Computer Networks
@CS.NYCU

Lecture 5: Network Layer: Control Plane

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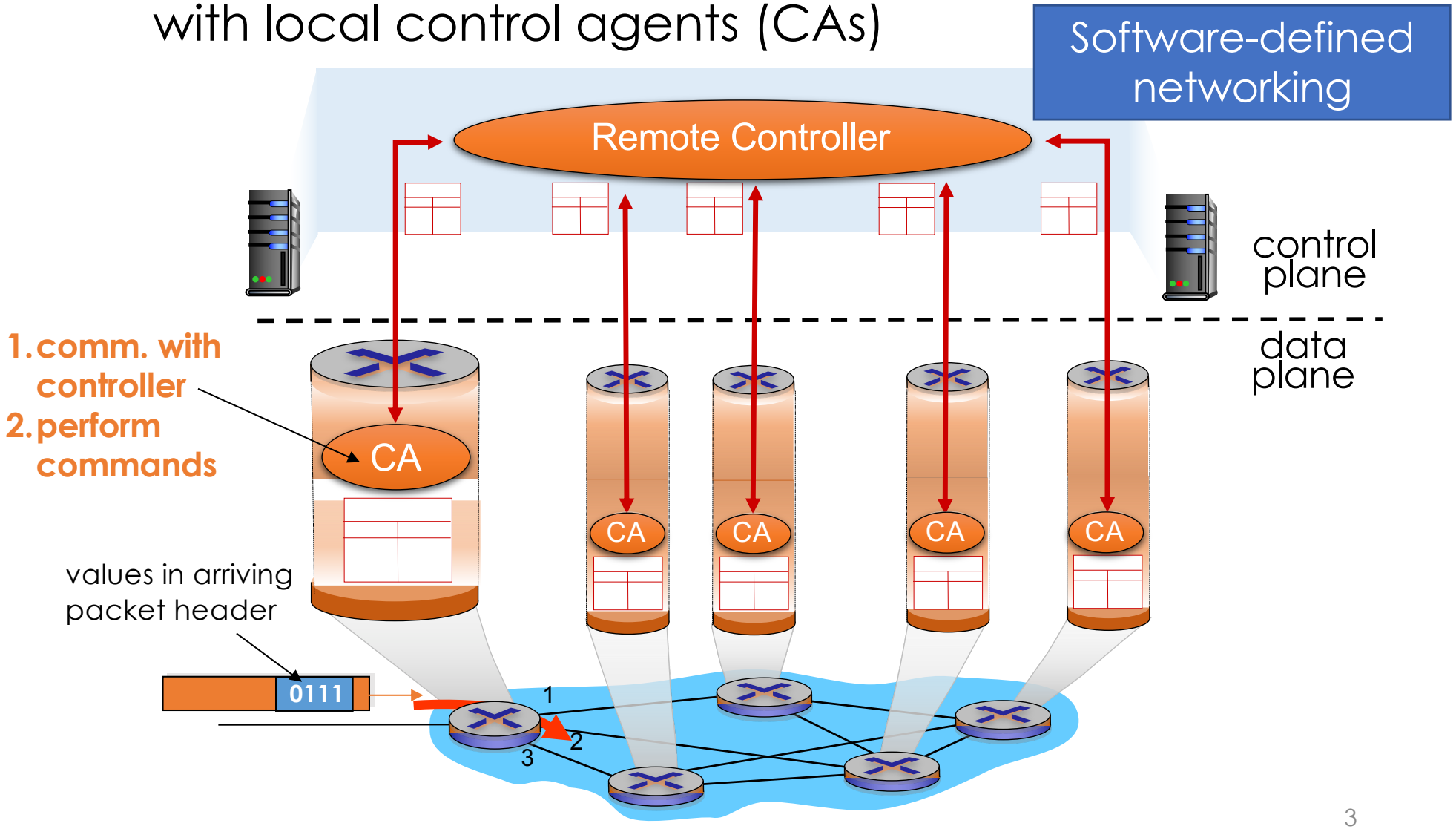
Slides modified from
"Computer Networking: A Top-Down Approach" 7th Edition

Outline

- Routing
  - Link-State Algorithm
  - Distance-Vector Algorithm
- Intra-AS Routing
- Inter-AP Routing
- **SDN Control Plane**
- ICMP
- SNMP

