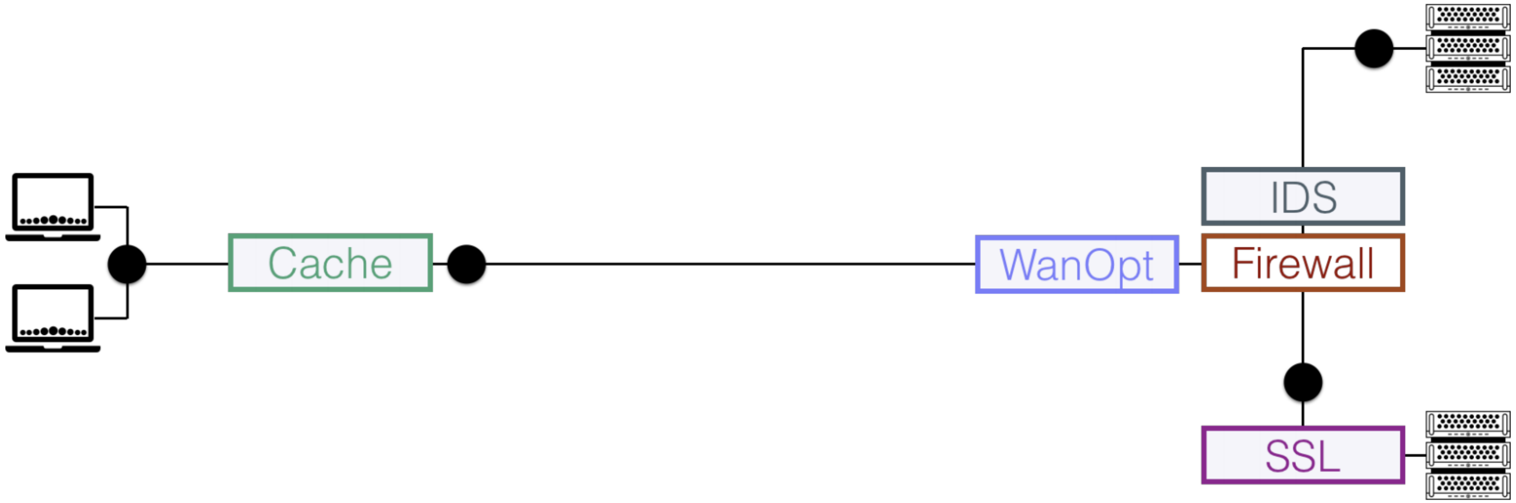
What else is programmable in the network?

- Programmable data plane

