Wrapping up BGP and the IP header

Spring 2024

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Outline

- Wrapping up BGP
  - Context
  - Goals
  - Approach
    - Wrap up Gao-Rexford
  - Protocol design
  - Limitations
- Designing the IP header

Recall: computing paths on the AS graph

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  - Customers pay providers
  - Peers don’t pay each other
- Paths are selected based on policy
- Policy reflects business goals (i.e., how money flows)
  - “Only carry traffic if you’re getting paid for it”
  - “Try and make/save money when sending traffic”

Recall: BGP

- Protocol that implements interdomain routing

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  - Each AS advertises its path to a prefix
  - Policy dictates which paths an AS selects (“import policy”) and which paths it advertises (“export policy”)

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  - Each AS advertises its path to a prefix
  - Policy dictates which paths an AS selects (“import policy”) and which paths it advertises (“export policy”)
- Gao-Rexford rules tell us what import/export policies will achieve business goals

Gao-Rexford Rule: Import policy

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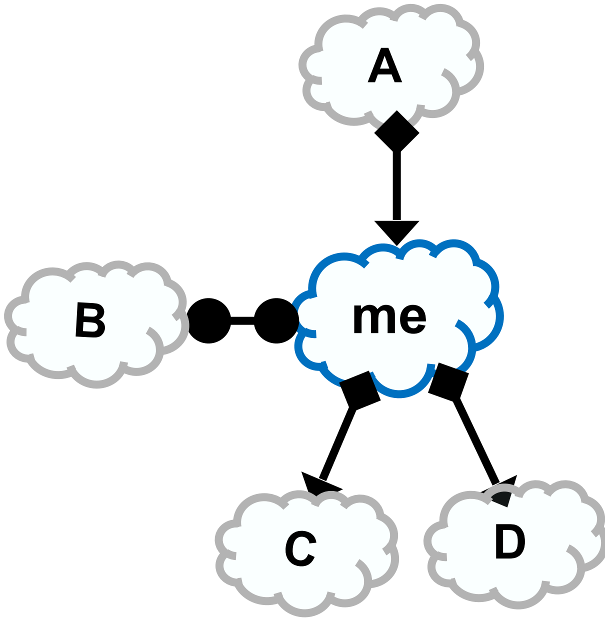
Gao-Rexford Rules: Export policy

Destination prefix advertised by…	Export route to…
Customer	Everyone (providers, peers, other customers)
Peer	Customers
Provider	Customers



Gao-Rexford Rules: Implication

- Under two assumptions about the AS graph (coming up), if all ASes follow Gao-Rexford, we can guarantee:
  - **Reachability**: any two ASes can communicate
  - **Convergence**: all routers agree on paths
- The above hold in steady state

Steady State and Convergence

- Steady state essentially means no changes
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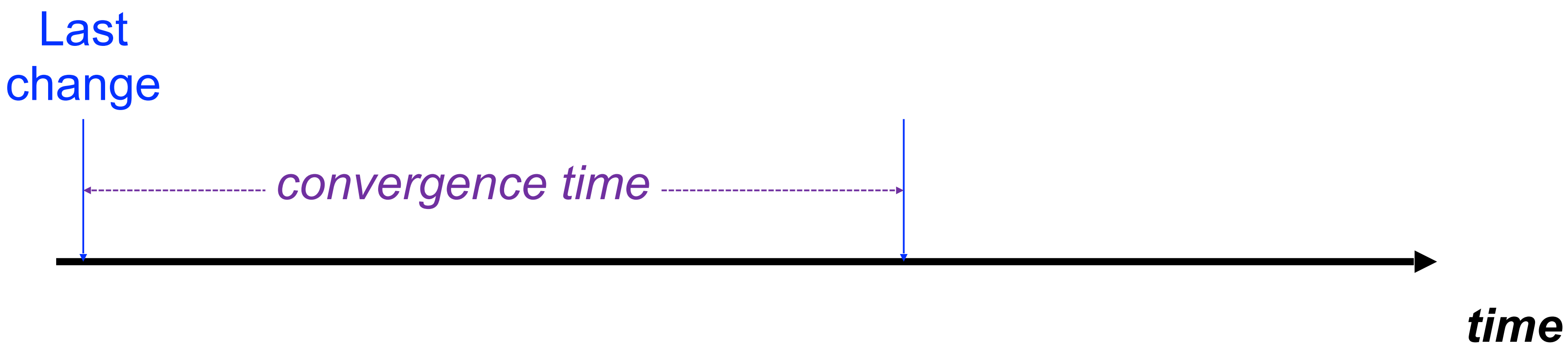

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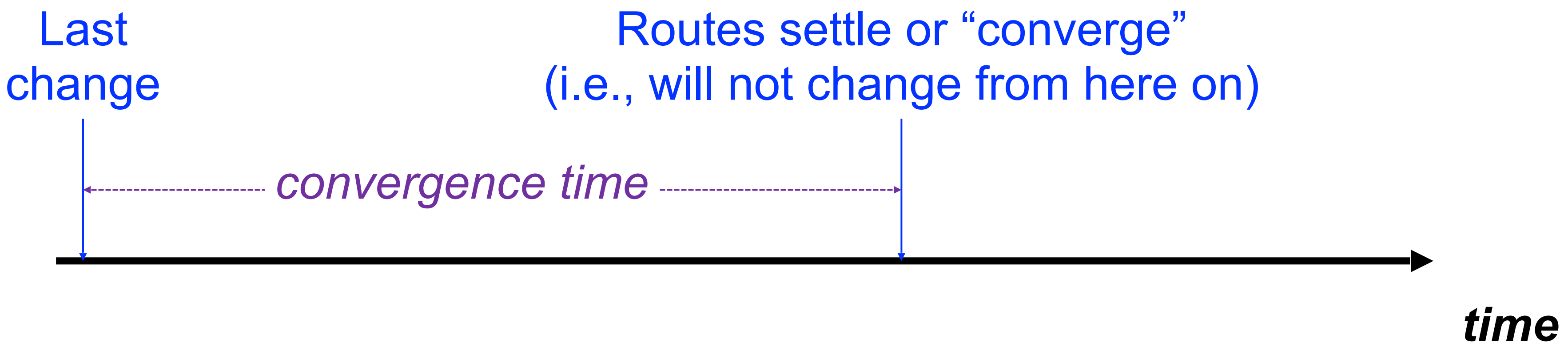

Two assumptions

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#1 The graph of customer-provider relationships is acyclic

- Cannot have A→B→...→C and then C→A (customer → provider)
- Means one can arrange providers in a hierarchy
- Note: OK if peering relationships are cyclic (A-B, B-C, C-A)

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  - **Reachability**: any two ASes can communicate
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- The above hold in steady state
- The above are <u>not</u> guaranteed for general policies!
  - (You'll see an example of this in section)

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- Good stuff happens when you follow G-R rules

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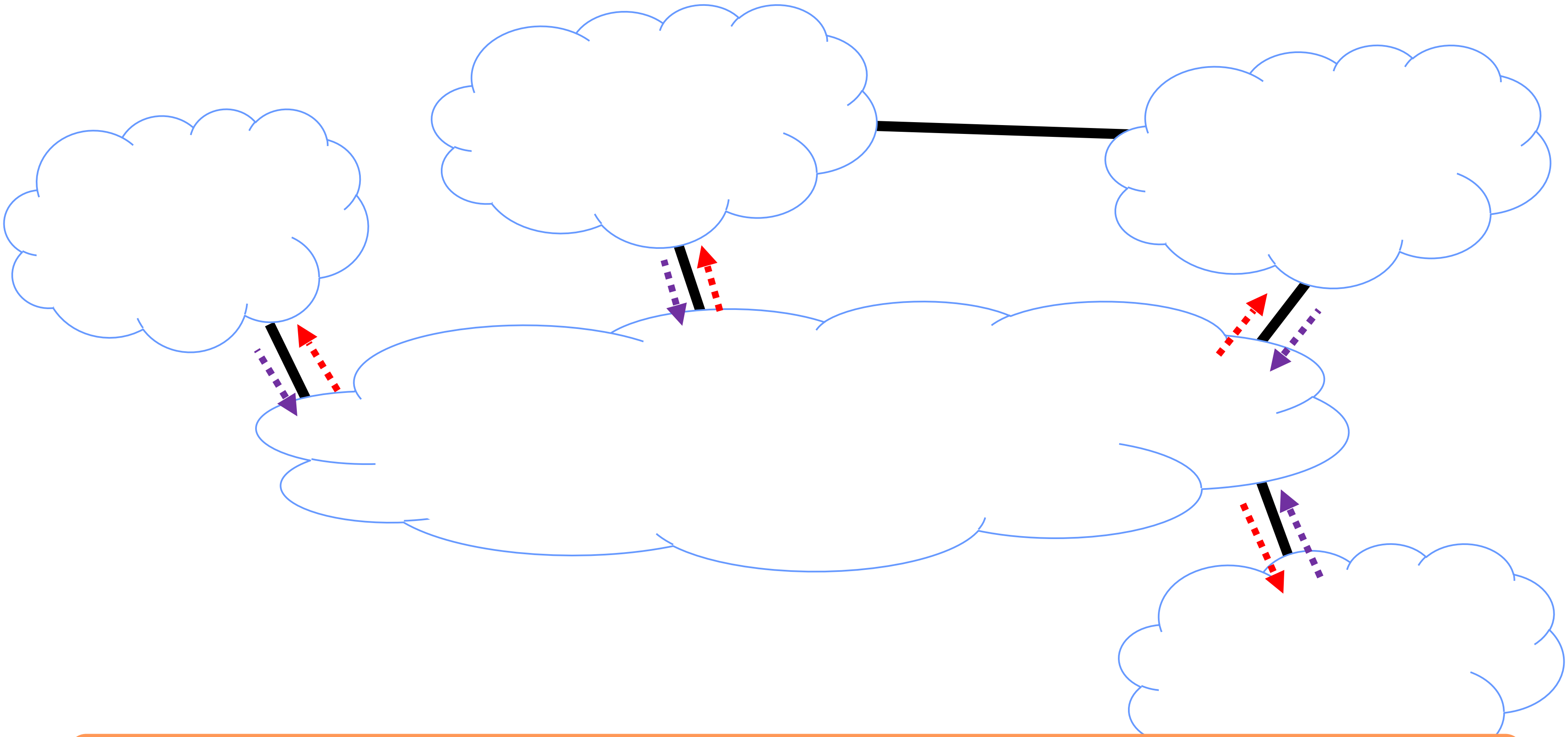
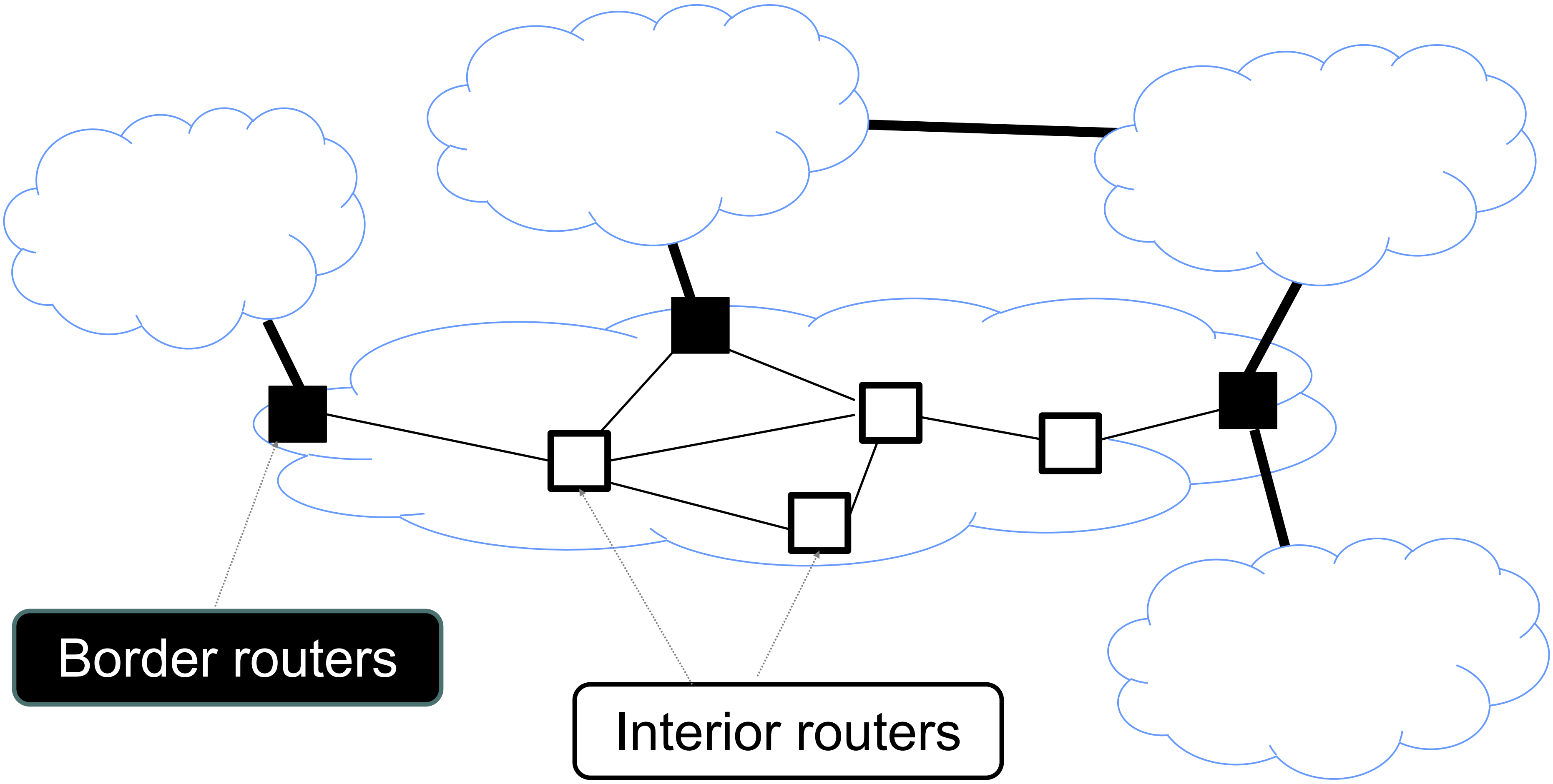
So far: our model of the AS graph



An AS advertises routes to its neighbor ASes

In reality...



Many design questions....

- How do we ensure the routers “act as one”?
  - The role of border *vs.* interior routers?
  - Interaction between BGP and IGP?
  - How does BGP implement all this?

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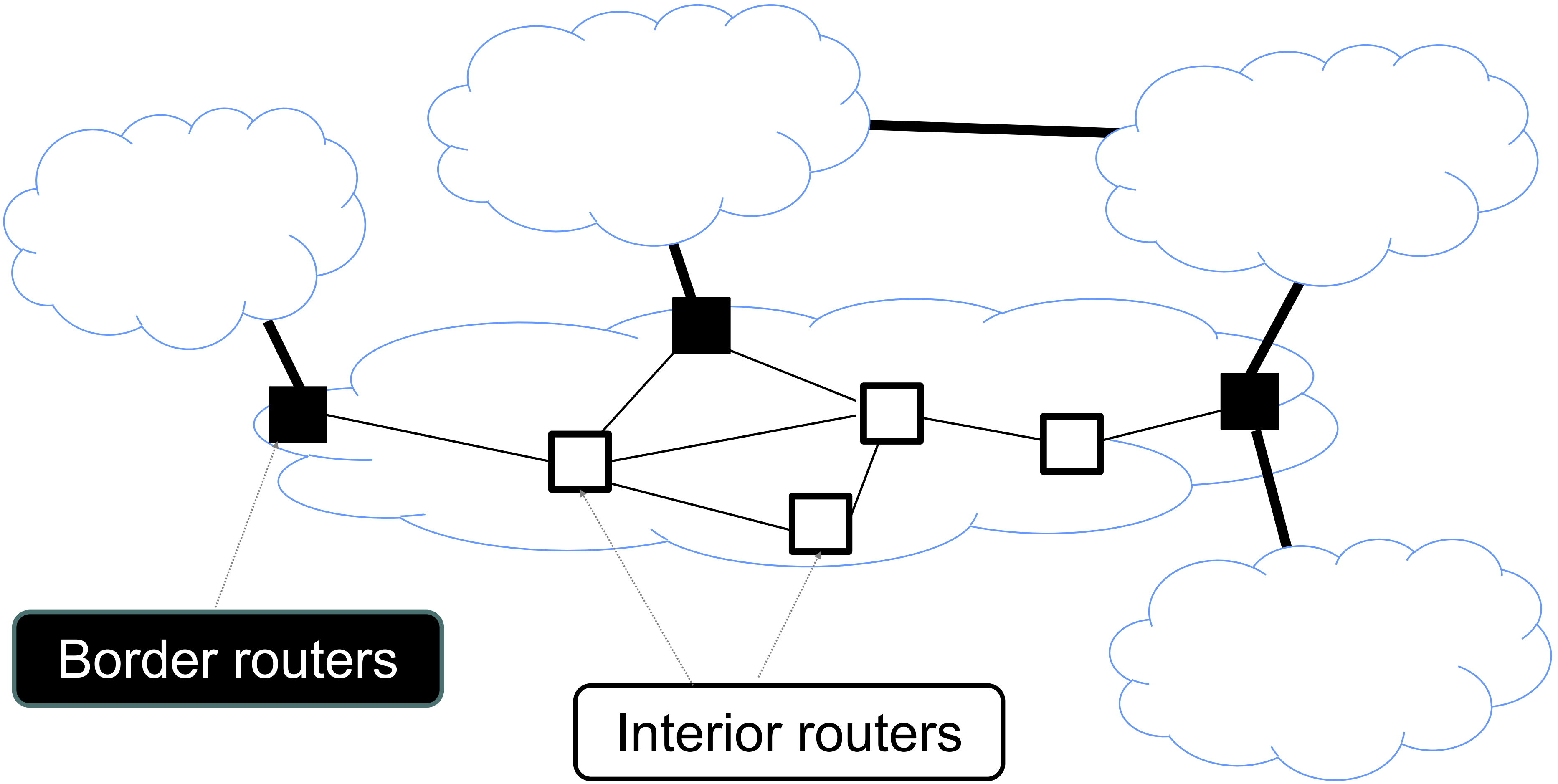