Centralized Control Plane

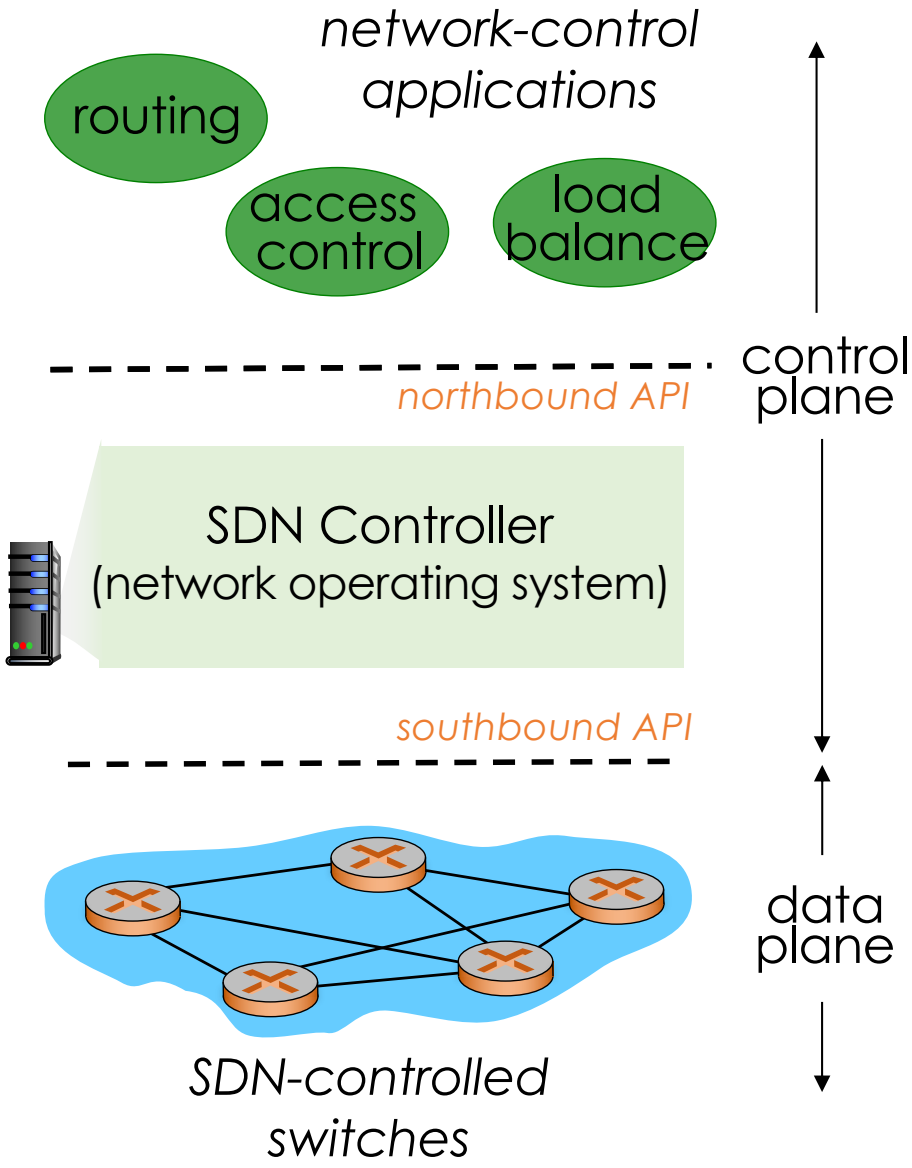
- A distinct (typically remote) controller interacts with local control agents (CAs)



SDN Characteristics

- Flow-based Forwarding
  - OpenFlow (now version 1.4): controller installs forwarding rules of a flow in certain OpenFlow switches
- Separation of data plane and control plane
  - Controller: do complex scheduling
  - Switch: "match plus action" (simple and fast)
- Controller is external to data-plane switches
  - Controller can be implemented on distributed servers → flexible, scalable
- Programmable network
  - Network becomes programmable as a controller is a "software" (e.g., use specific routing algorithm rather than Dijkstra's algorithm)

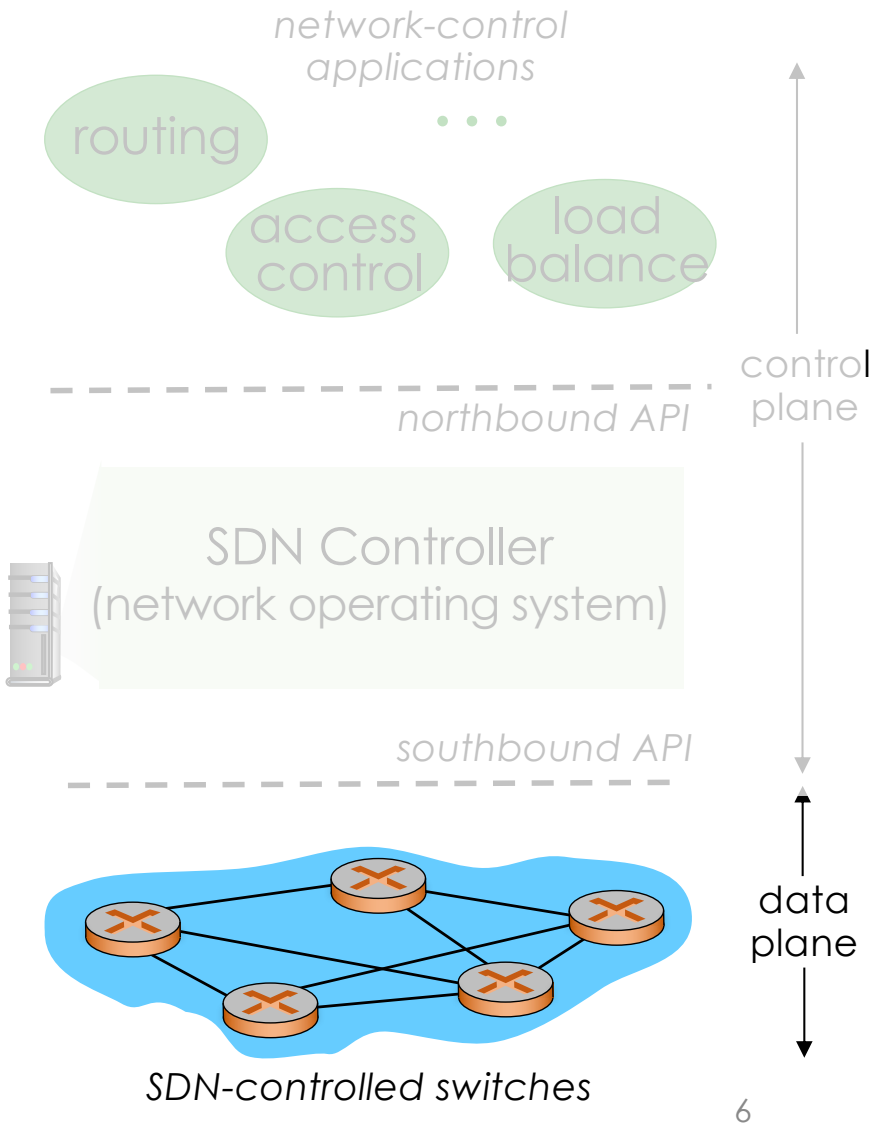
SDN Architecture



SDN Architecture: Data Plane

Data plane switches

- Fast, simple, commodity switches implementing generalized forwarding in hardware
- Switch flow table computed, installed by controller
- API for table-based switch control (e.g., OpenFlow)
  - define what is controllable and what is not
- Follow OpenFlow to communicate with controller