- **Network function virtualization**

Middleboxes

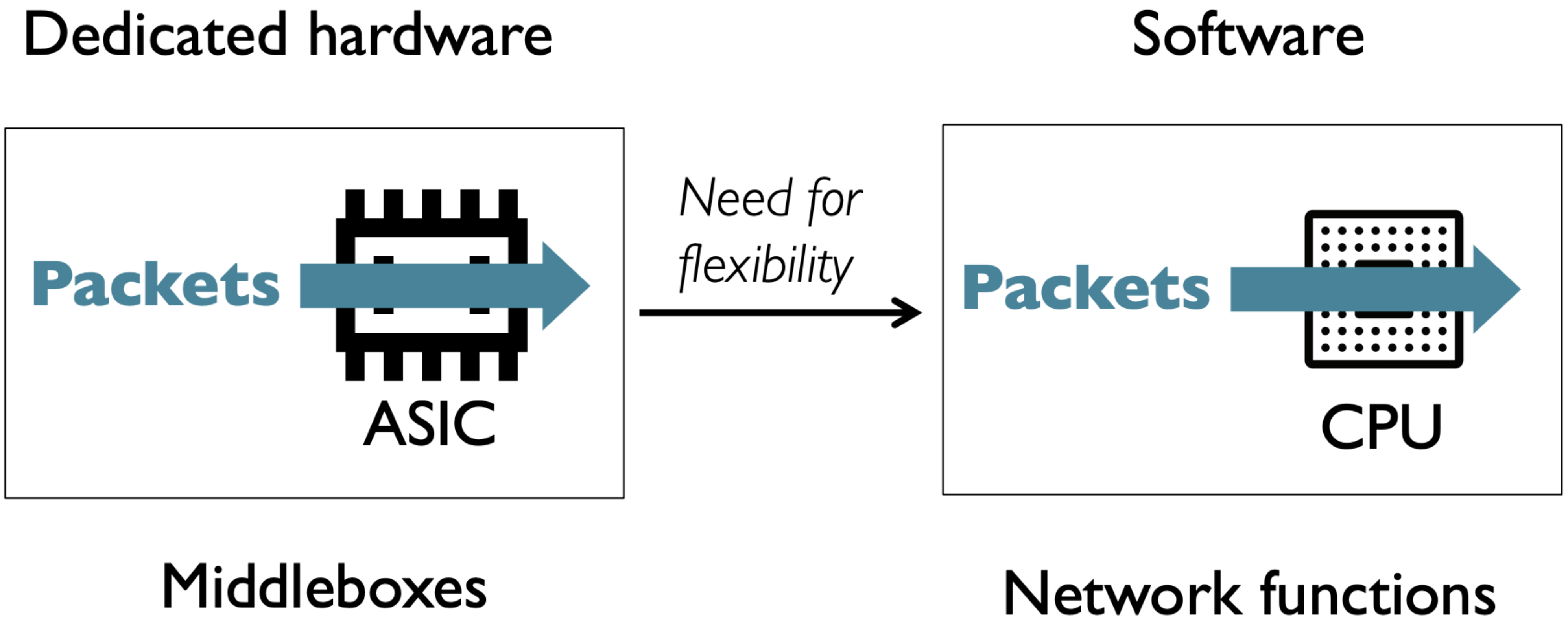
Data delivery is not the only required functionality.



