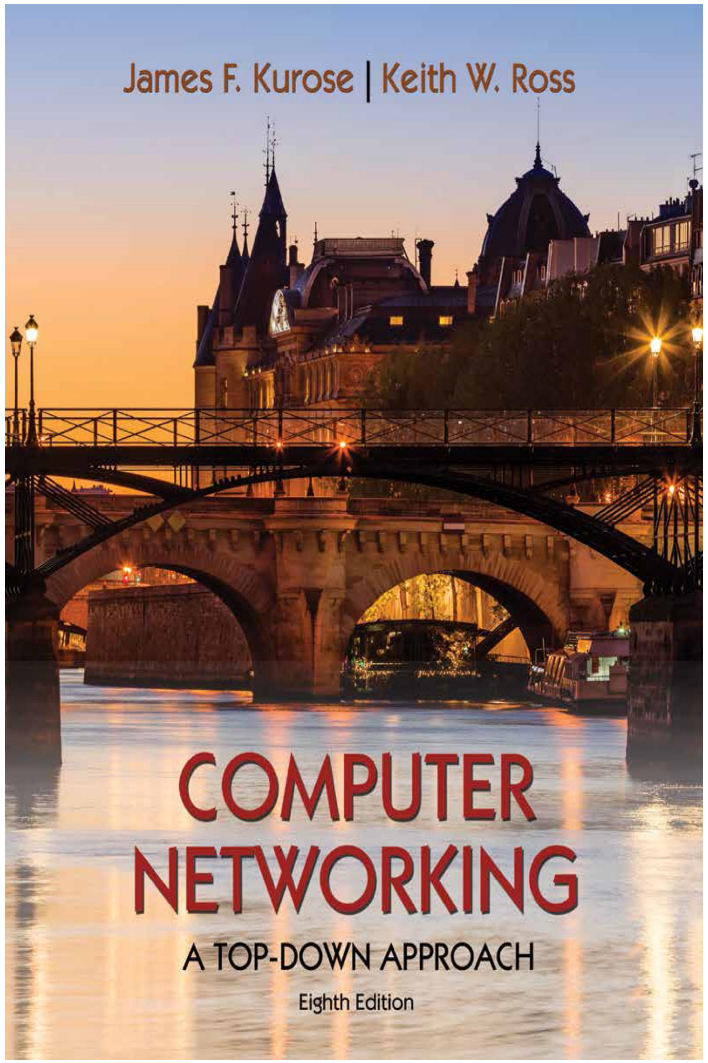
Network Layer: Control Plane

- introduction
- routing algorithms
  - link state
  - distance vector
- intra-ISP routing: OSPF
- routing among ISPs: BGP
- SDN control plane
- Internet Control Message Protocol
- Network management, configuration

Computer Networks



Making routing scalable

our routing study thus far:
idealized

- all routers identical
- network “flat”

… not true in practice

scale: billions of destinations:

- can’t store all destinations in routing tables!
- exchanging link-state or DV information would swamp links!

administrative autonomy:

- Internet: a network of networks
- each network admin may want to control routing in its own network

Internet approach to scalable routing

aggregate routers into regions known as "autonomous systems" (AS) (a.k.a. "domains")

intra-AS (aka "intra-domain"): routing among routers *within same AS ("network")*