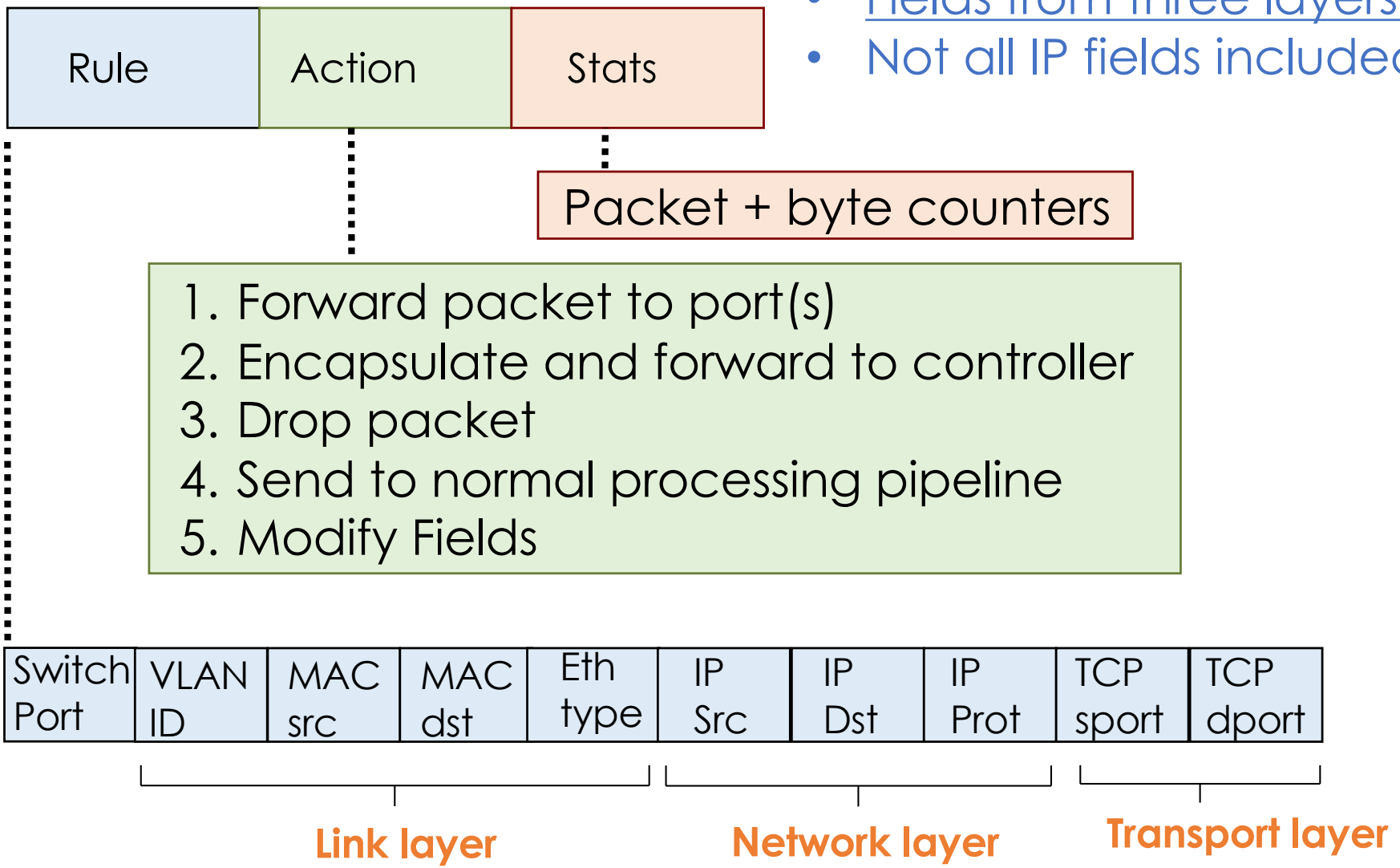


OpenFlow

- Standard for SDN data plane and controllers
  - Currently, version 1.4
- Match-plus-Action
  - **Match**
    - Look up the felids in each packet header
    - Hardware-based matching: performed in TCAM (fast, but expensive, power consuming)
  - **Action**
    - Forwarding: to one ore more output port
    - Load balancing
    - Rewrite: rewrite header values (e.g., NAT)
    - Blocking/dropping
    - Further processing: send to the controller
  - **Counter**
    - Keep statistics (# bytes or # packets)