Elements in the network path for security, performance enhancements etc.

One-third of all network devices in enterprises are middleboxes!
Sherry et al., SIGCOMM'12

Evolution of Middleboxes



Dedicated hardware

Packets

ASIC

Middleboxes

Need for flexibility

Software

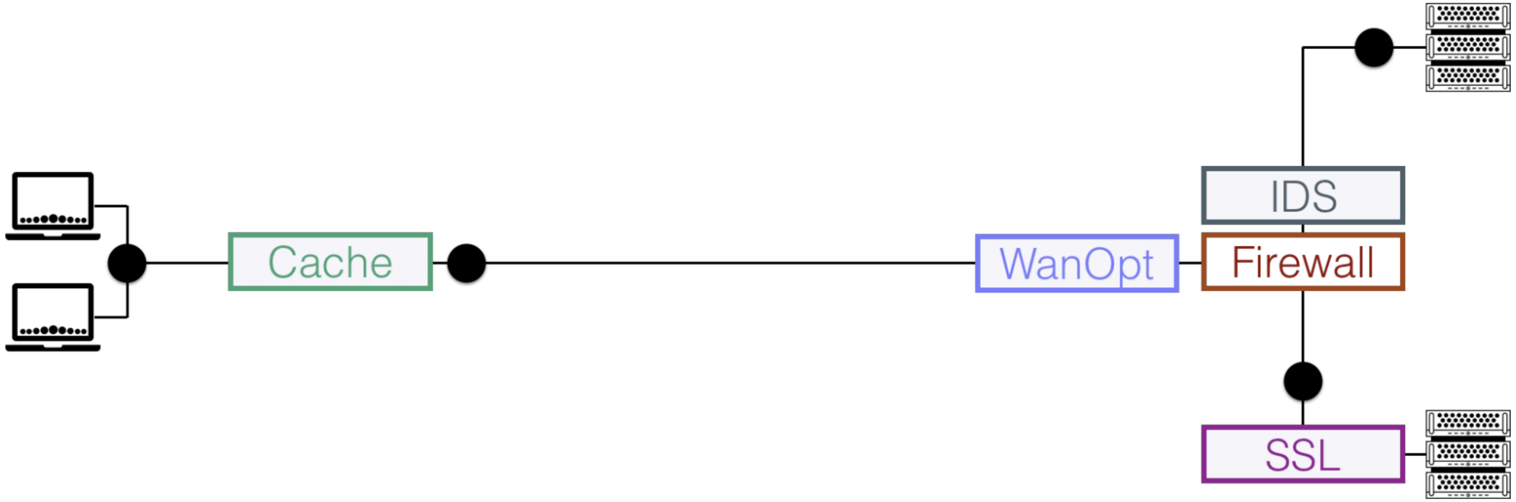
Packets

CPU

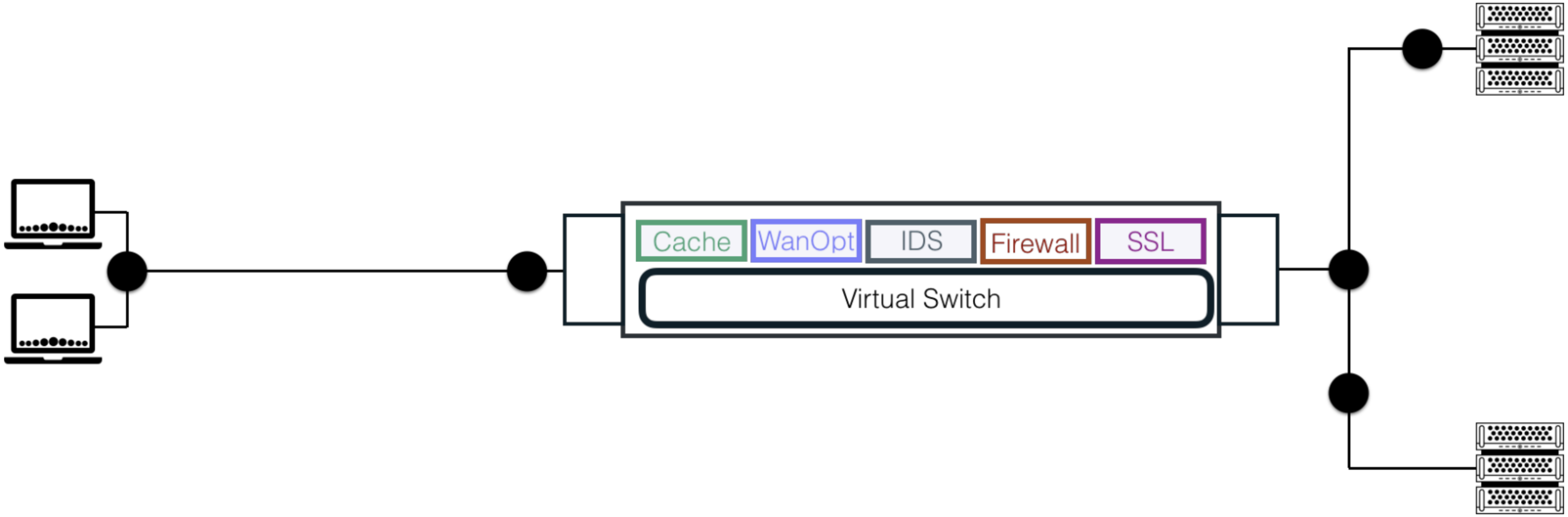
Network functions

From Hardware Middleboxes..

Data delivery is not the only required functionality.



To Software Network Functions (NF)



Primarily deployed in a VM

(Network Function Virtualization or NFV)