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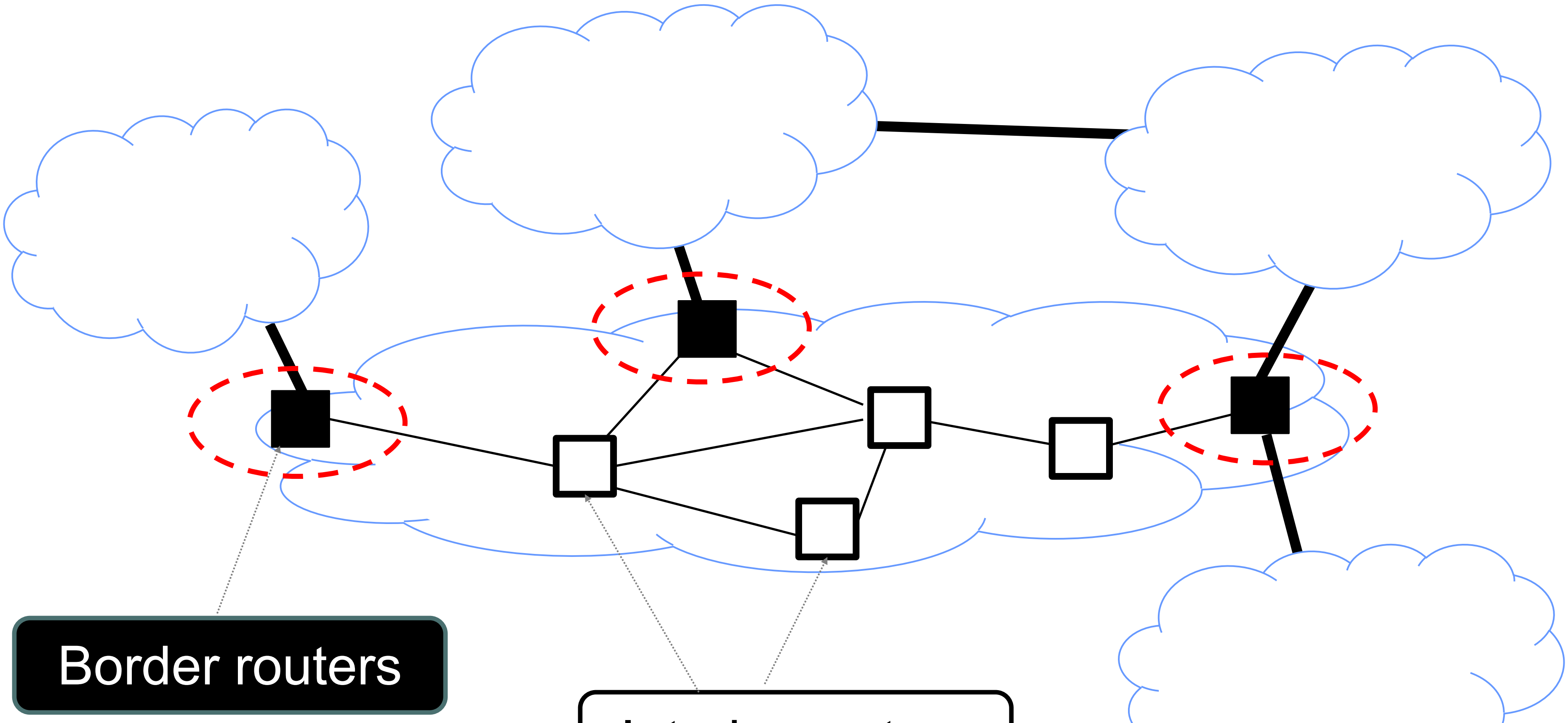

Border routers at an Autonomous System

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- Specifies what messages BGP “speakers” exchange
  - message types and syntax
- And how to process these messages
  - e.g., *“when you receive a BGP update, do…. “*

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- Customer that connects to a single provider AS
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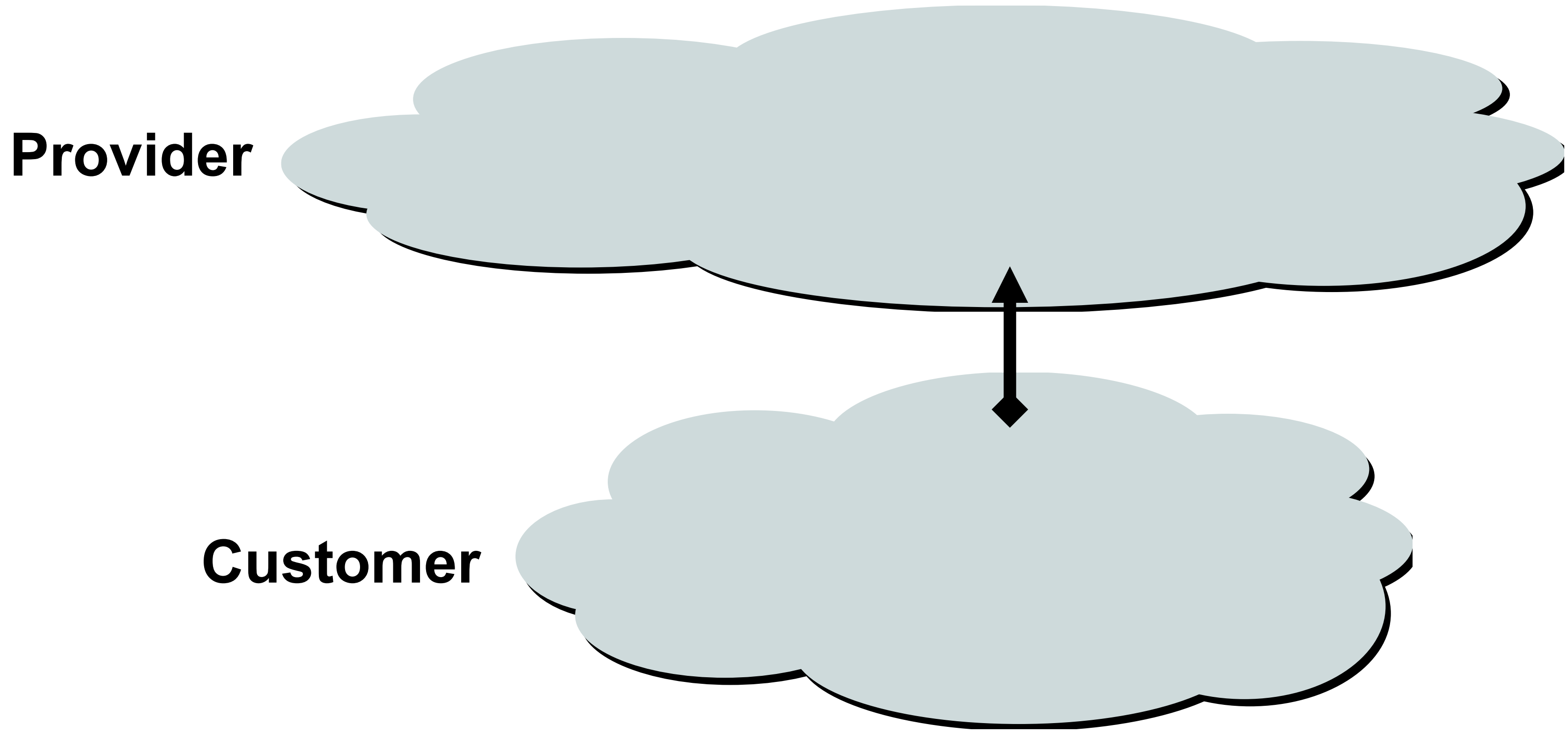

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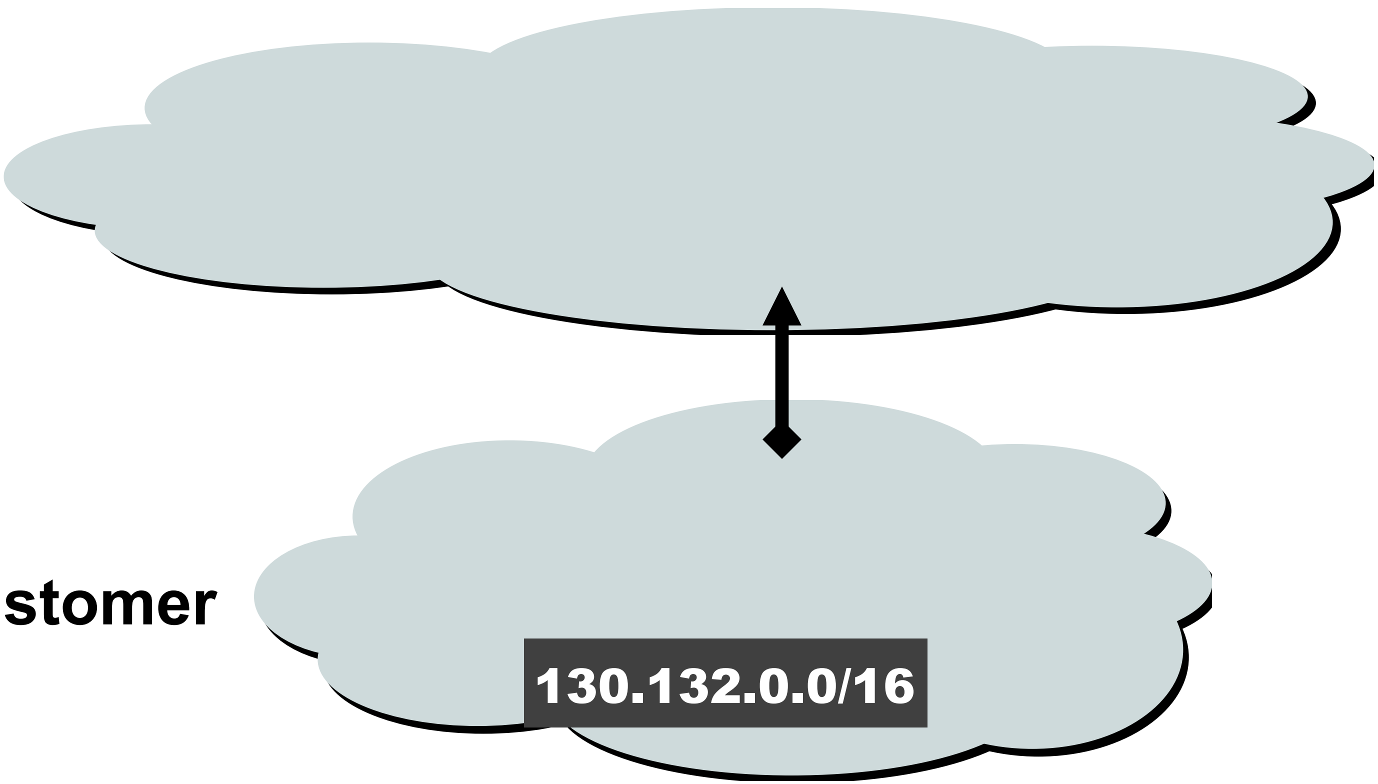

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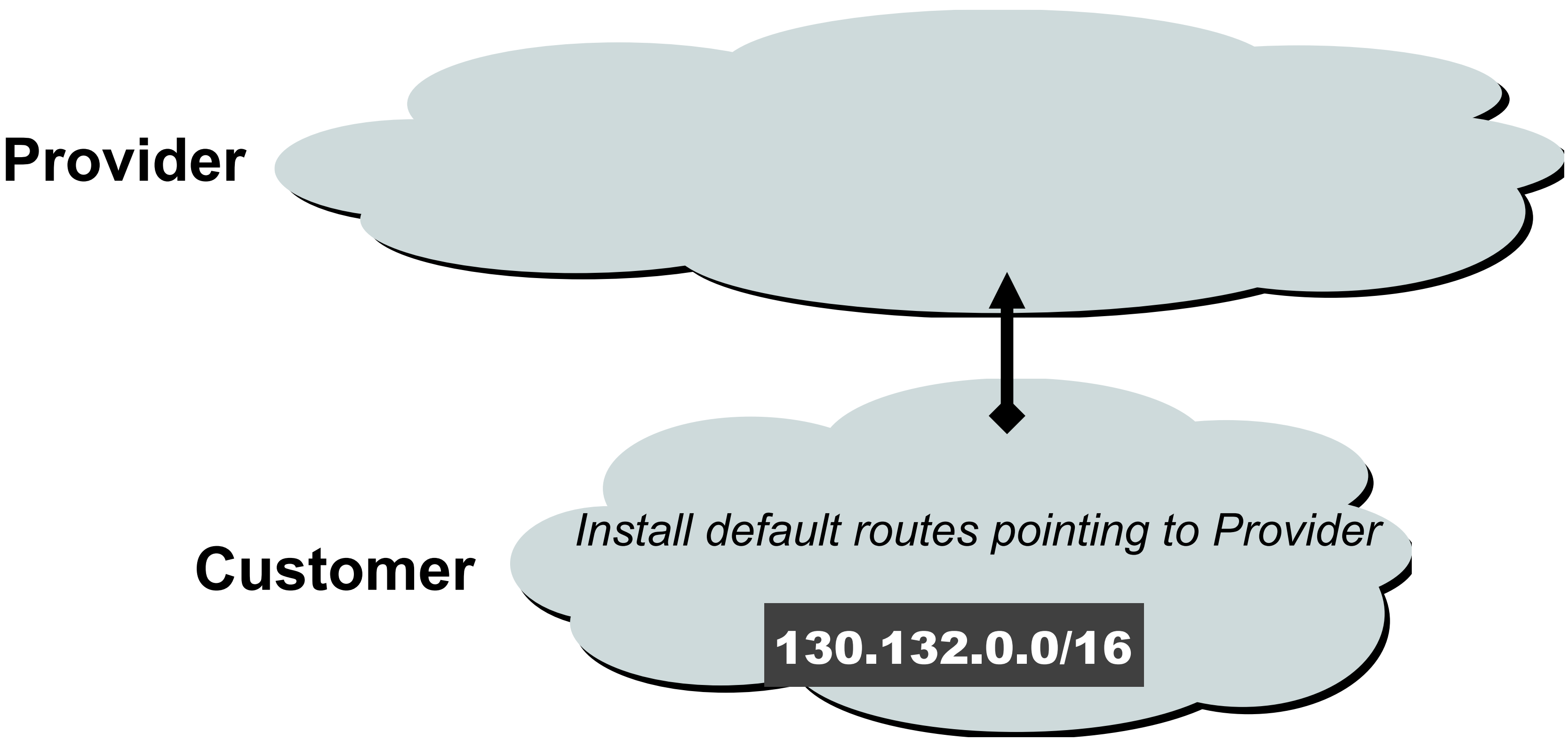

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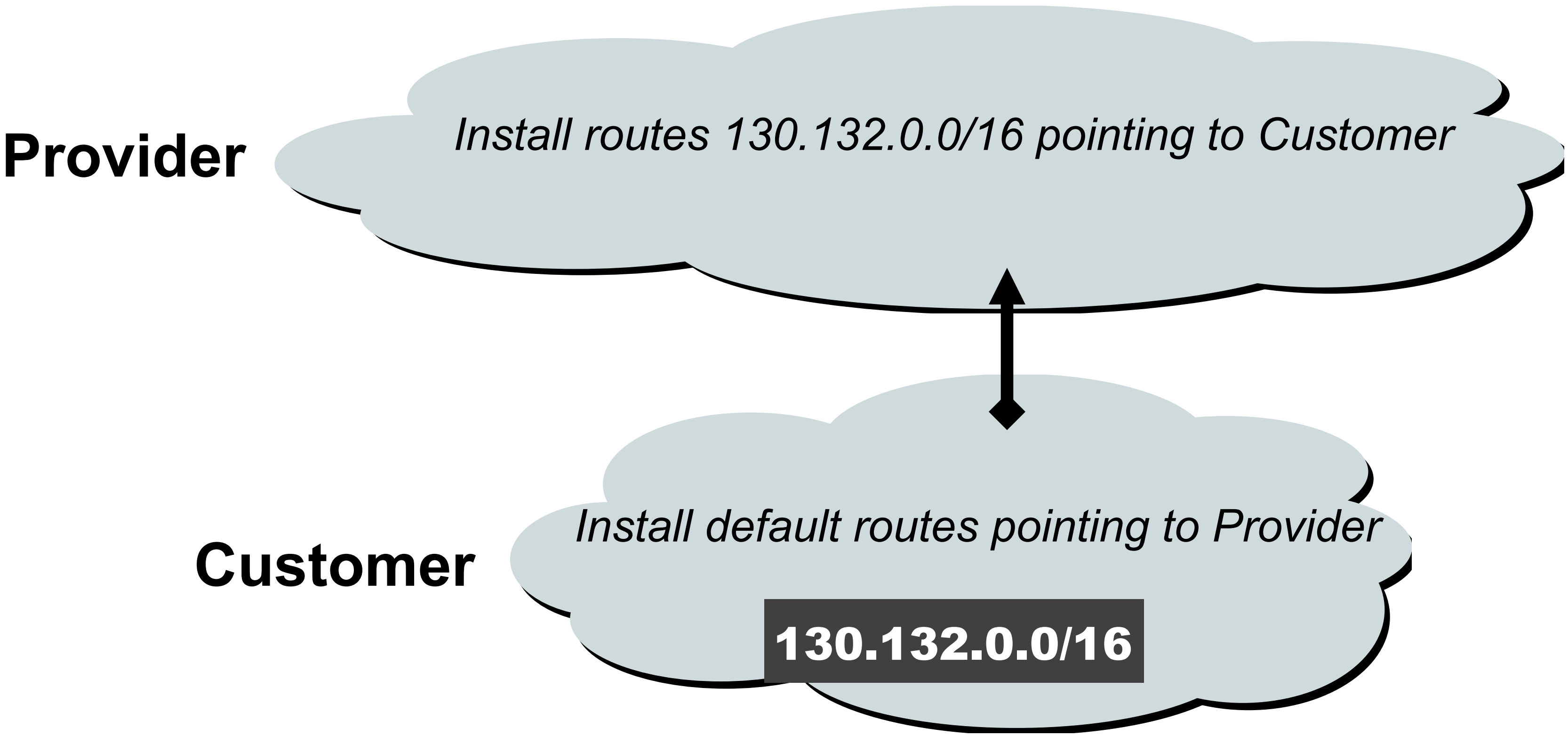