Packet Header Field

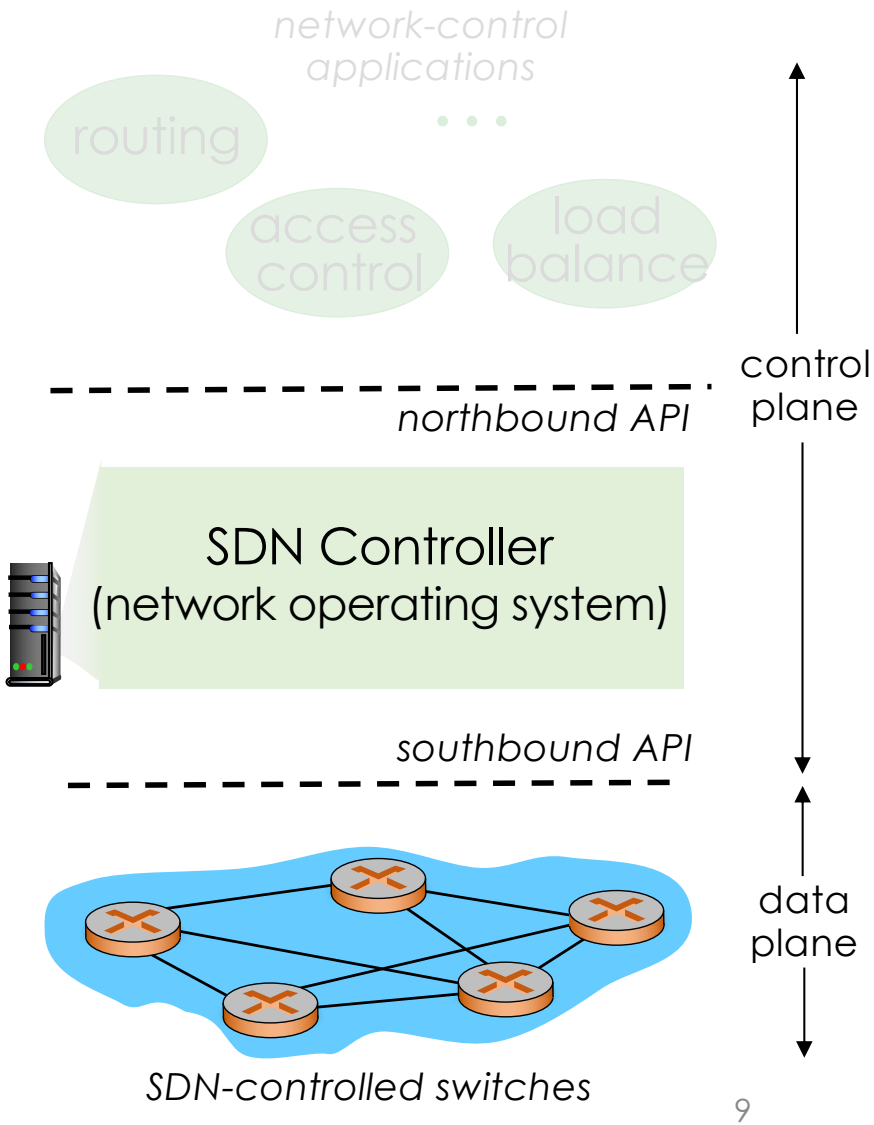
- Fields from three layers!
- Not all IP fields included



SDN Architecture: Controller

SDN controller (network OS):

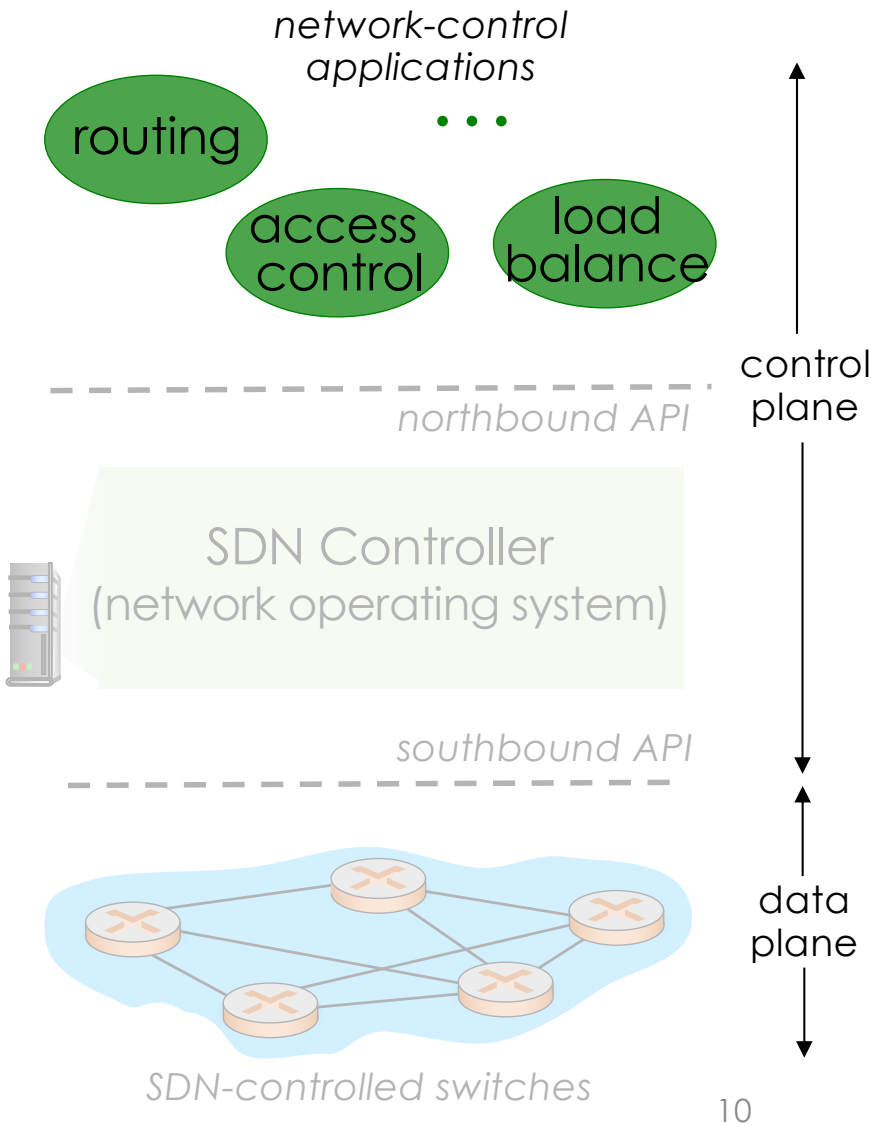
- Decision maker!
- Interact with network control applications via northbound API
- Interact with network switches via southbound API
- Implemented as distributed system for performance, scalability, fault-tolerance, robustness



SDN Architecture: Control App

network-control apps:

- "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

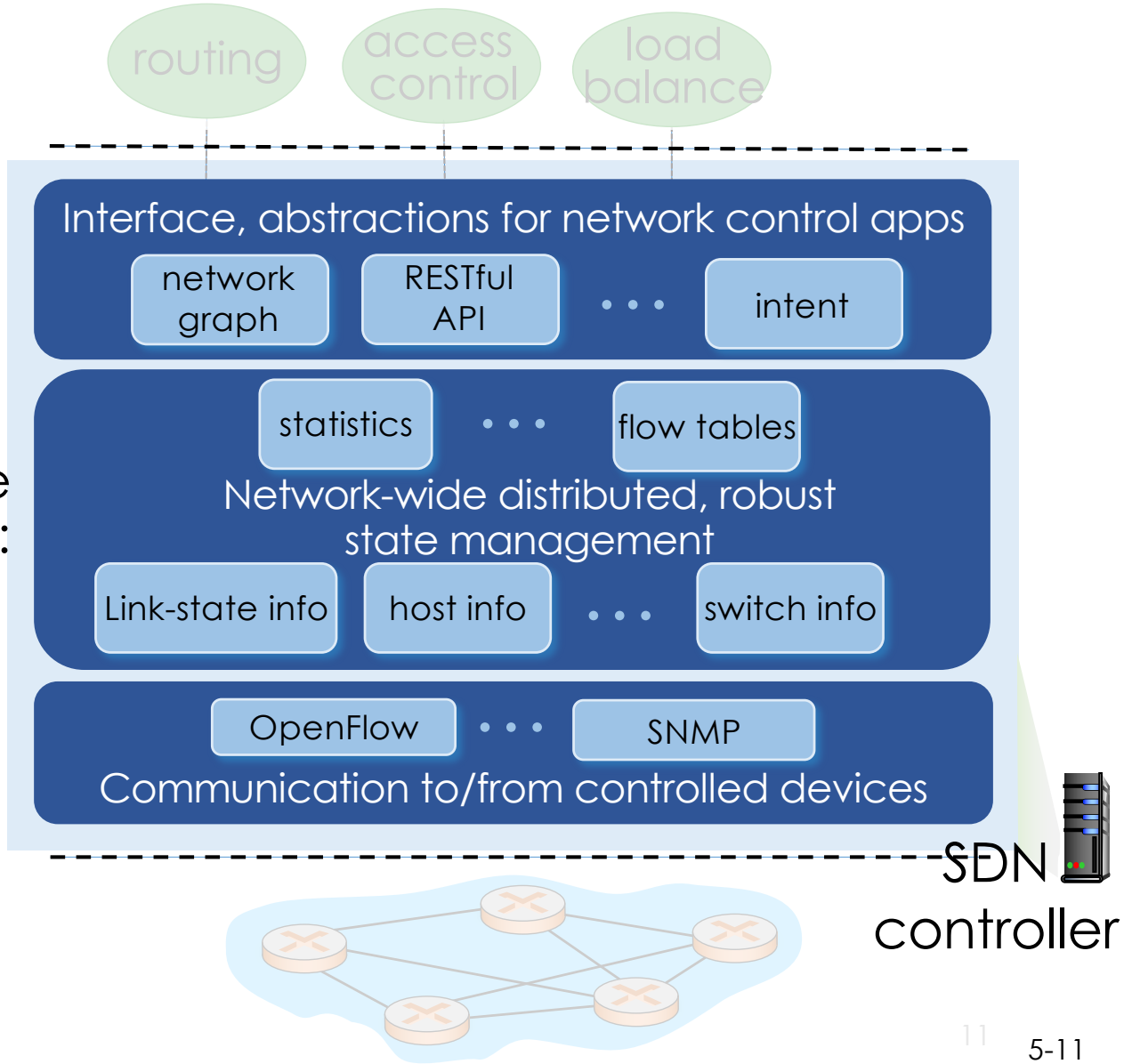


Components of SDN Controller

Interface layer to network control apps: abstractions API

network-wide state management layer: state of links, switches, services: a *distributed database*