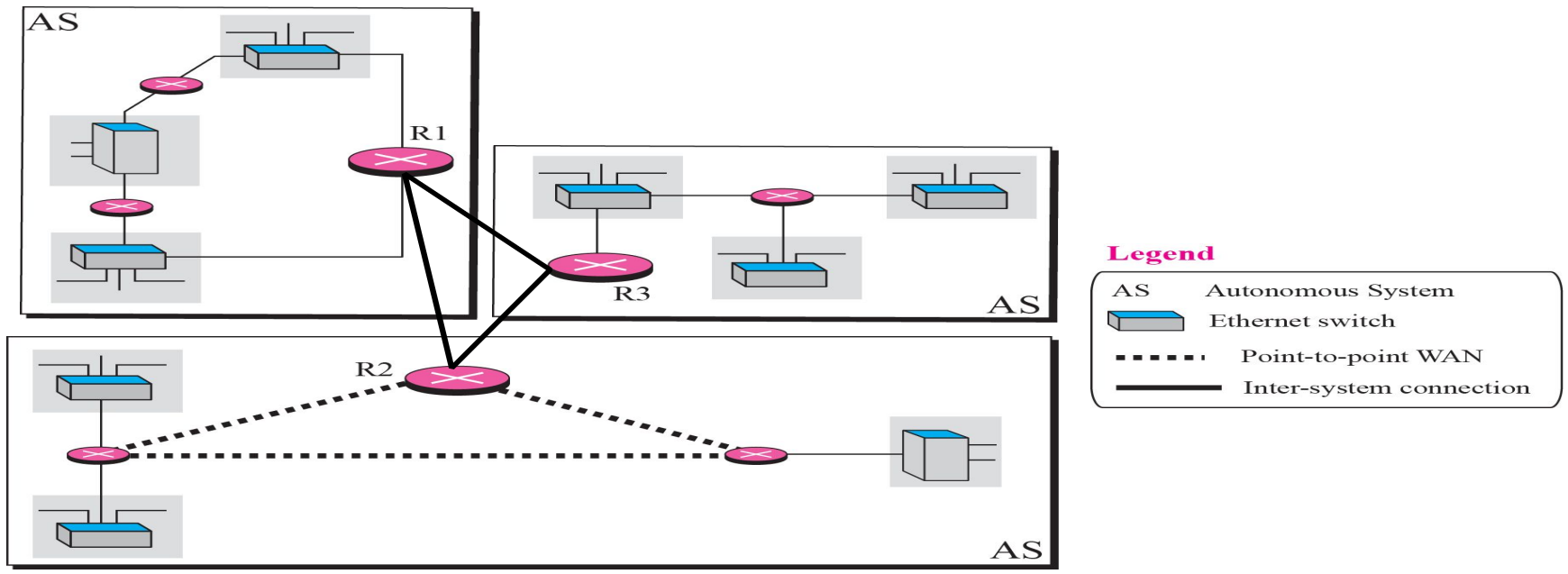
- all routers in AS must run same intra-domain protocol
- routers in different AS can run different intra-domain routing protocols
- gateway router: at "edge" of its own AS, has link(s) to router(s) in other AS'es