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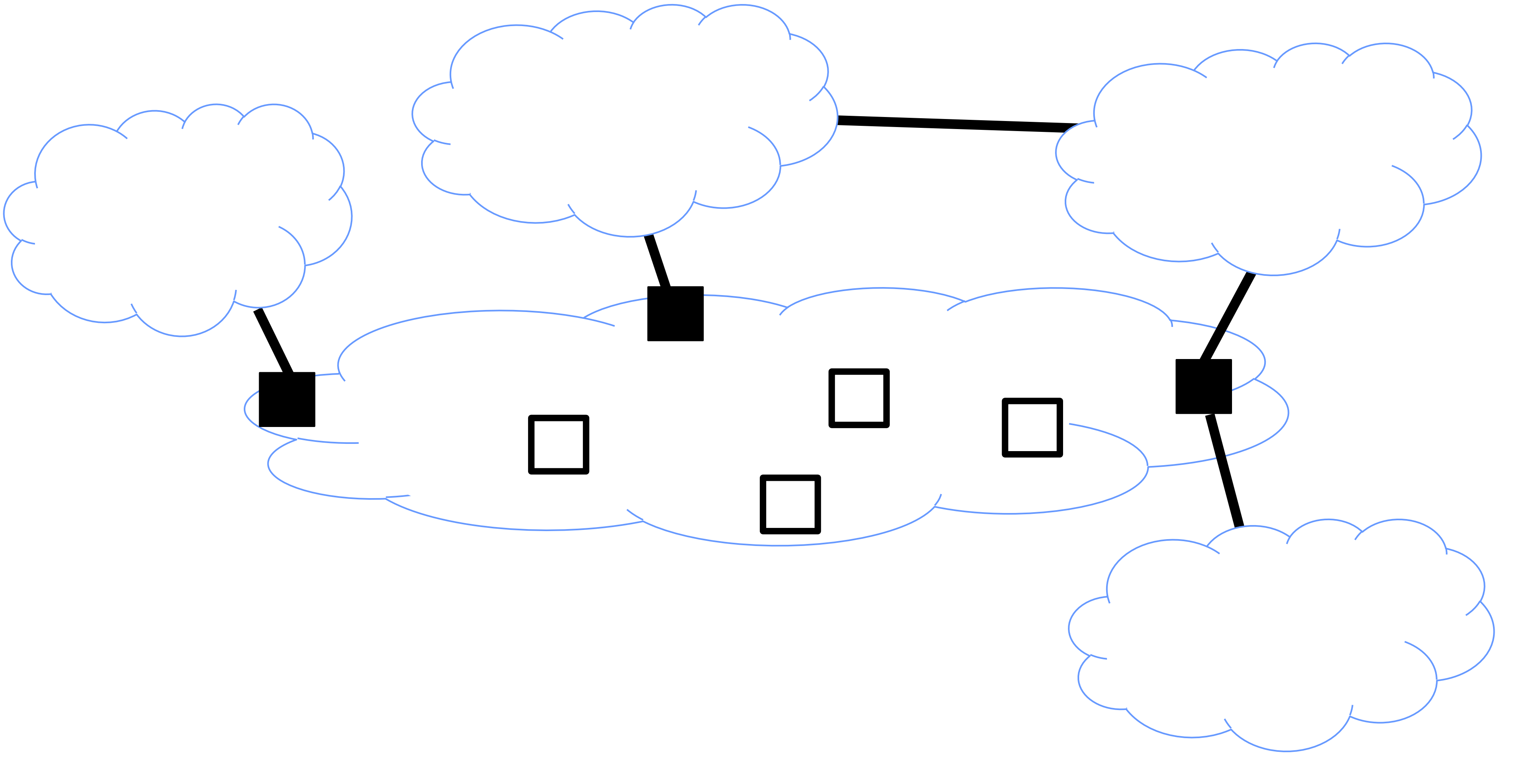

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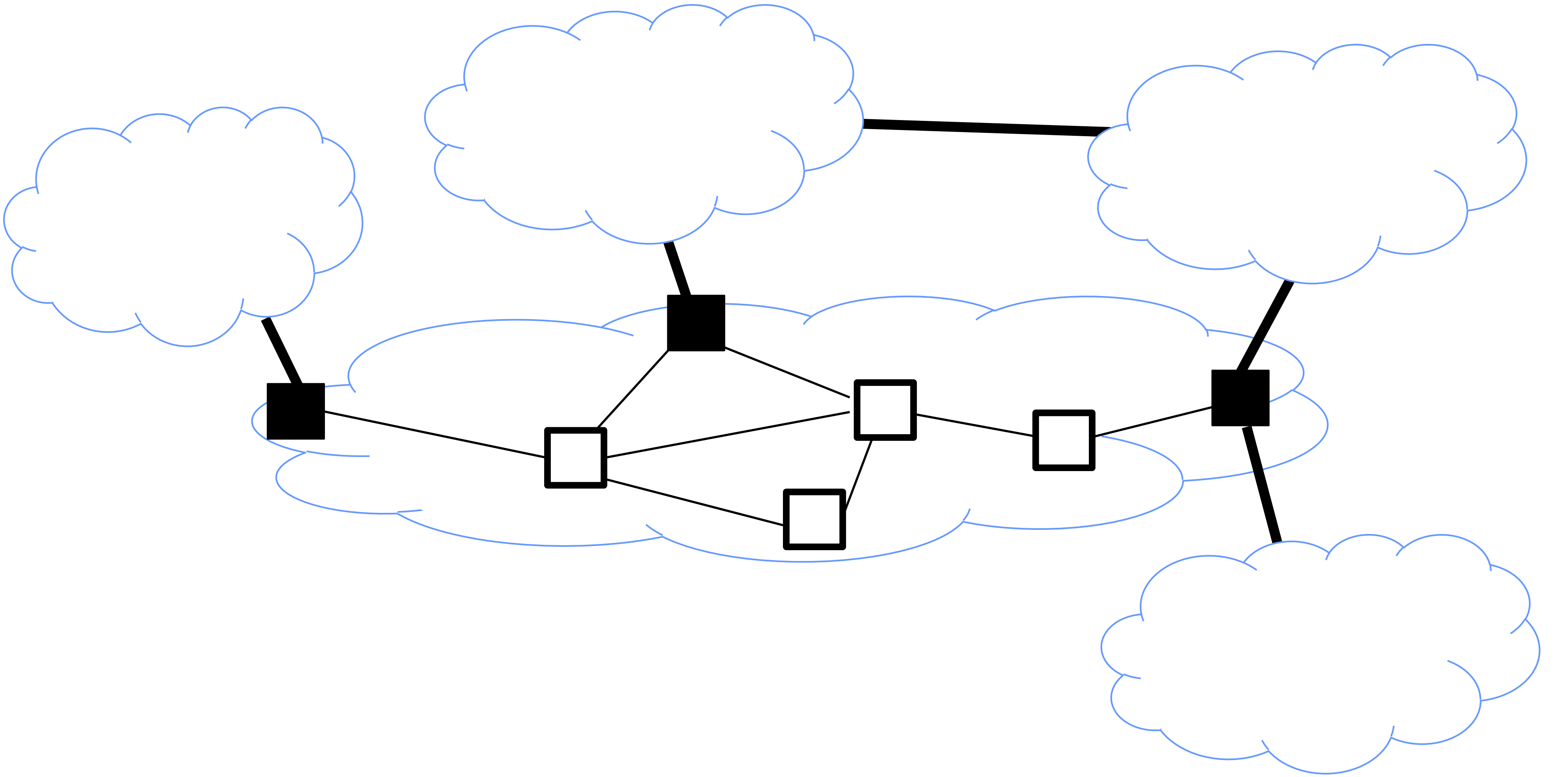

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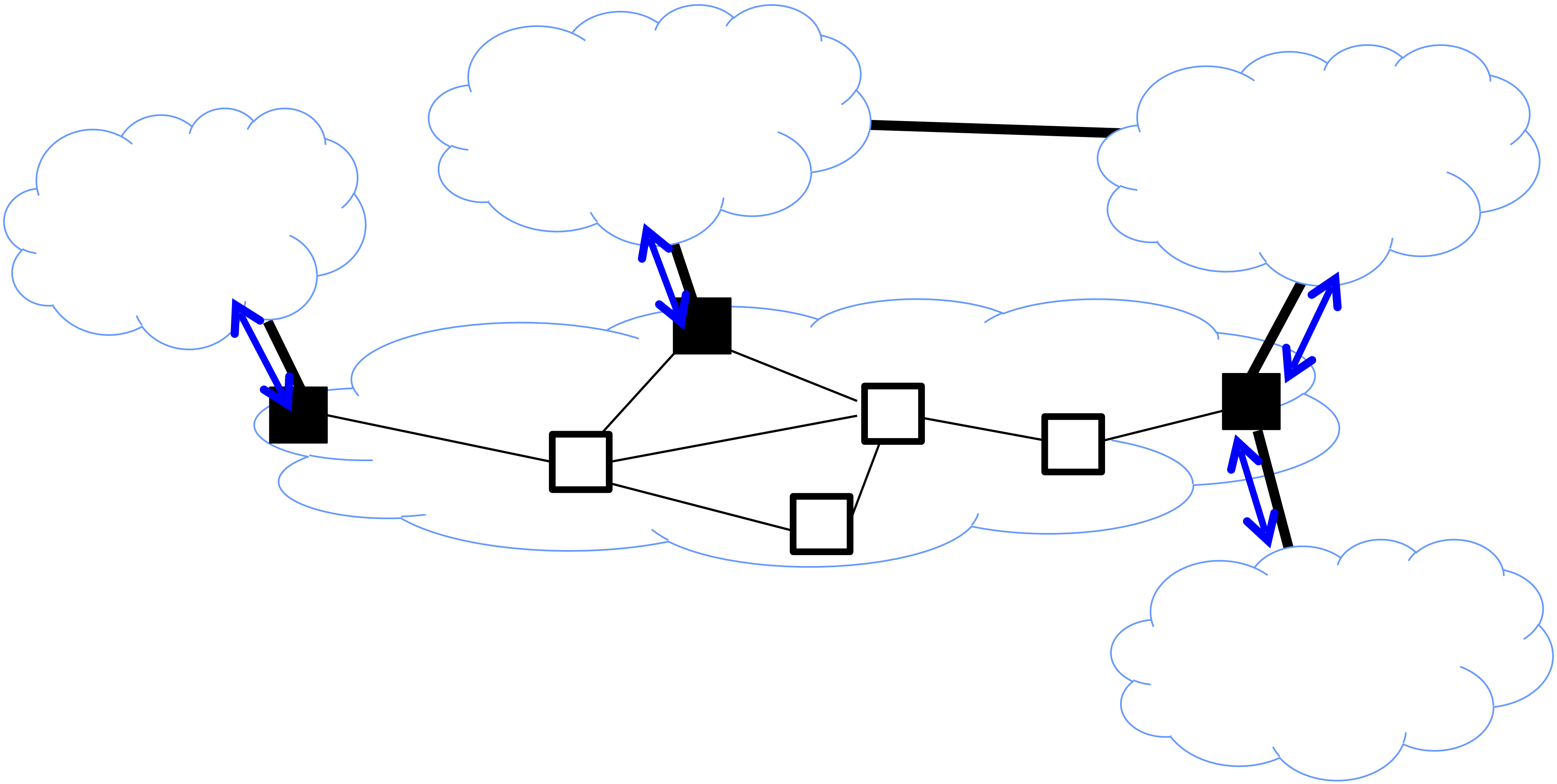

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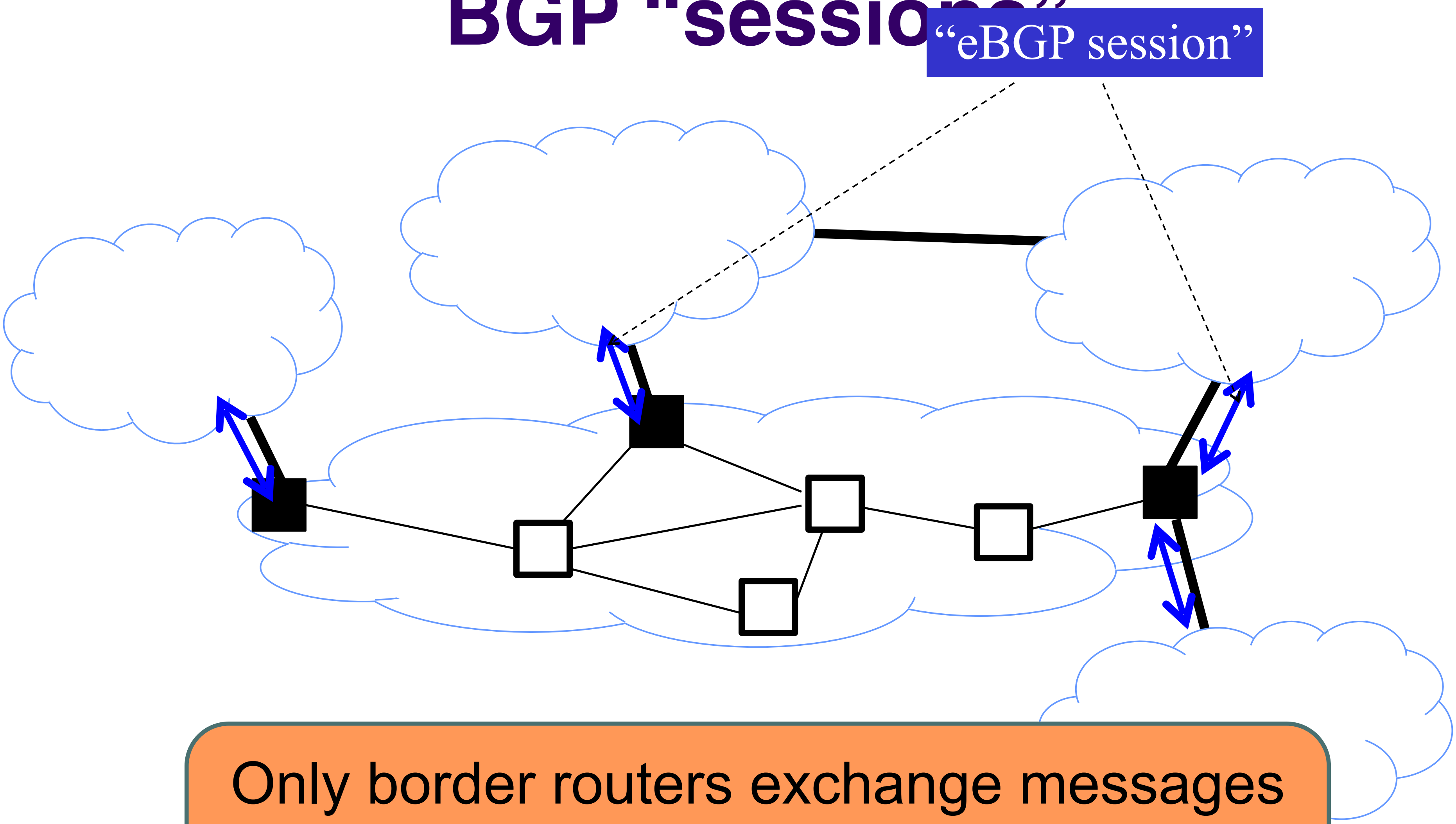

Only border routers exchange messages with routers in external domains (hence, *external BGP* or "eBGP")