communication layer: communicate between SDN controller and controlled switches



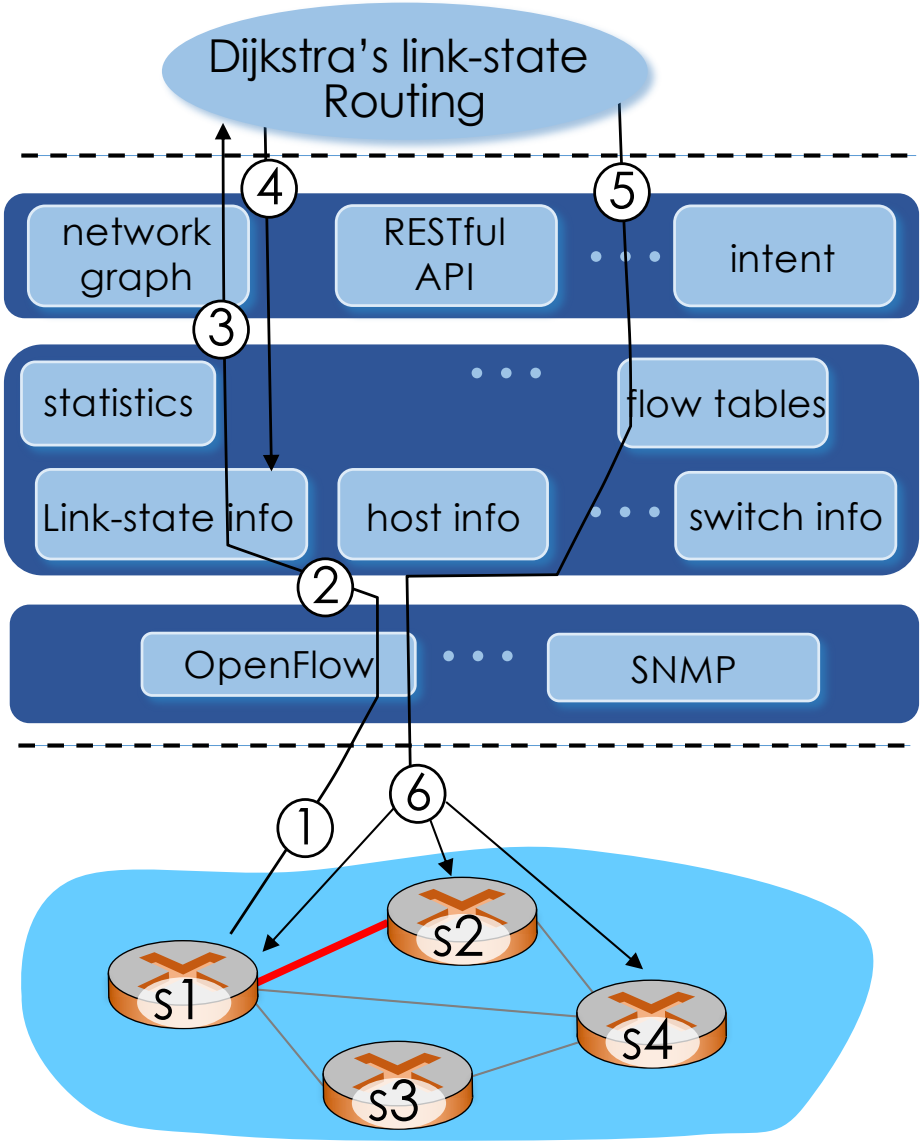
OpenFlow

- A protocol defines operations between an SDN controller and an SDN-controlled switch
  - OpenFlow switch: follow OpenFlow protocol
  - legacy switch: does not understand OpenFlow
- Operate over **TCP**
- Default port: **6653**
- Open Networking Foundation (**ONF**)
  - non-profit organization
  - promote networking through software-defined networking (SDN)
  - standardize the OpenFlow protocol and related technologies

OpenFlow Messages

- From controller to switch
  - **Configuration**: query and set a switch's parameter
  - **Modify-State**: add/delete/modify flowtable entries
  - **Read-State**: collect statistics and counter values
  - **Send-Packet**: send a specific packet out of a specified port at a requested switch
- From switch to controller
  - **Flow-Removed**: informs the controller of a missing flow (after a timeout)
  - **Port-Status**: inform the change in port status
  - **Packet-In**: send packets to the controller if it does not know how to handle it

SDN Control Example



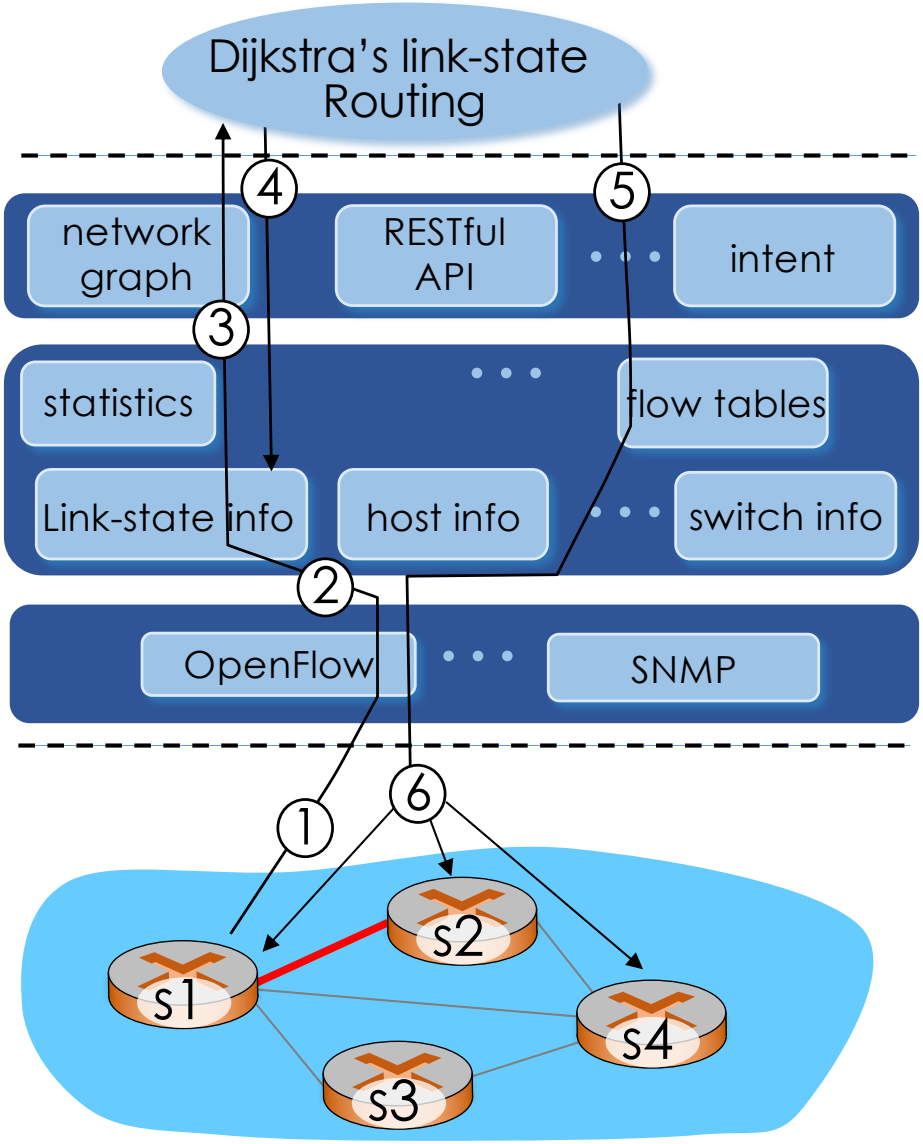
① S1, experiencing link failure using OpenFlow port status message to notify controller