inter-AS (aka "inter-domain"): routing *among* AS'es

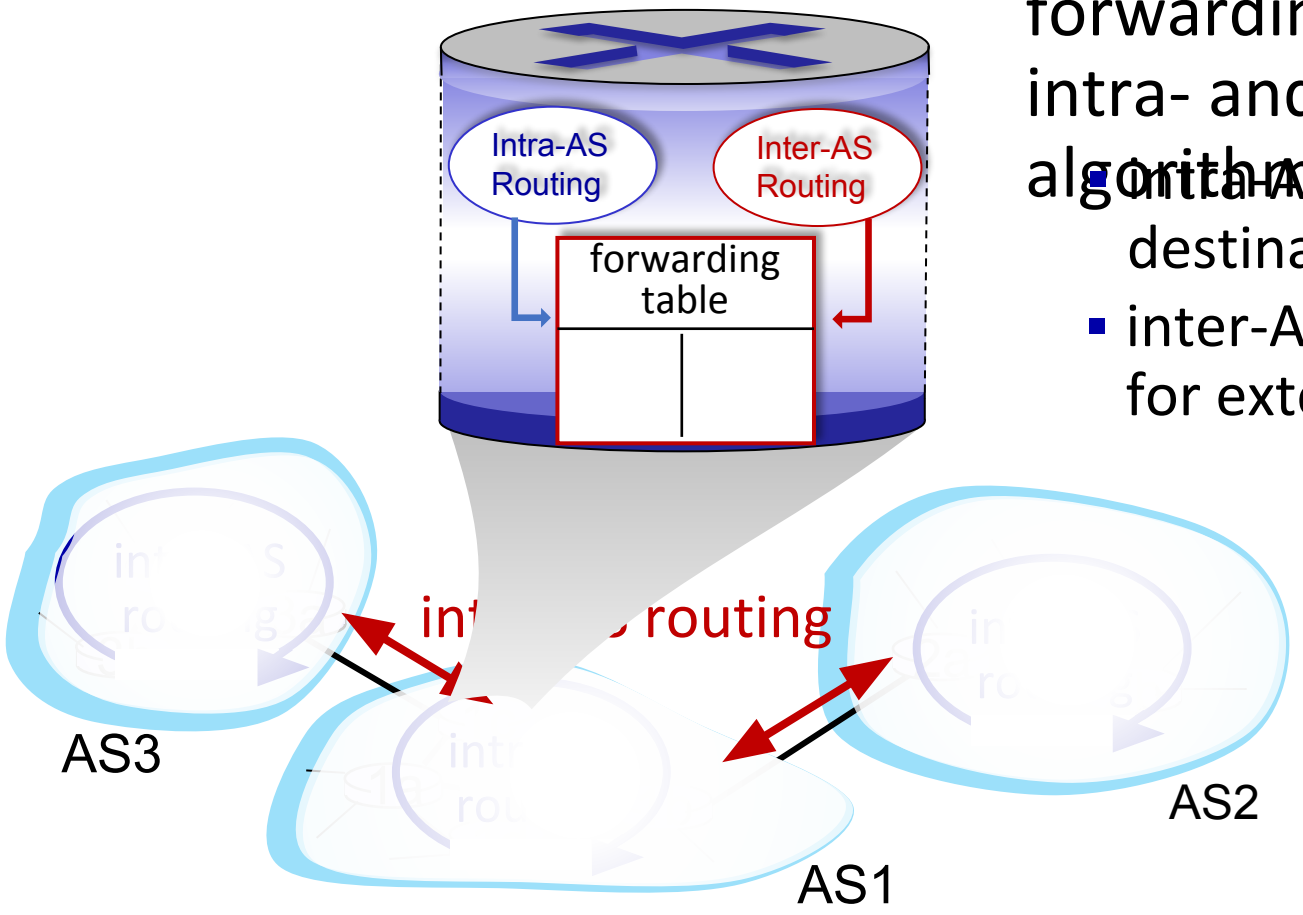
- gateways perform inter-domain routing (as well as intra-domain routing)

Autonomous Systems

- Group of networks and routers under the authority of a single administration is called an **Autonomous System**
- Routing inside an autonomous system is called **intra-domain or Interior** routing.
- Routing between autonomous systems is called **inter-domain Exterior** routing