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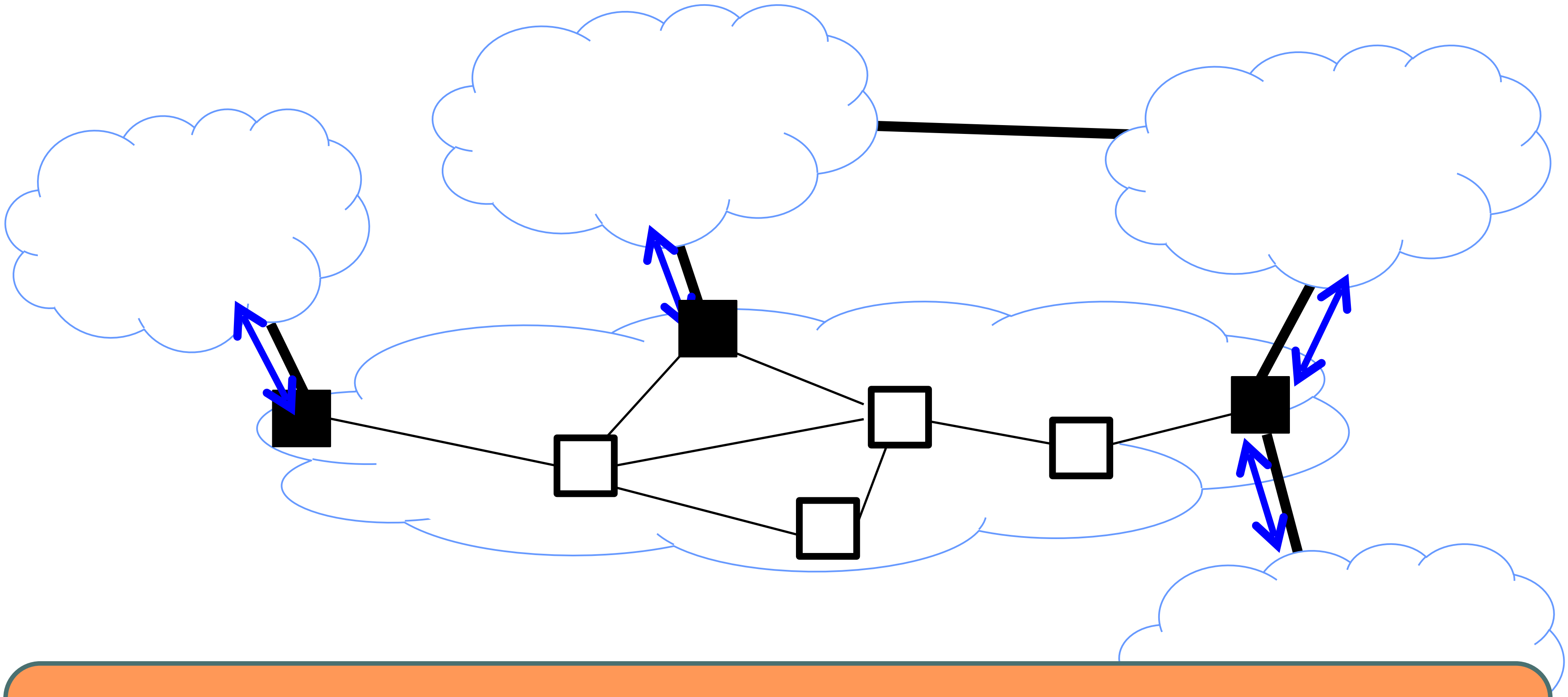

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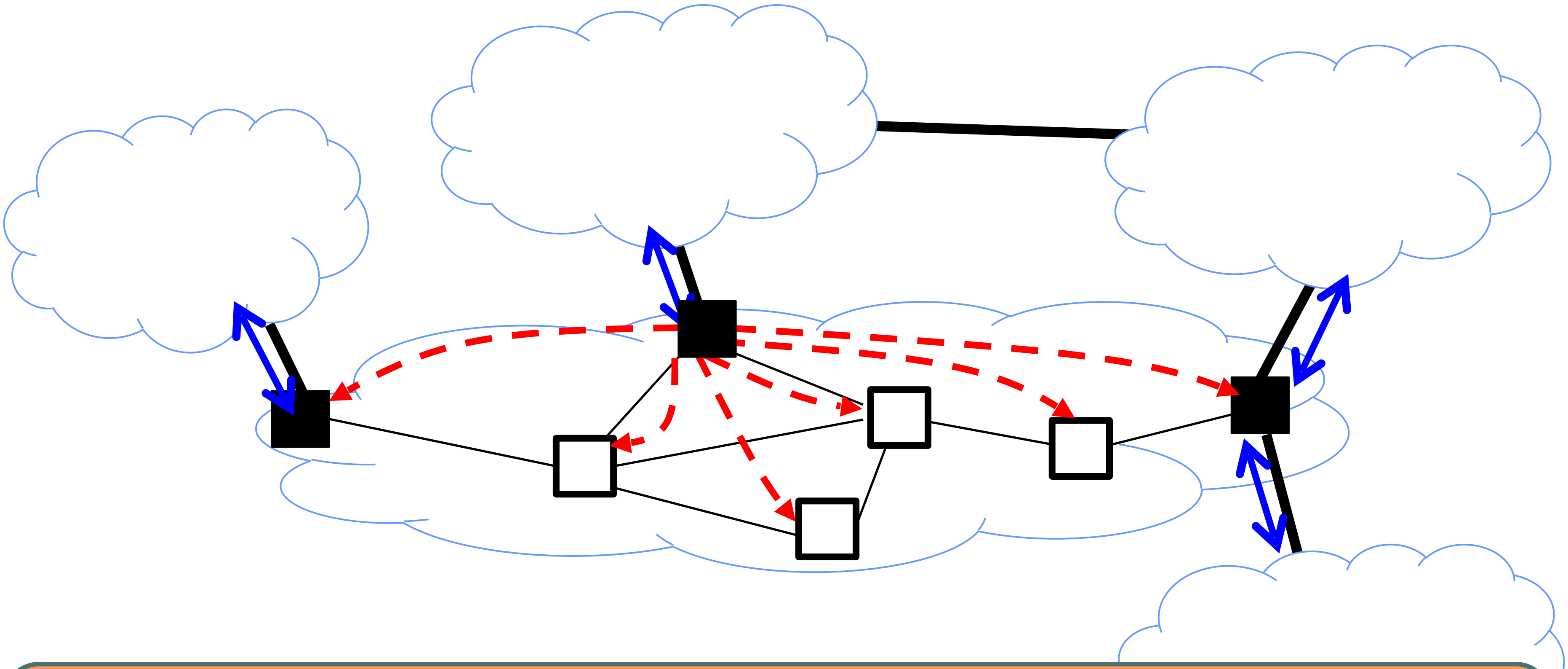

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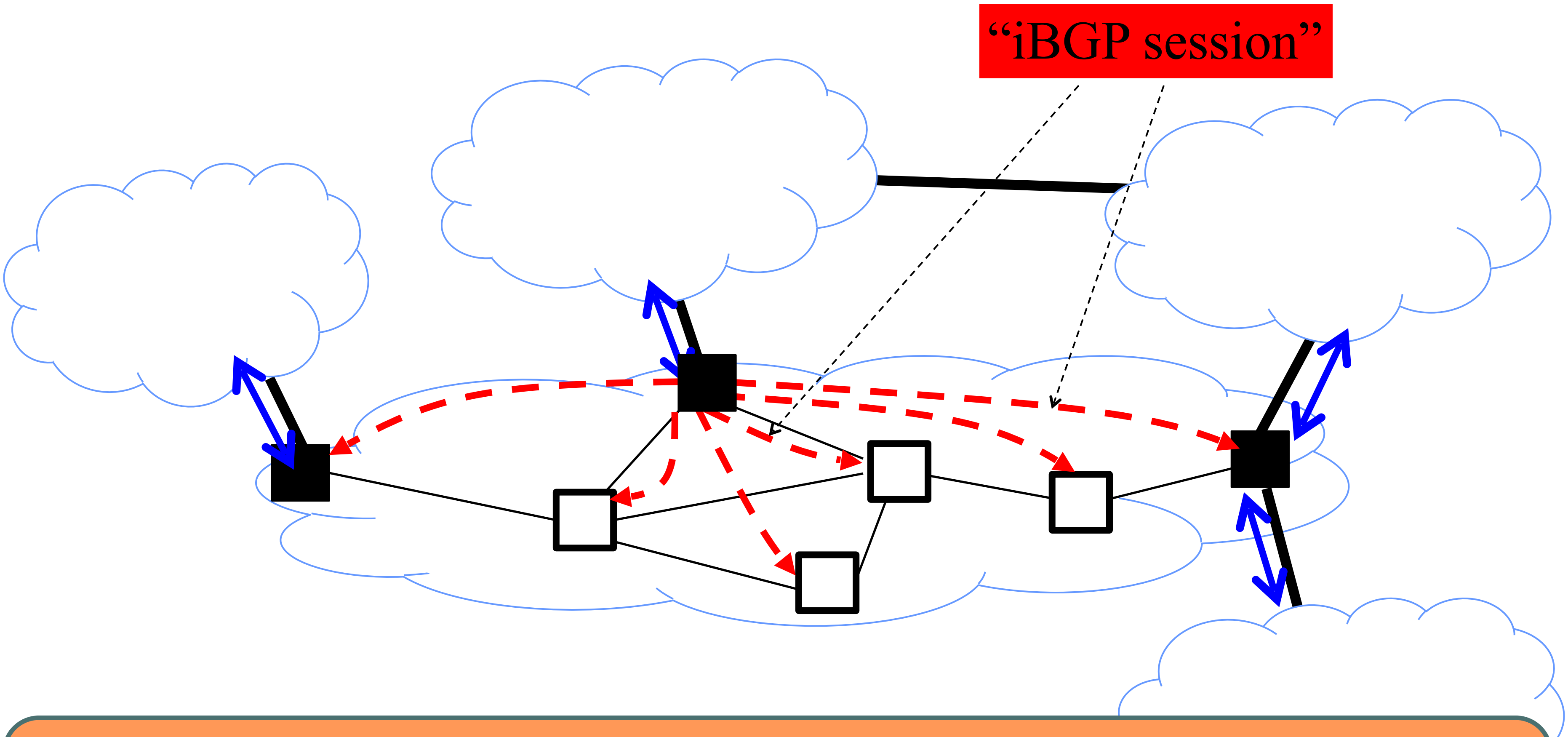

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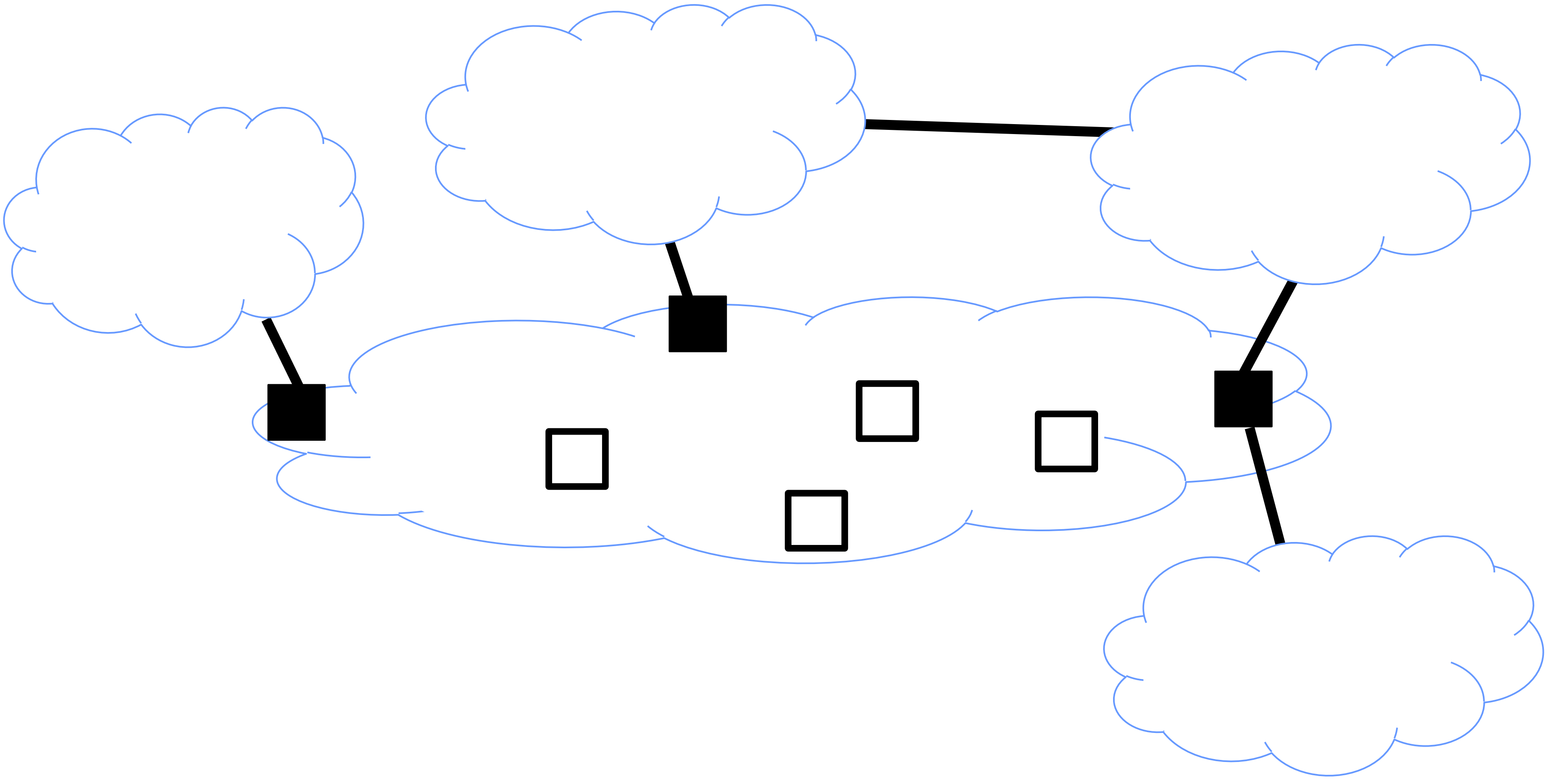
- IGP: “Interior Gateway Protocol” = Intradomain routing protocol
  - provide internal reachability
  - e.g., OSPF, RIP

Putting the pieces together



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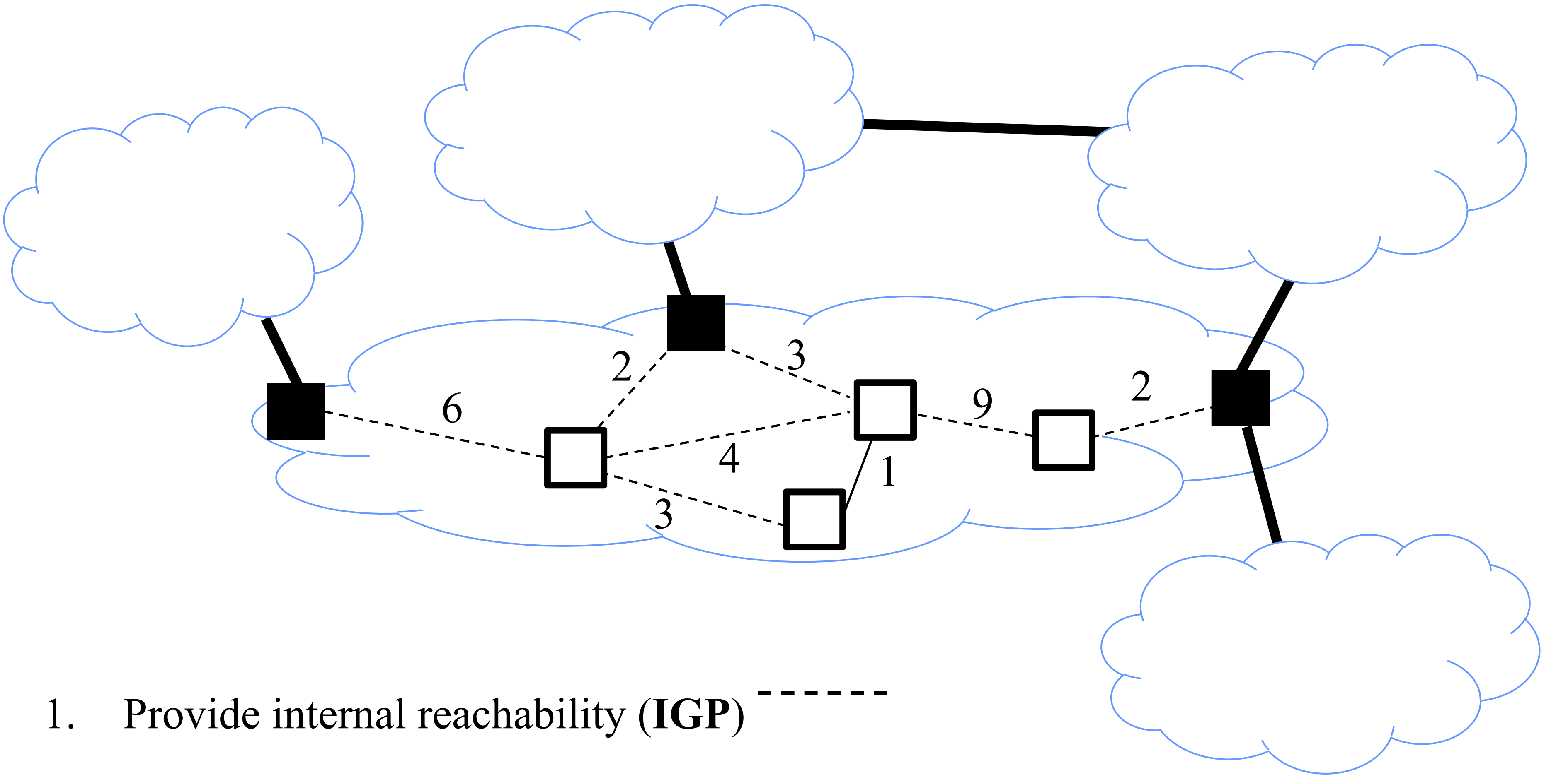