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

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

SDN Control 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

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- SNMP

ICMP

- Internet Control Message Protocol
  - RFC 792
  - Used by hosts and routers to exchange network-layer information, e.g., error reporting
- Part of IP, but, architecturally, lie above IP as it is embedded inside IP datagrams

- Applications: ping, traceroute, etc

ICMP Message types

- Each ICMP message has a type and a code field

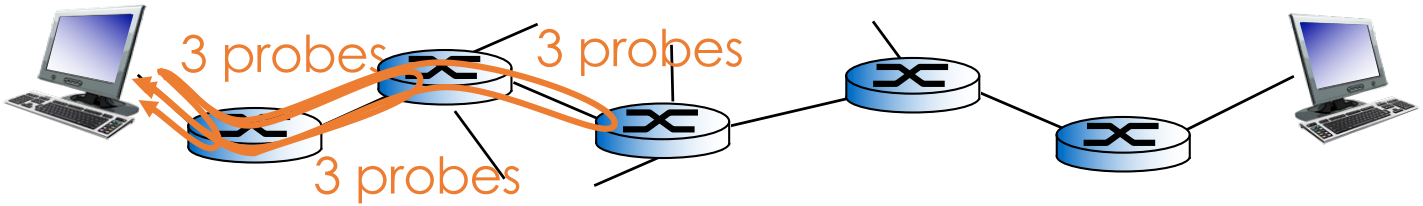
Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired (used by traceroute)
12	0	bad IP header

Traceroute and ICMP

- source sends series of UDP segments to destination
  - Set TTL to 1, 2, 3, ….
- when datagram in *n*th set arrives to *nth* router:
  - router discards datagram and sends source ICMP message (type 11, code 0)
  - ICMP message includes name of router & IP address
  - Source records RTTs

stopping criteria:

- UDP segment eventually arrives at destination host
- destination returns ICMP "port unreachable" message (type 3, code 3)
- source stops



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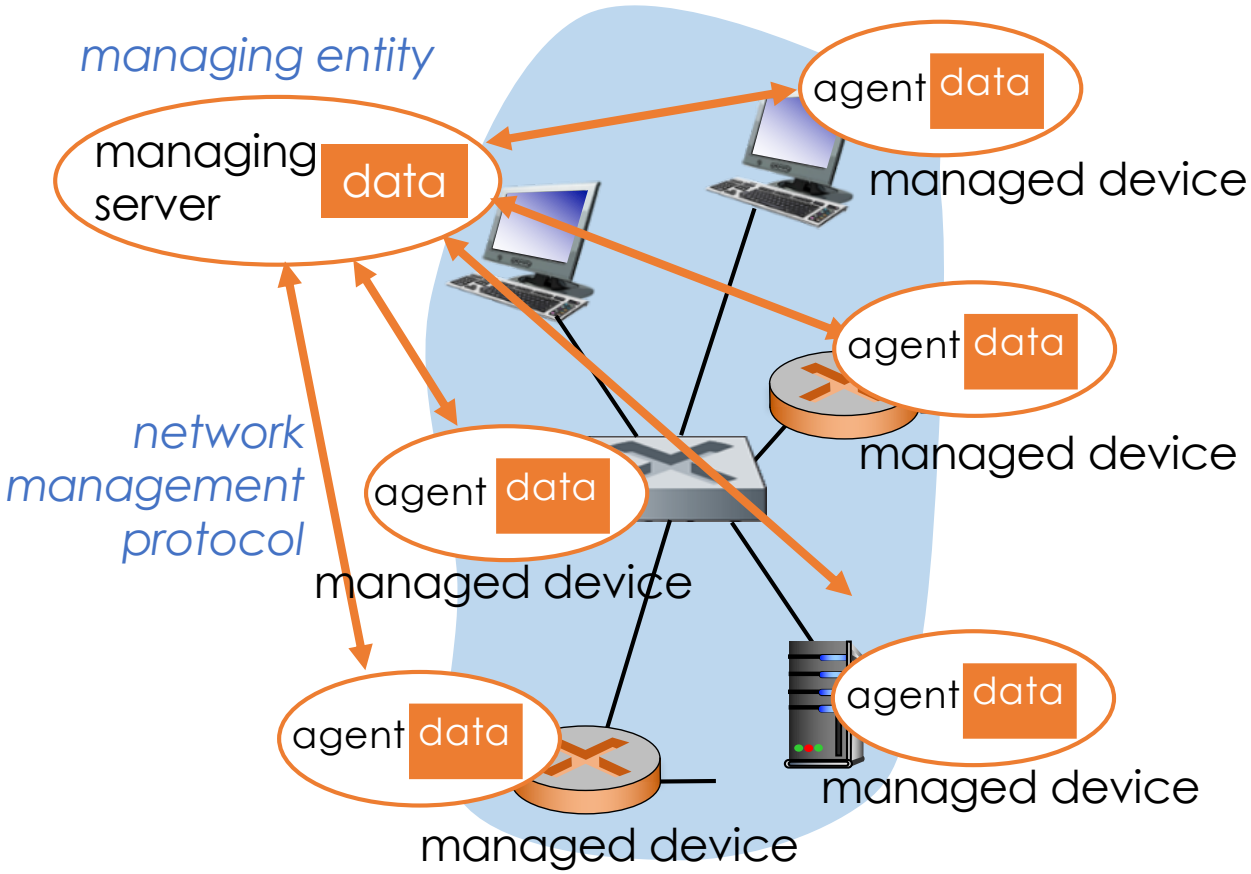
Network Management

- Deployment, integration and coordination of the hardware, software and human elements
- Monitor, test, poll, configure, analyze, evaluate and control the network
- Required before SDN released
- Simple Network Management Protocol (**SNMP**)
  - Devices that typically support SNMP include cable modems, routers, switches, servers, workstations, printers, and more
  - Three components:
    - Managed device
    - Agent: software which runs on managed devices
    - Network management station (NMS): software which runs on the manager