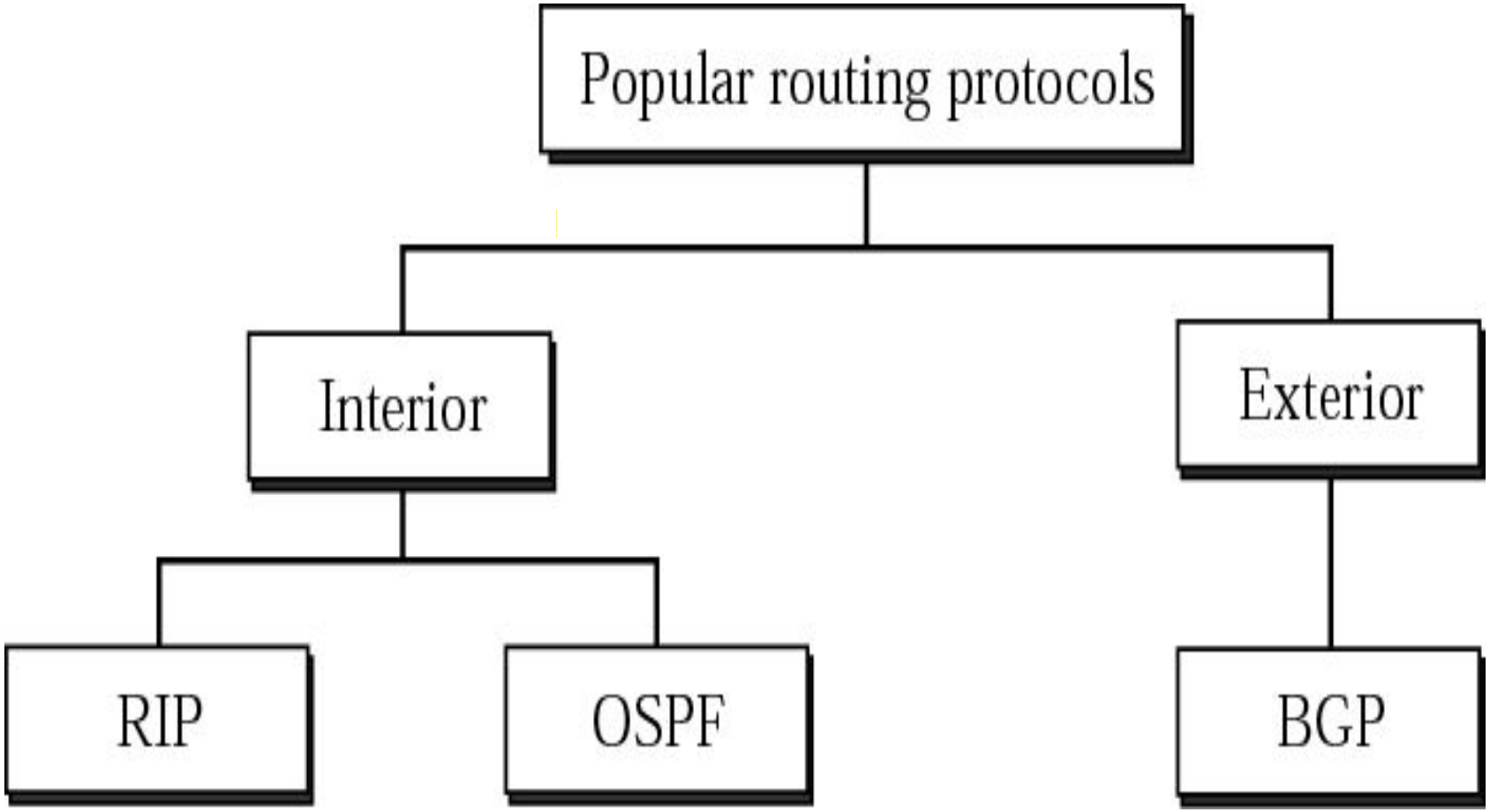
Interconnected ASes



forwarding table configured by intra- and inter-AS routing algorithms

- intra-AS routing determine entries for destinations *within* AS
- inter-AS & intra-AS determine entries for external destinations

Popular Routing protocols



Intra-AS routing: routing within an AS

most common intra-AS routing protocols:

- RIP: Routing Information Protocol [RFC 1723]
  - classic DV: DVs exchanged every 30 secs
  - no longer widely used
- OSPF: Open Shortest Path First [RFC 2328]
  - classic link-state routing
  - IS-IS protocol (ISO standard, not RFC standard) essentially same as OSPF
- EIGRP: Enhanced Interior Gateway Routing Protocol
  - DV based
  - formerly Cisco-proprietary for decades
  - became open in 2013 [RFC 7868])

OSPF (Open Shortest Path First) routing

- "open": publicly available
- classic link-state
  - each router floods OSPF link-state advertisements (directly over IP rather than using TCP/UDP) to all other routers in entire AS
  - multiple link costs metrics possible: bandwidth, delay
  - each router has full topology, uses Dijkstra's algorithm to compute forwarding table
- *security:* all OSPF messages authenticated (to prevent malicious intrusion)

Hierarchical OSPF

- two-level hierarchy: local area, backbone.
  - link-state advertisements flooded only in area, or backbone
  - each node has detailed area topology; only knows direction to reach other destinations