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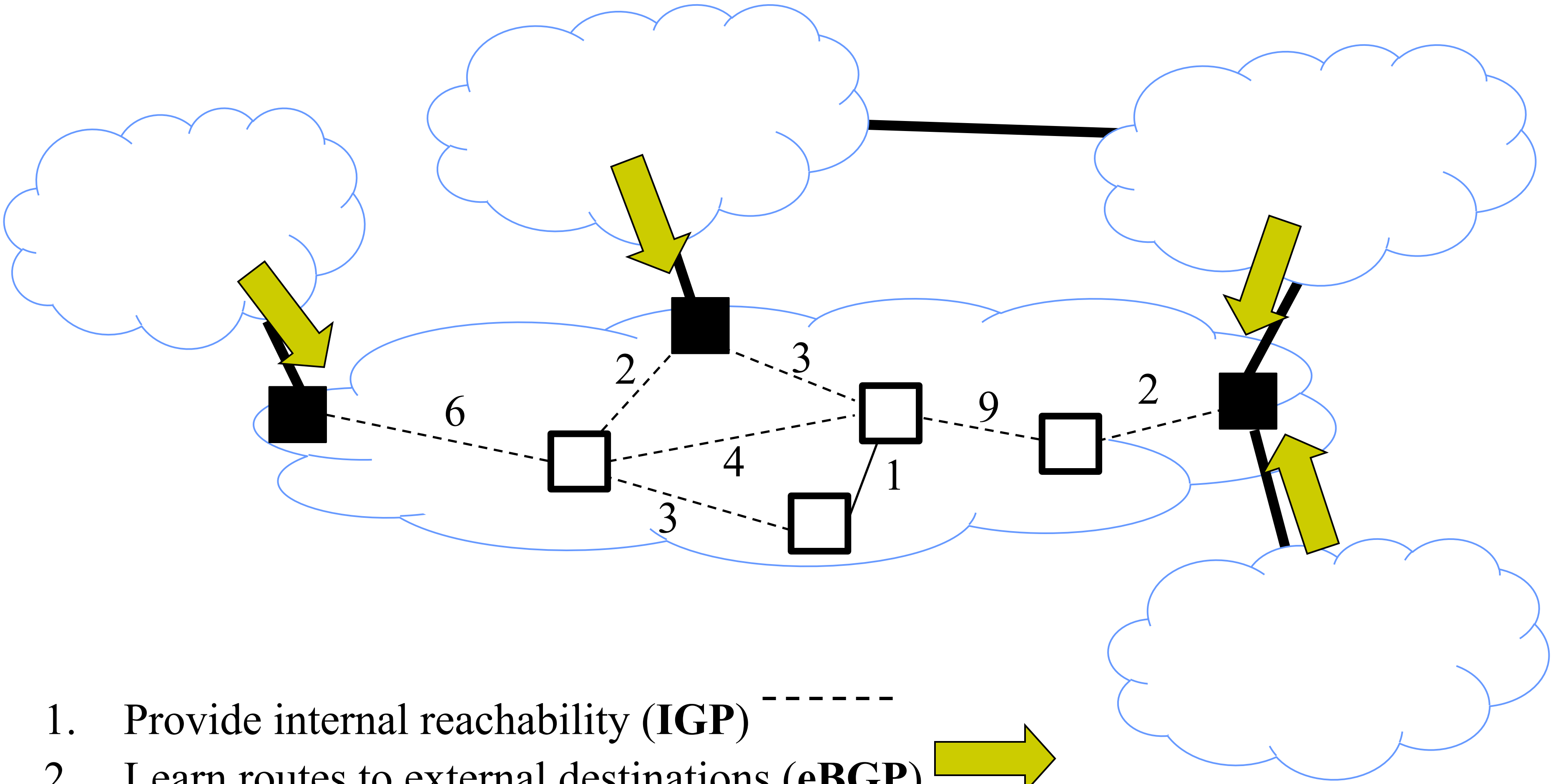

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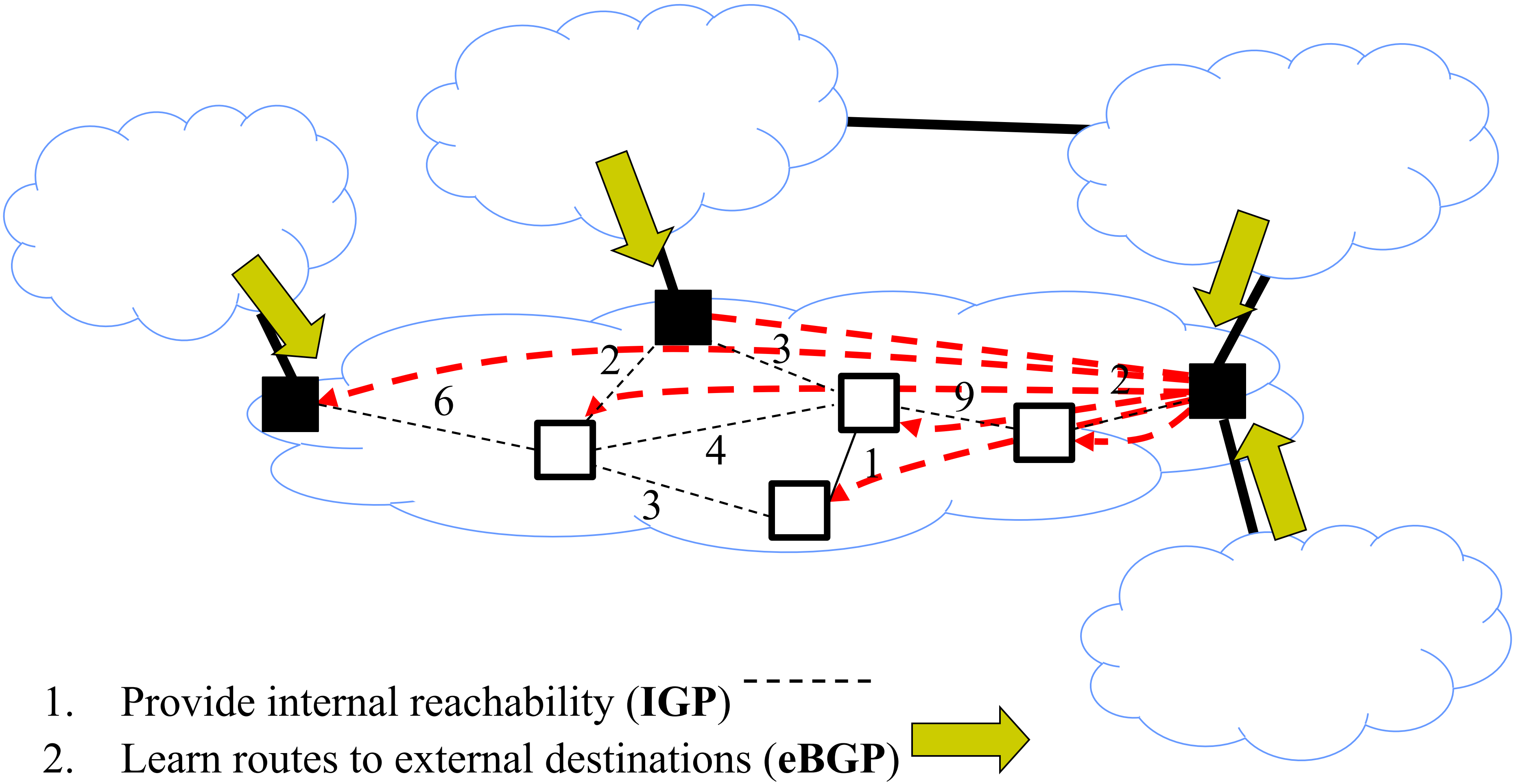

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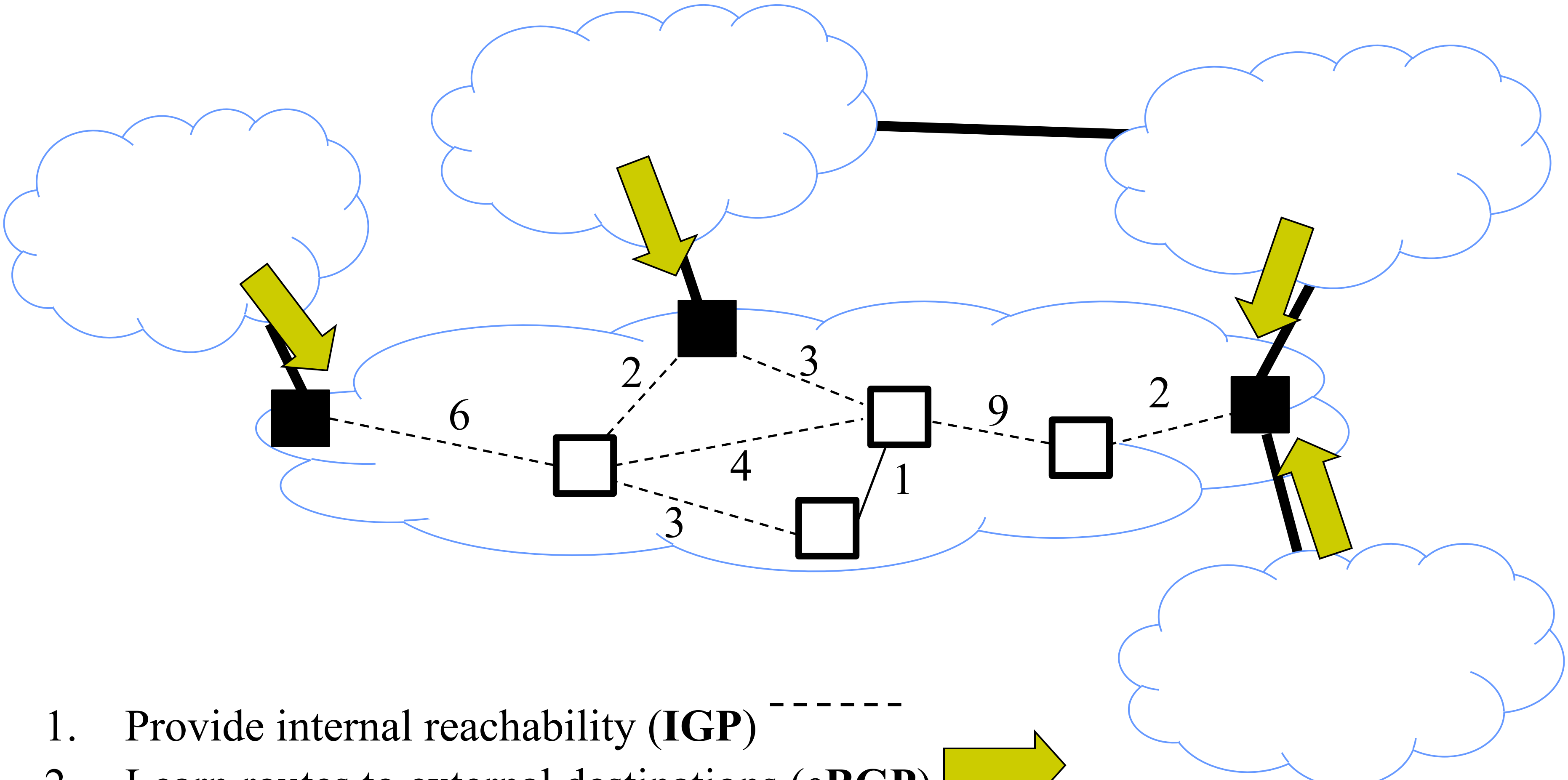

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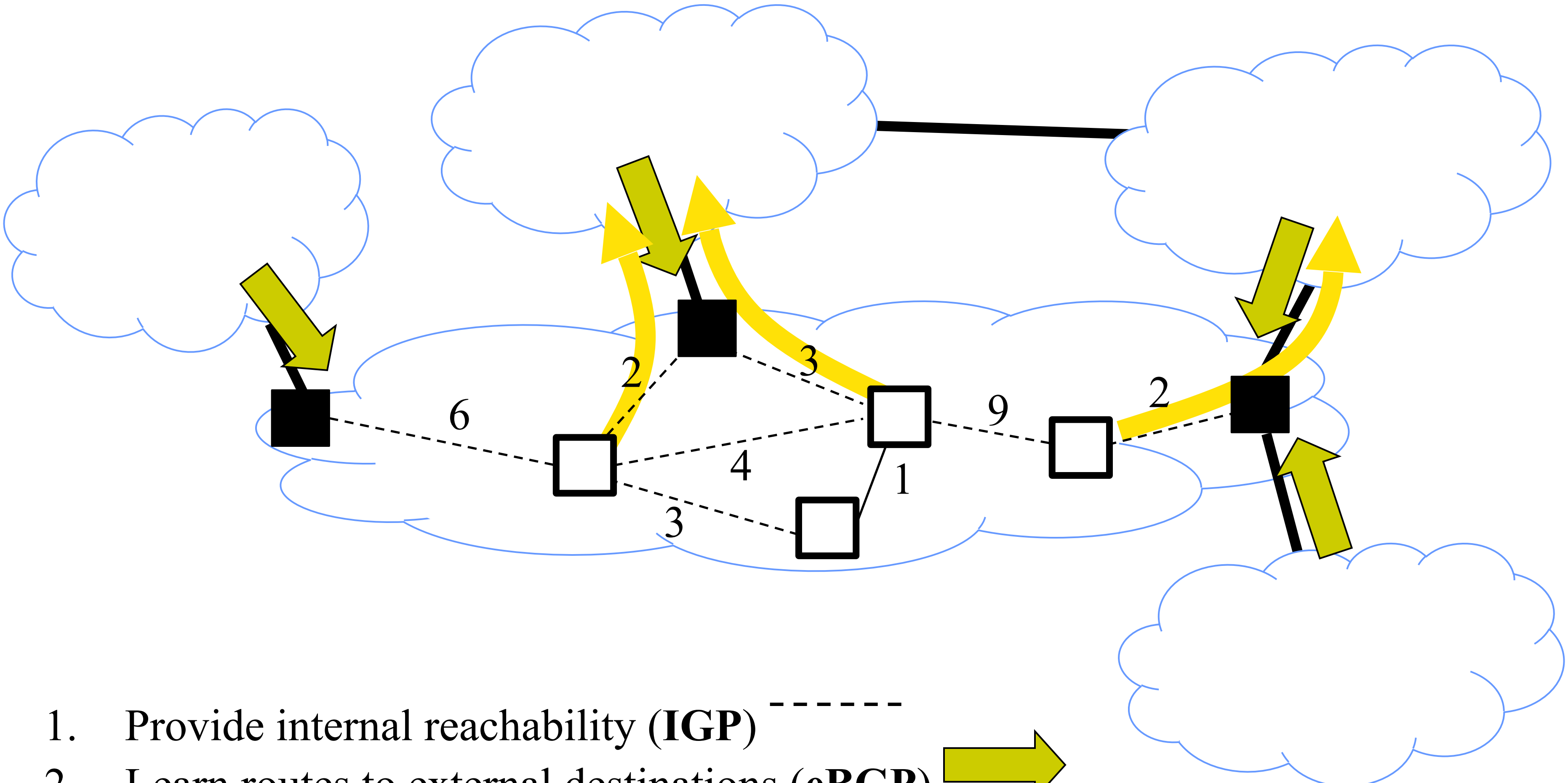

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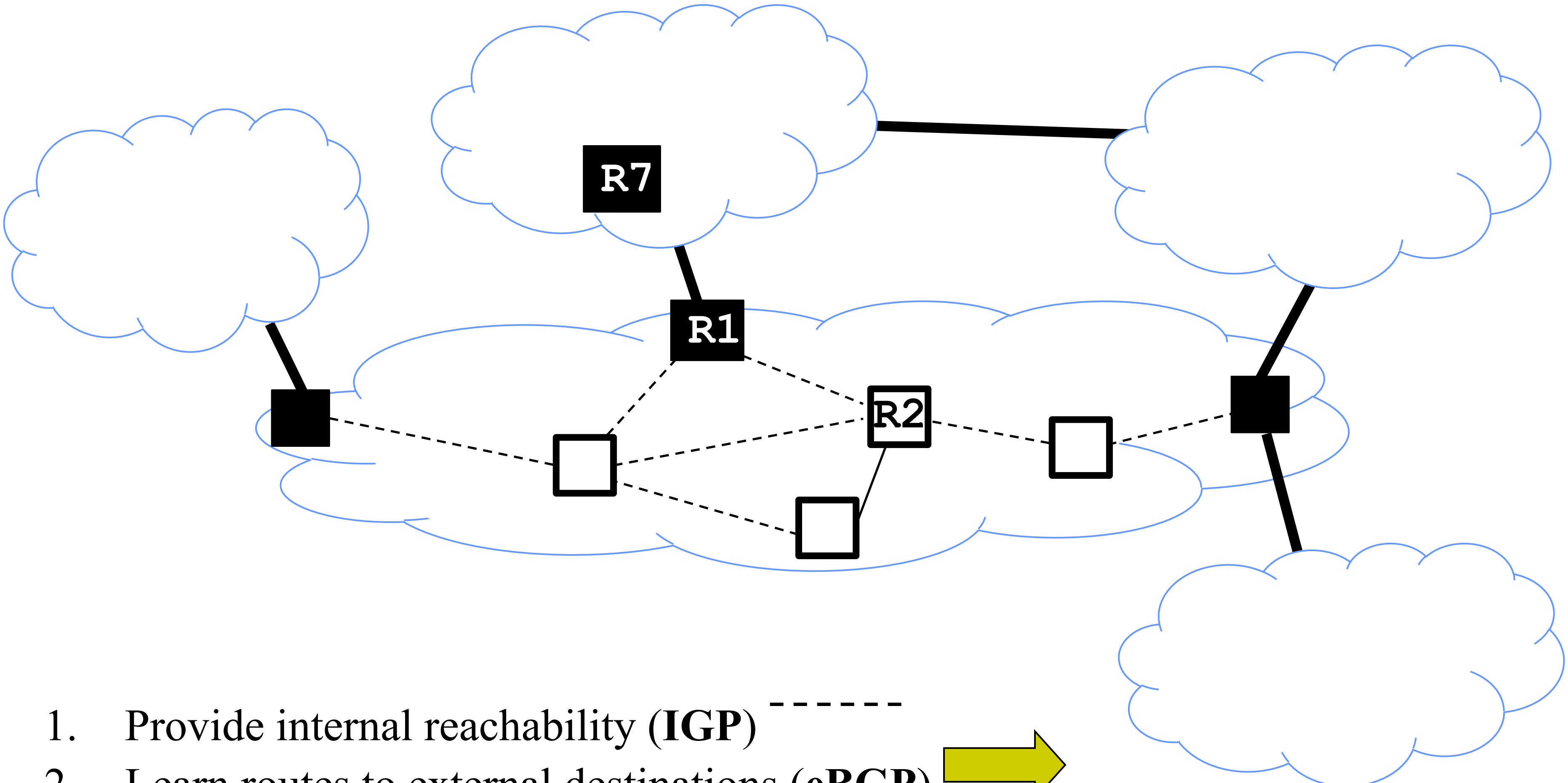