Functional Elements, not Middleboxes

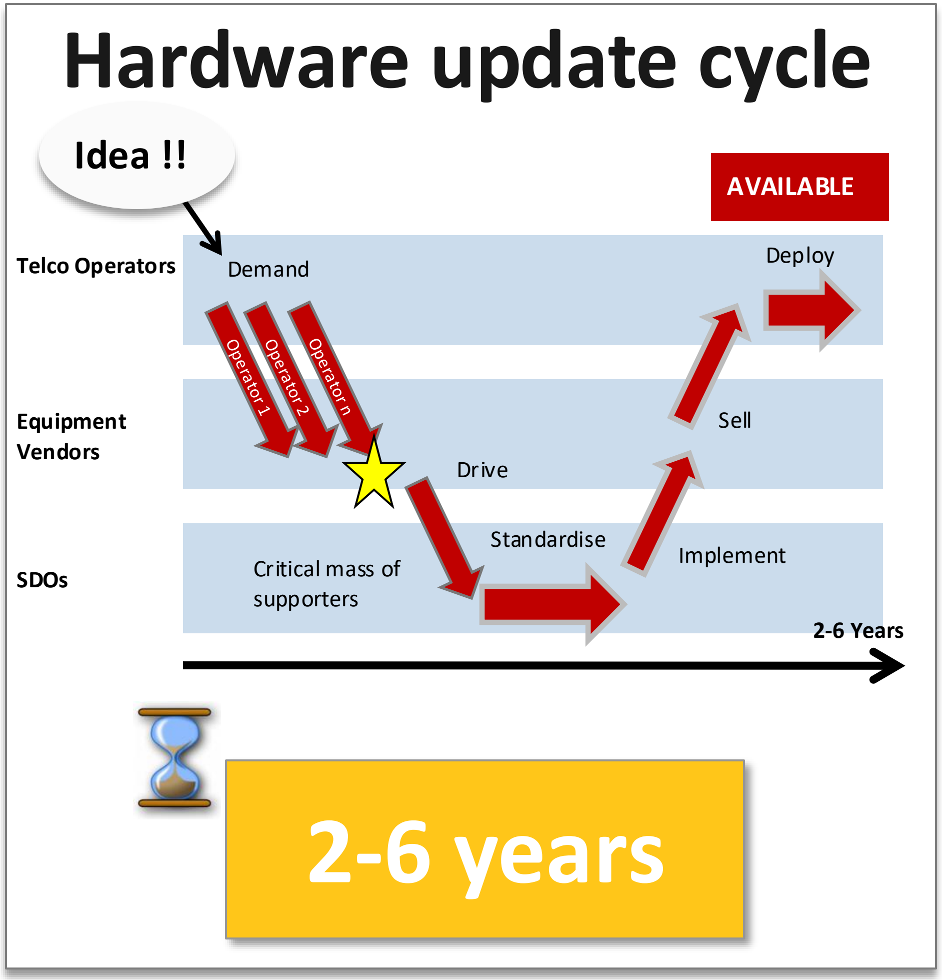
- WAN Optimizer = Caching + Deduplication + Compression + Encryption + Forward Error Correction + Rate Limiter

- Application Firewall = IP Defragmenter + Application Detection Engine + Logger + Blocker

- IDS = IP Defragmenter + Preprocessing + Misuse Detection Engine + Logger

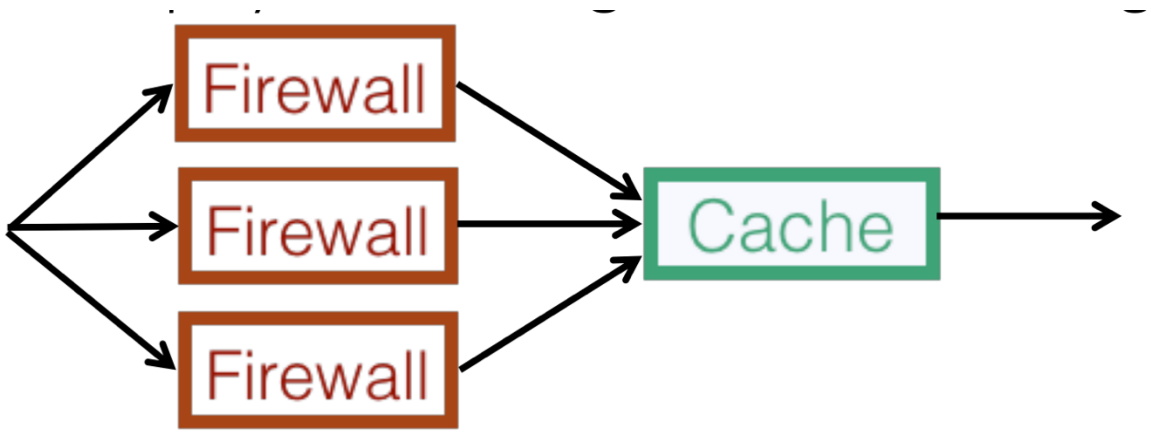
Why NFV?

- Softwarization leads to faster innovation



Why NFV?

- Softwarization leads to faster innovation
- Ease of deployment, configuration, and management
- Consolidation: Reduce number of hardware boxes in the network



Being adopted by both carriers and cloud providers

NFV Challenges

- Virtual network function management
  - Where and how to install network functions?
- Unpredictable (low) Performance
  - How to mitigate the overheads of virtualization?
- Fault Tolerance
  - How to handle recovery in case of faults?

Summary

- Increased programmability in the networks
  - Greater flexibility → Faster innovation

- Programmable control plane
  - SDN

- Programmable data plane
  - SDN-2 / P4

- Software middleboxes implemented in VMs
  - Network function virtualization (NFV)

Attendance