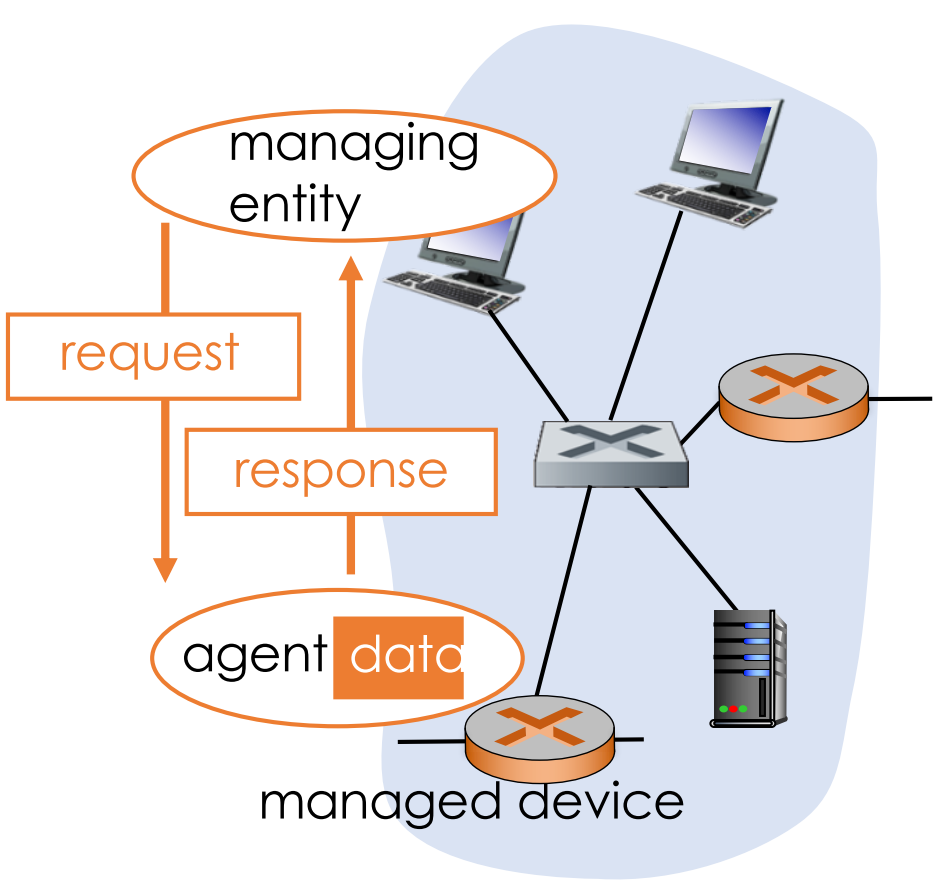
Elements of Network Management



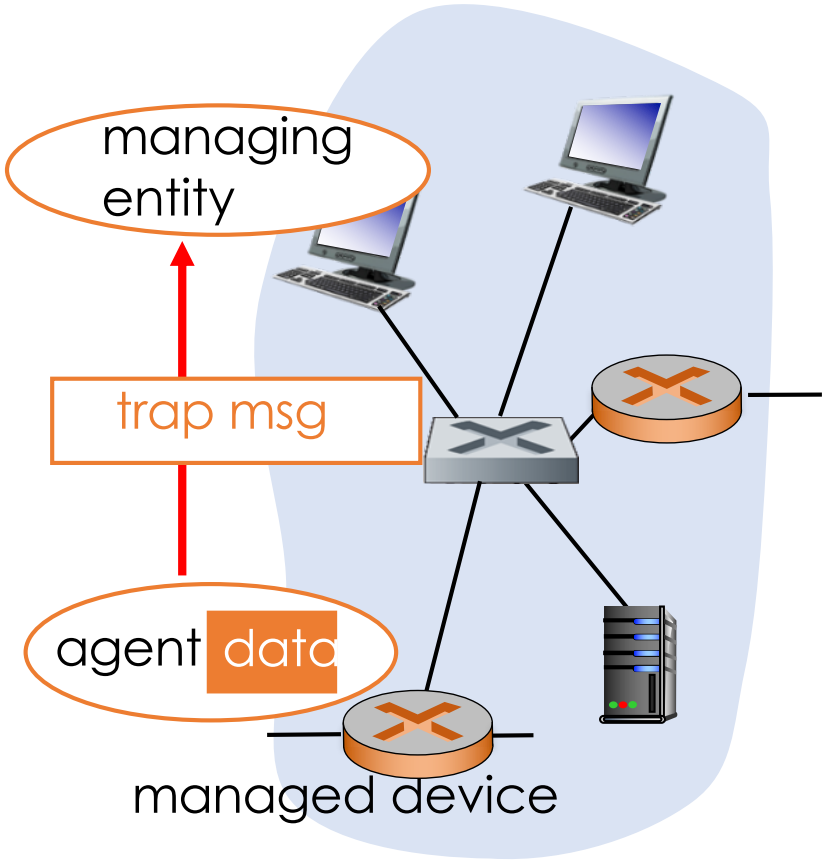
- managed devices contain managed objects
- their data are gathered into a Management Information Base (MIB)

SNMP Communications

Two ways to convey MIB info, commands:



request/response mode



trap mode

SNMP Message Types

Message Type	Fuction
GetRequest GetNextRequest GetBulkRequest	manager-to-agent: "get me data" (data instance, next data in list, block of data)
InformRequest	manager-to-manager: here's MIB value
SetRequest	manager-to-agent: set MIB value
Response	Agent-to-manager: value, response to request
Trap	Agent-to-manager: inform manager of exceptional event

SNMP PDU Format

Usually run over UDP