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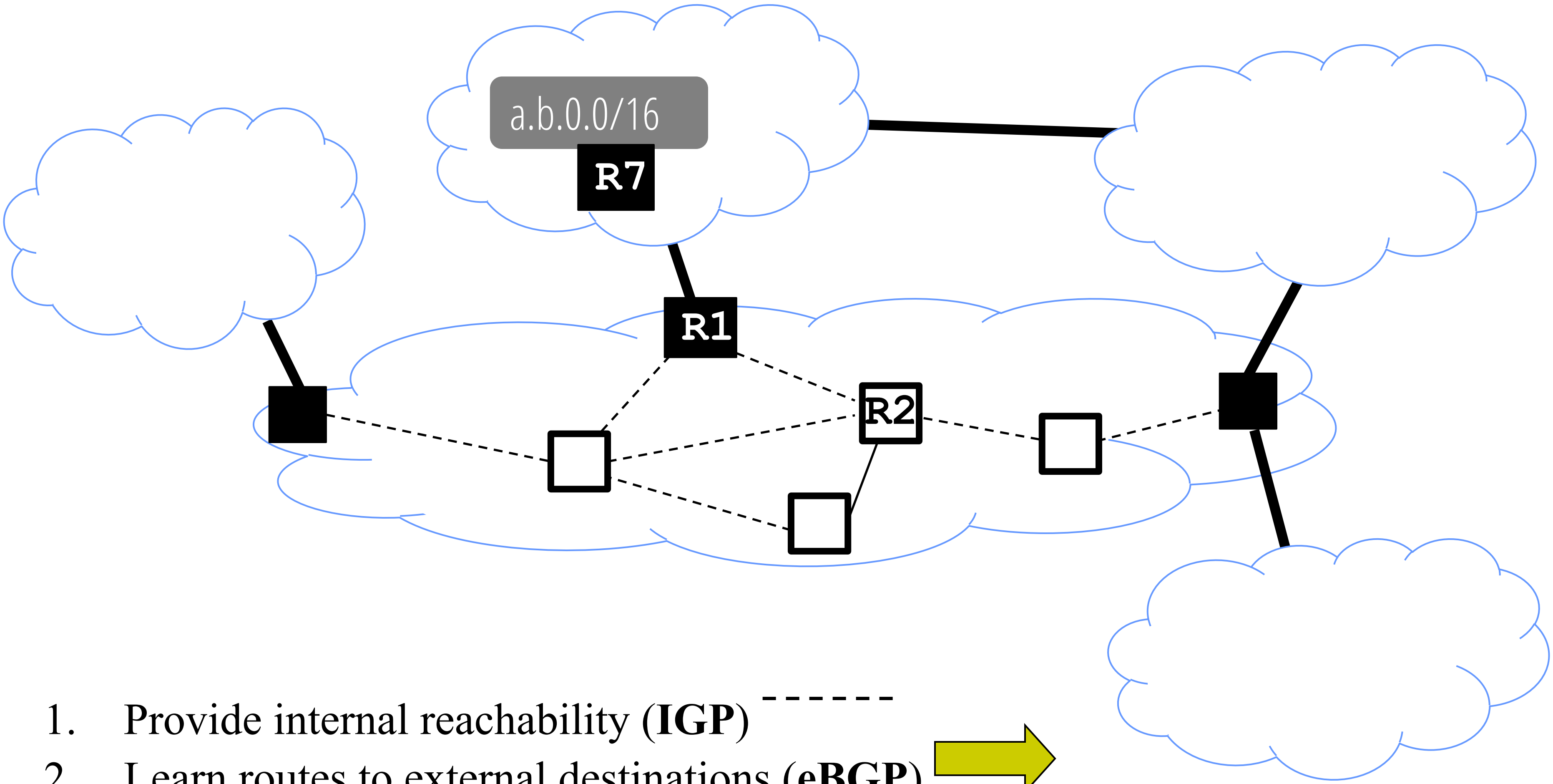

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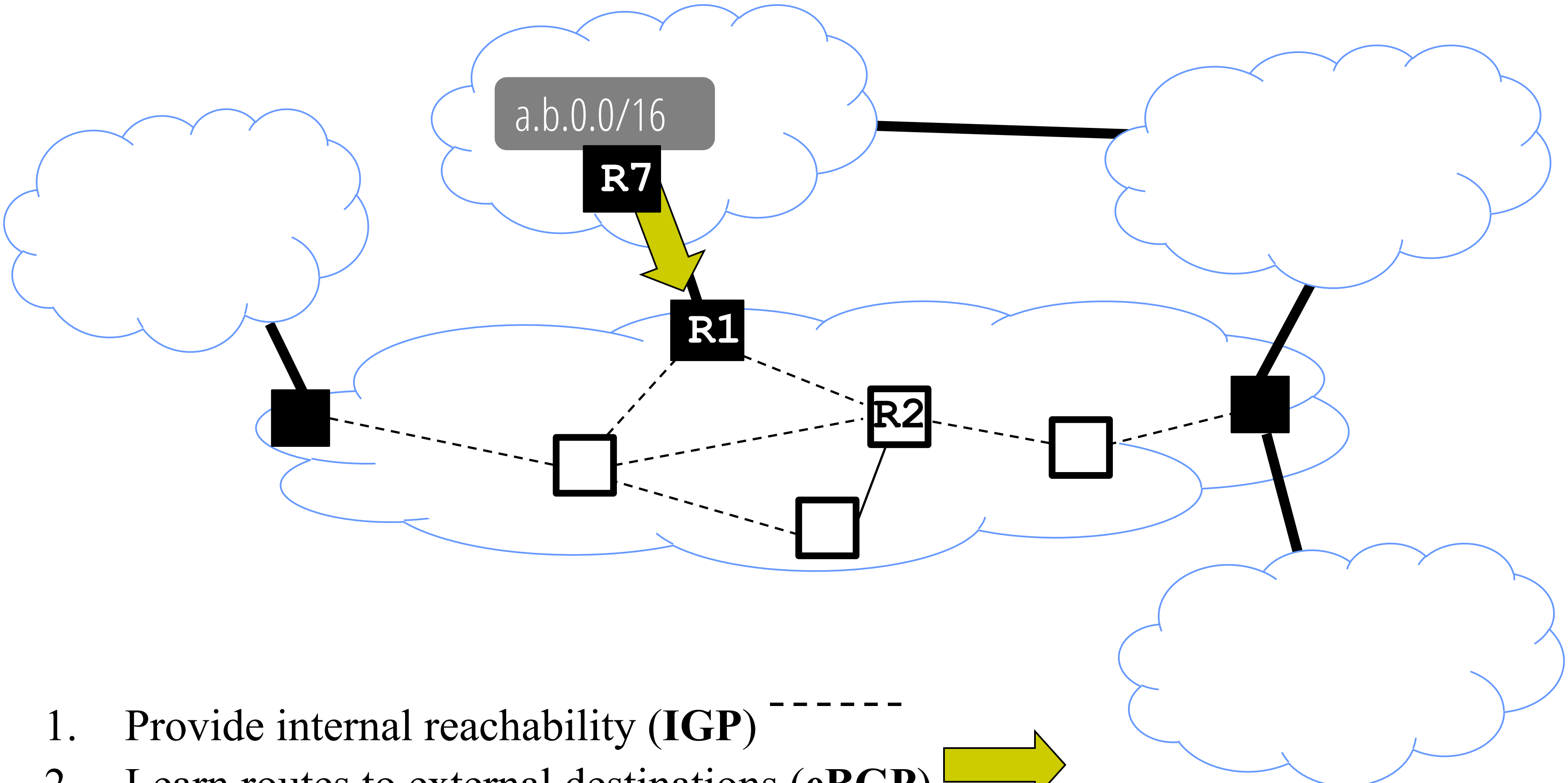

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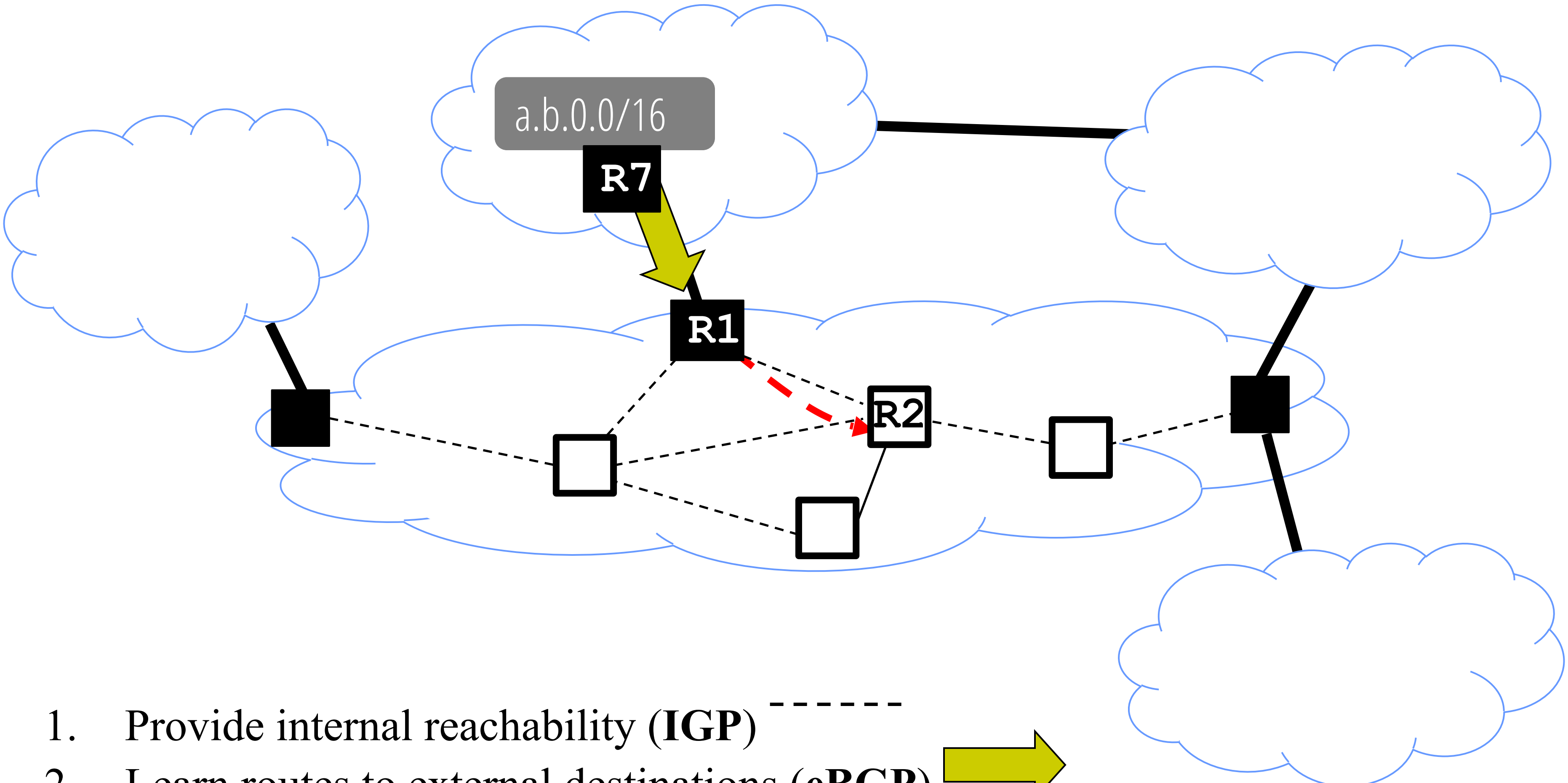

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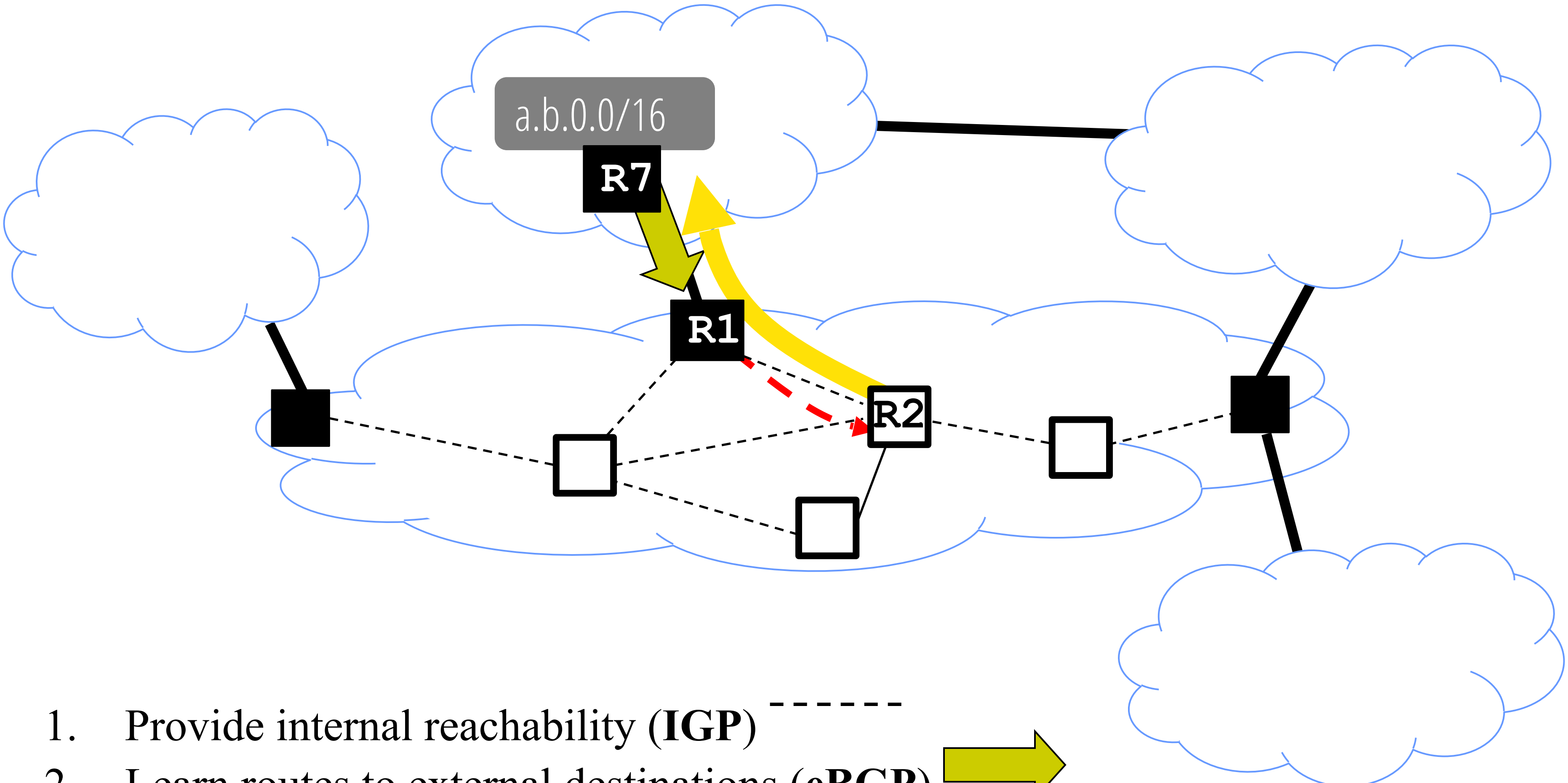

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- For external locations: use iBGP to find egress
  - Use IGP to find next hop to egress router

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- Our option: run iBGP between all routers in domain
  - Requires NxB iBGP connections. Could be a scaling issue.
  - This is what we will assume

Many design questions....

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- How do we ensure the routers in an AS "act as one"?
  - The role of border vs. interior routers?
  - Interaction between BGP and IGP
  - How is all this implemented?
    - Route updates and attributes

BGP protocol message types

- Many different message types
  - Open
  - Keepalive
  - Notification
  - ...
  - Update
    - Inform neighbor of new routes
    - Inform neighbor of updates to old routes
    - “Withdraw” a route that’s now inactive

Route Updates

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- Format *<IP prefix: route attributes>*
  - attributes describe properties of the route

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- Others are propagated in eBGP route advertisements
- There are many standardized attributes in BGP
  - We will discuss four important ones

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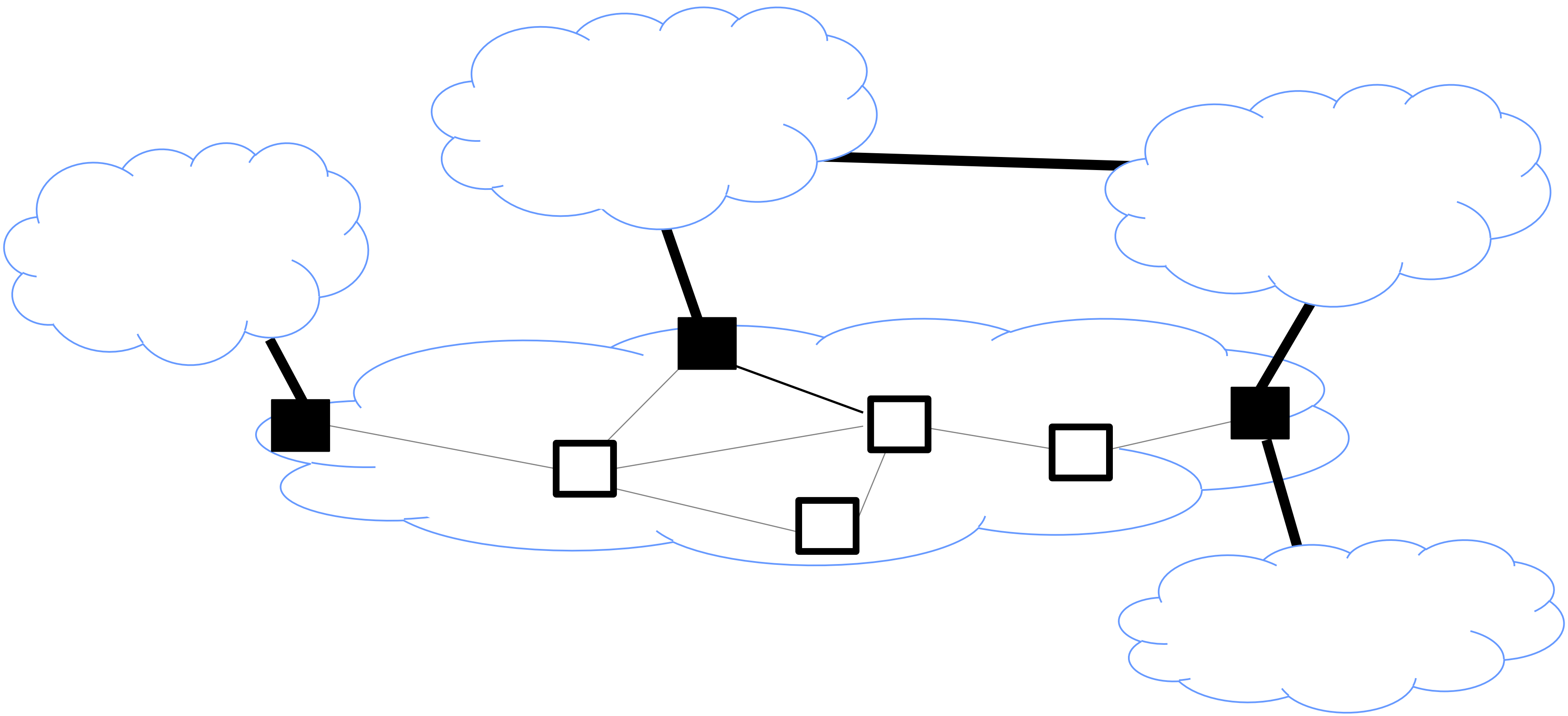

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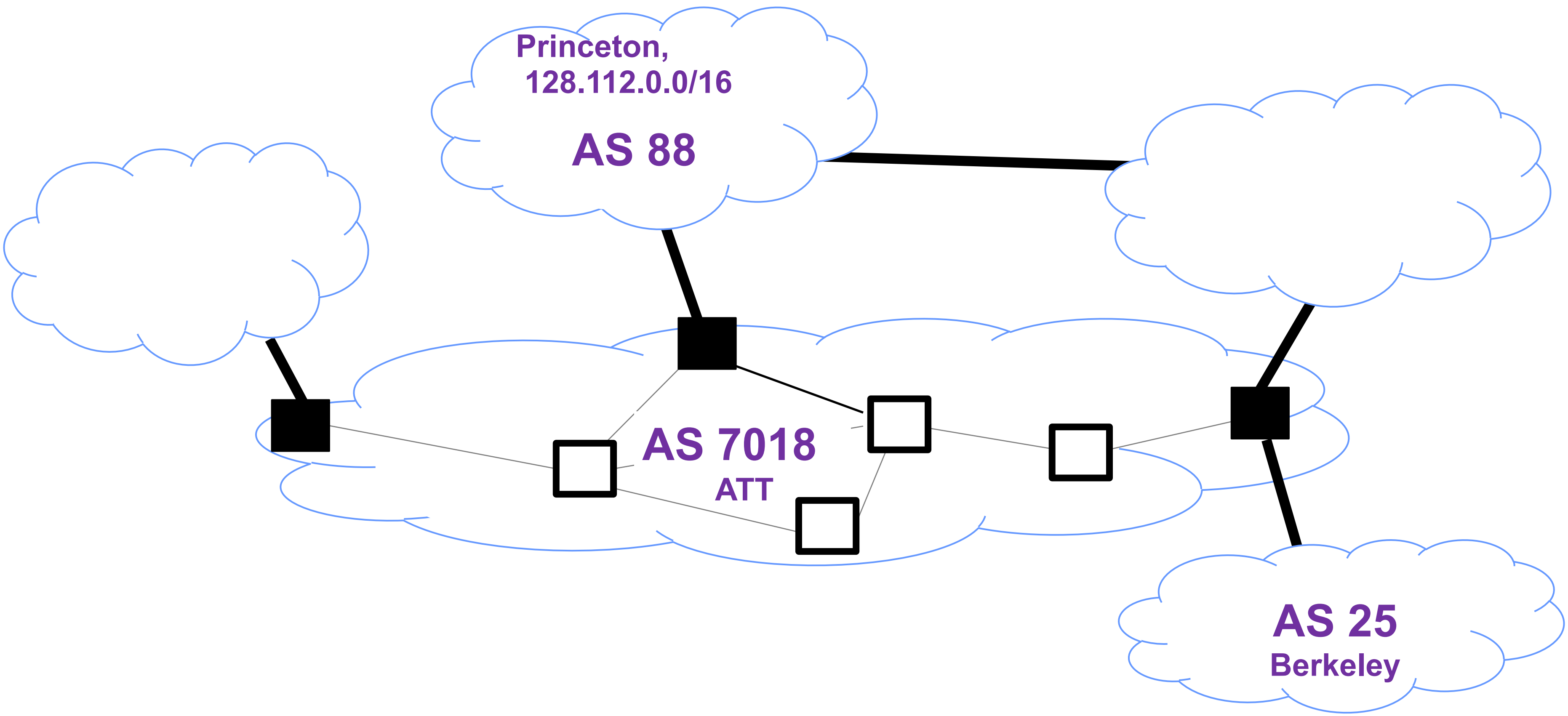

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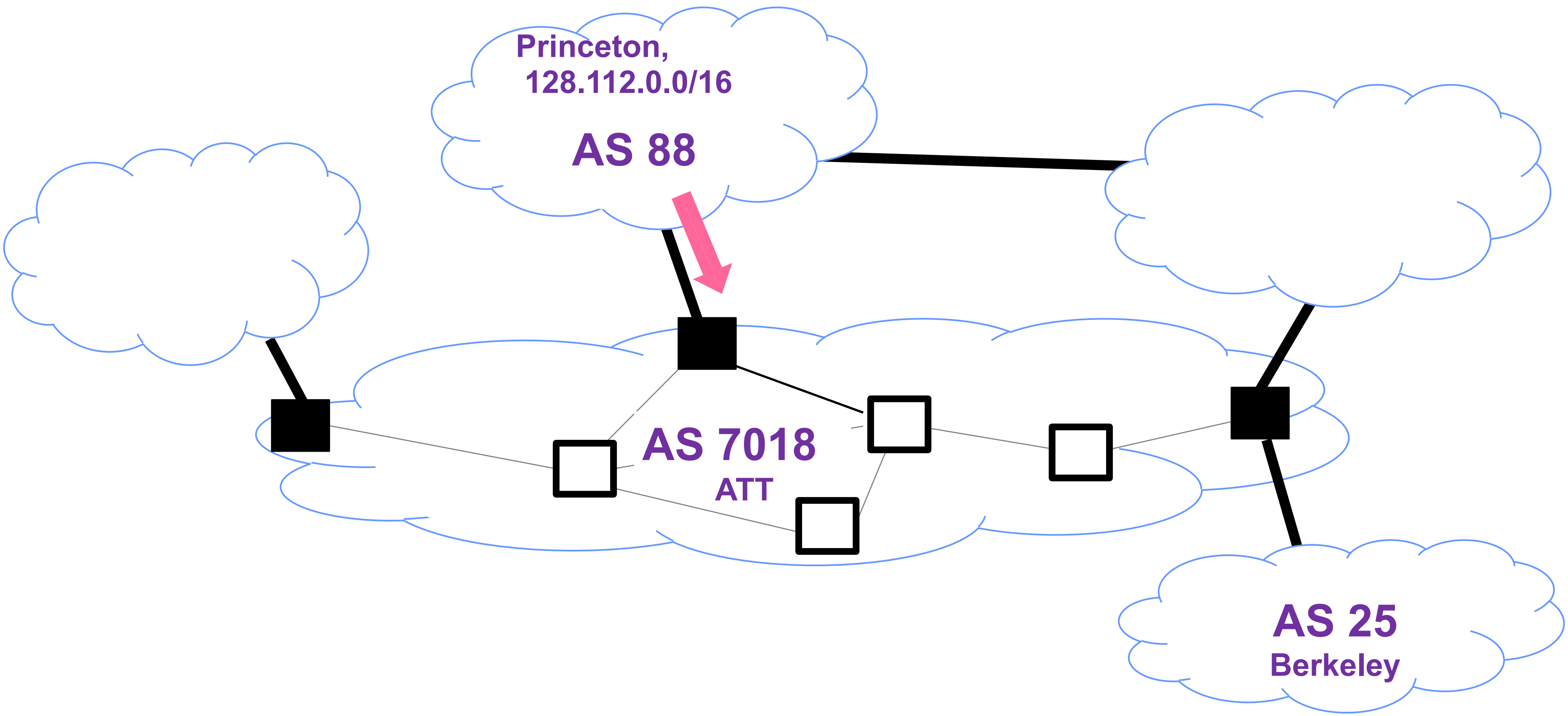

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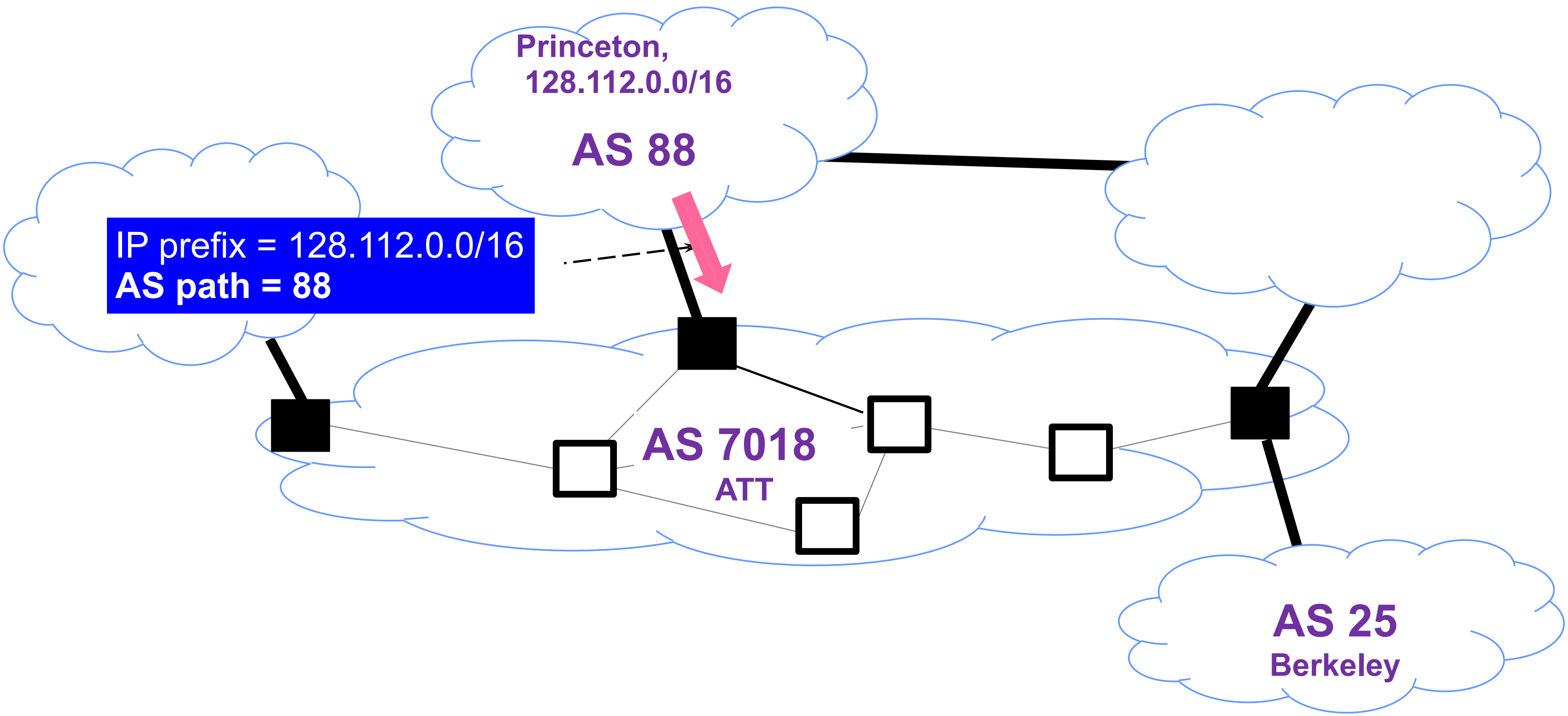

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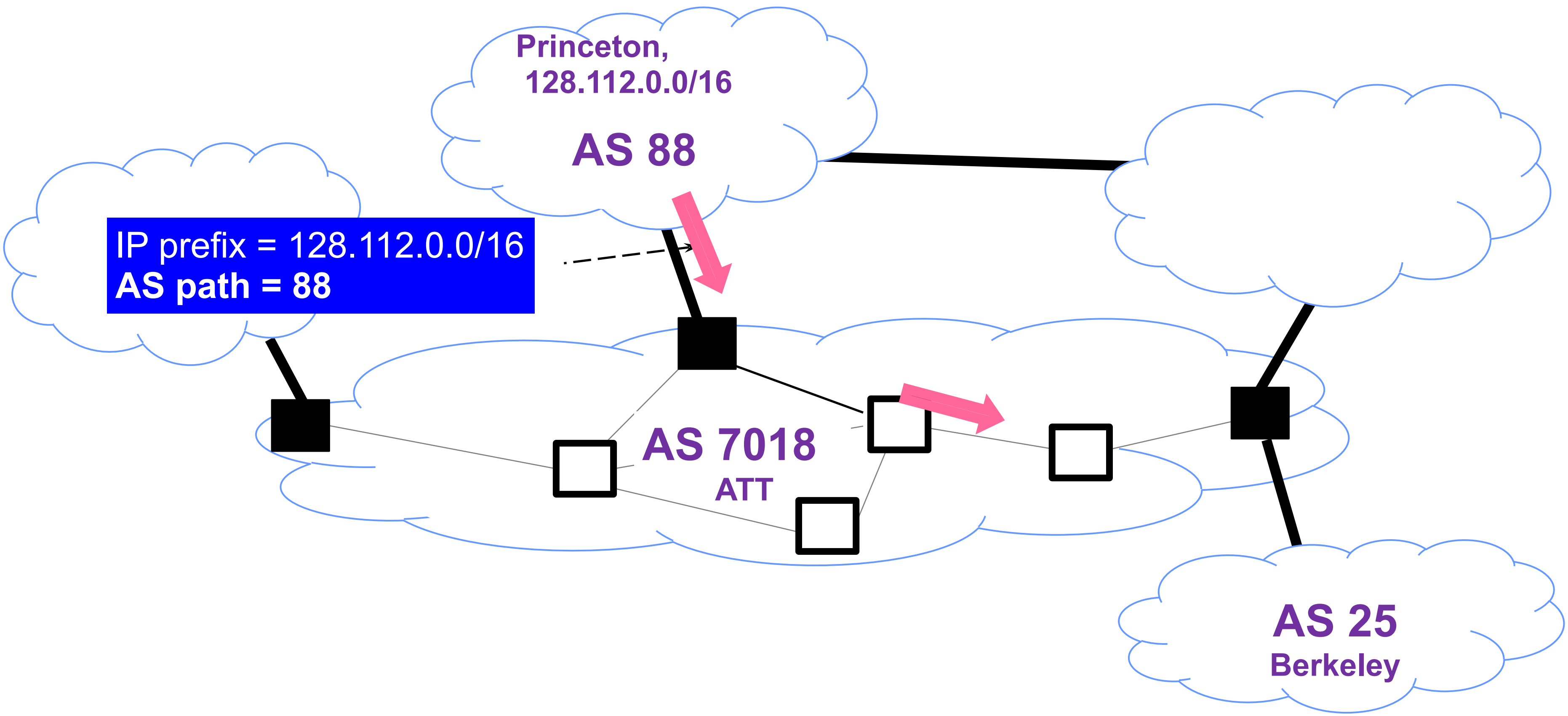

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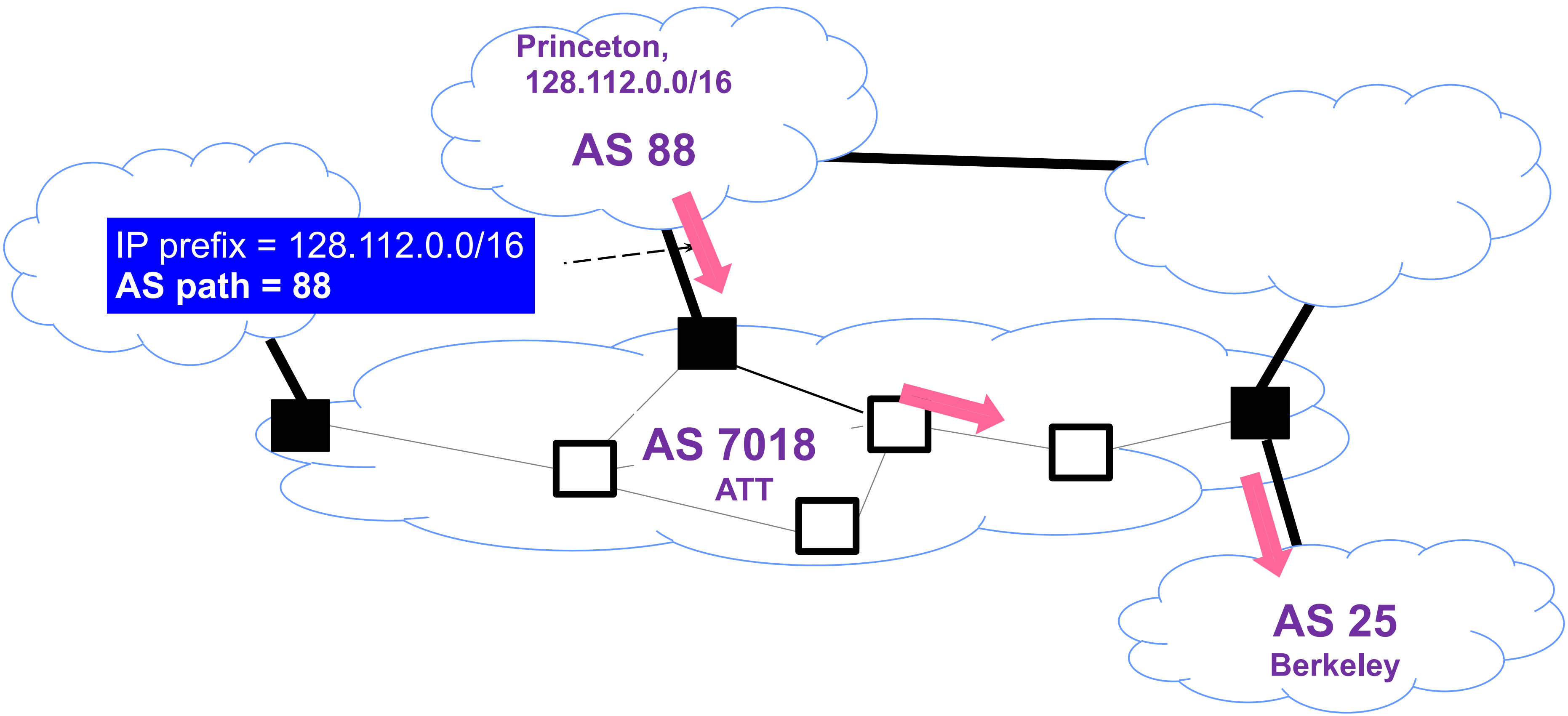

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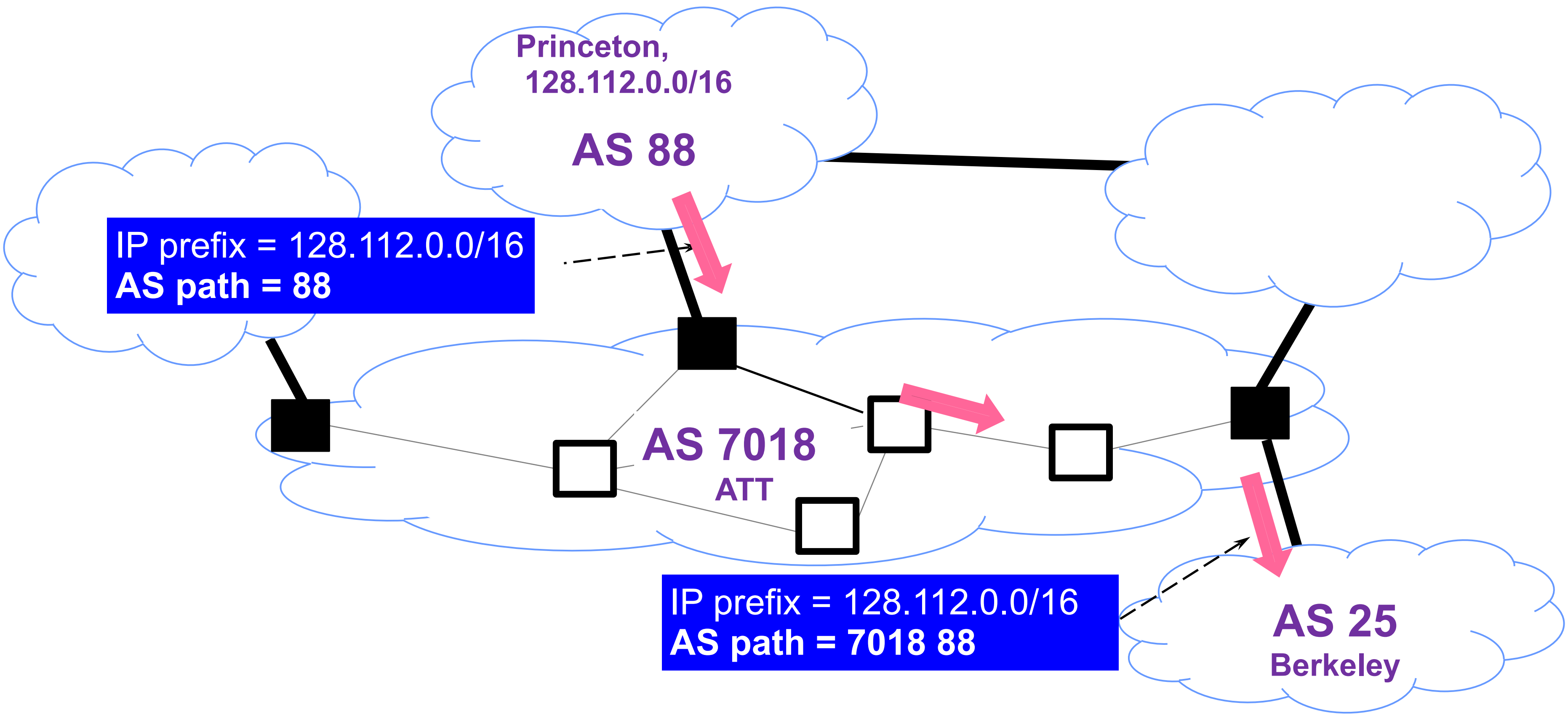

Attributes (2): LOCAL PREFERENCE

- Used to choose between different AS paths
- Local to an AS; carried only in iBGP messages
- The higher the value the more that route is preferred

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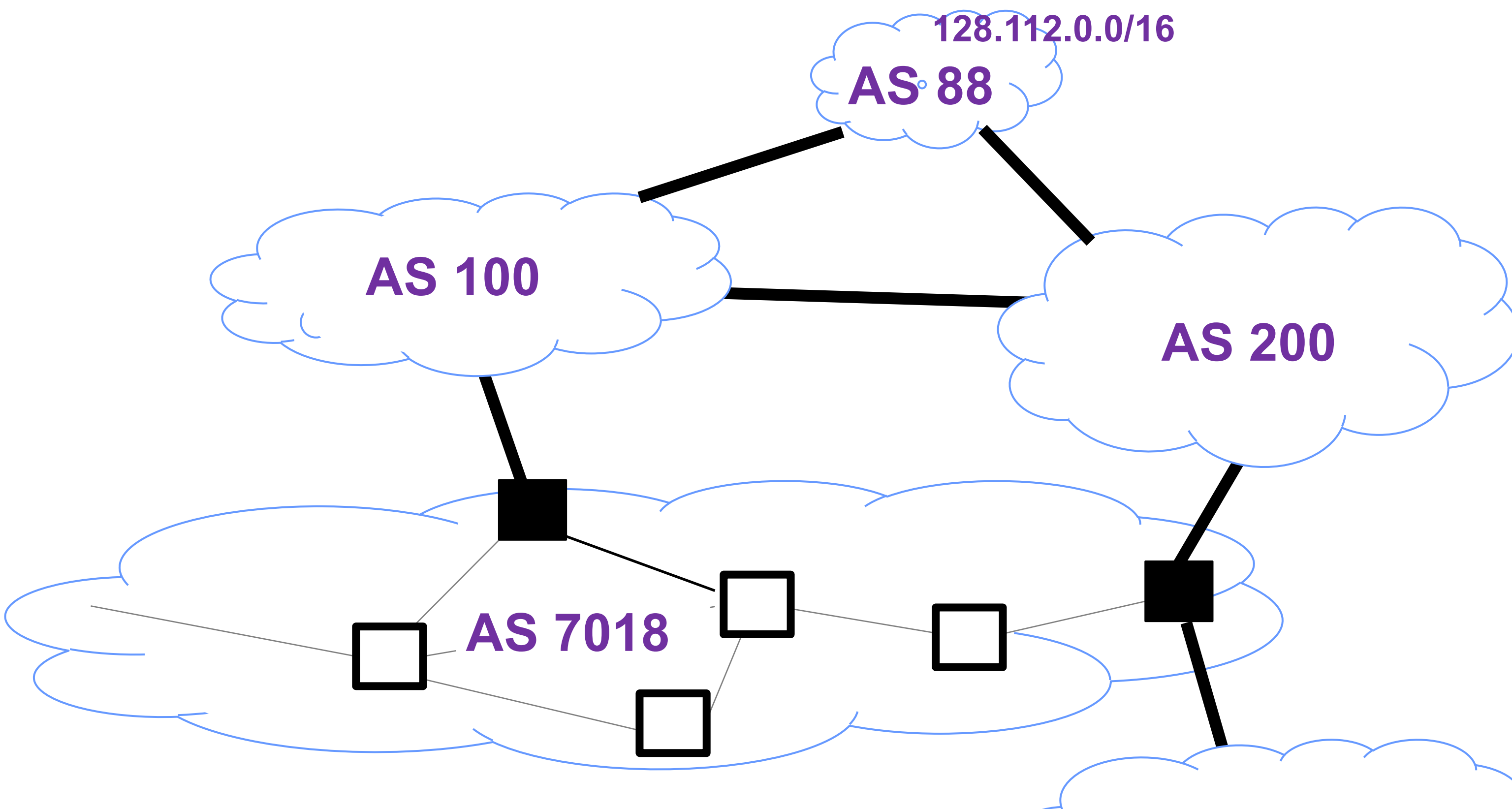

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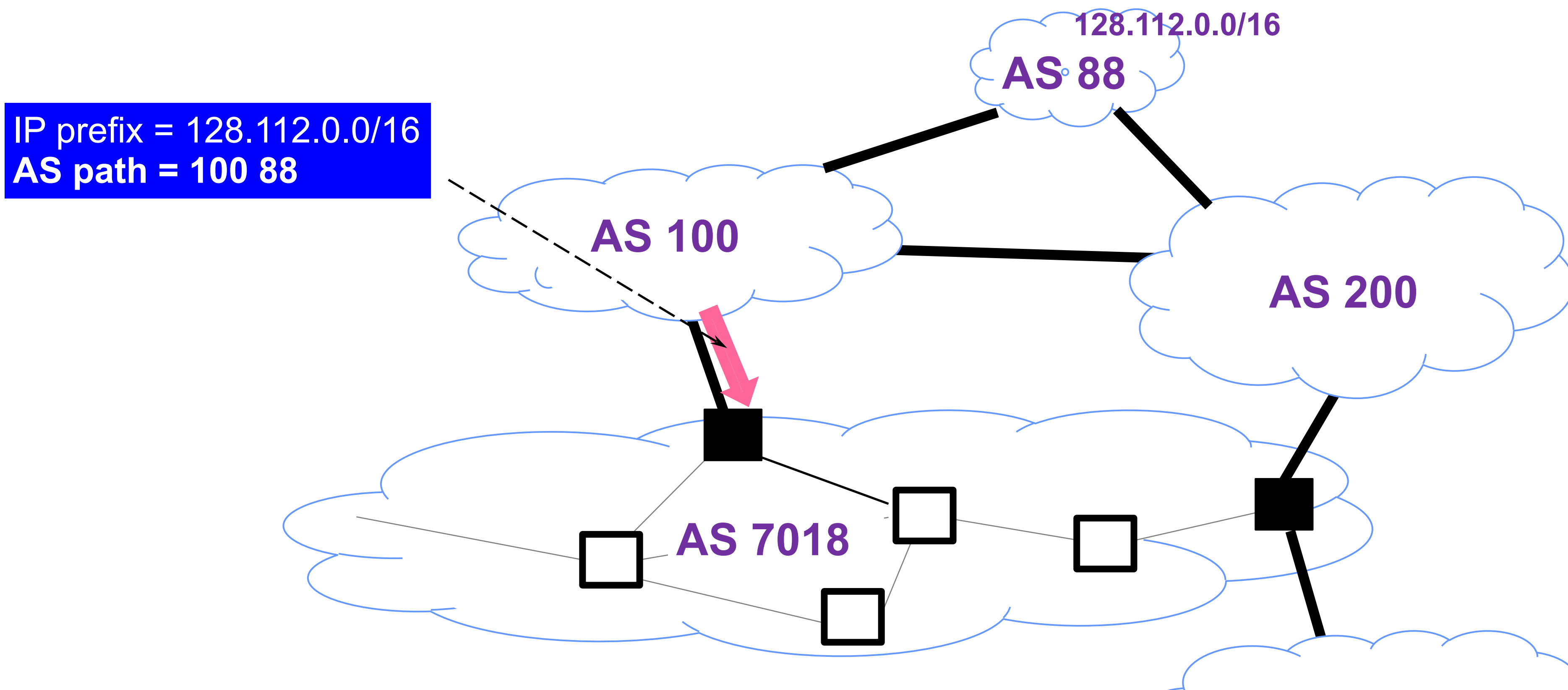

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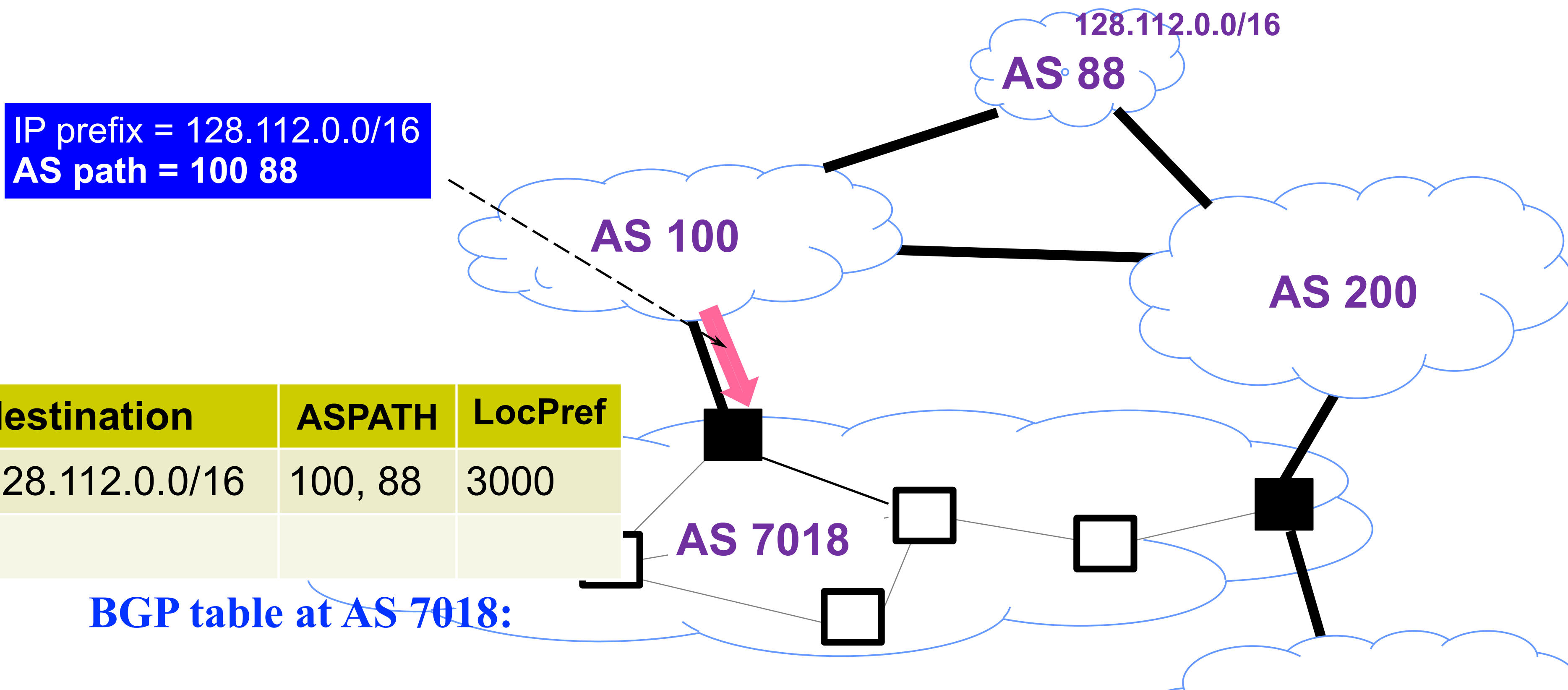

BGP table at AS 7018:

destination	ASPATH	LocPref
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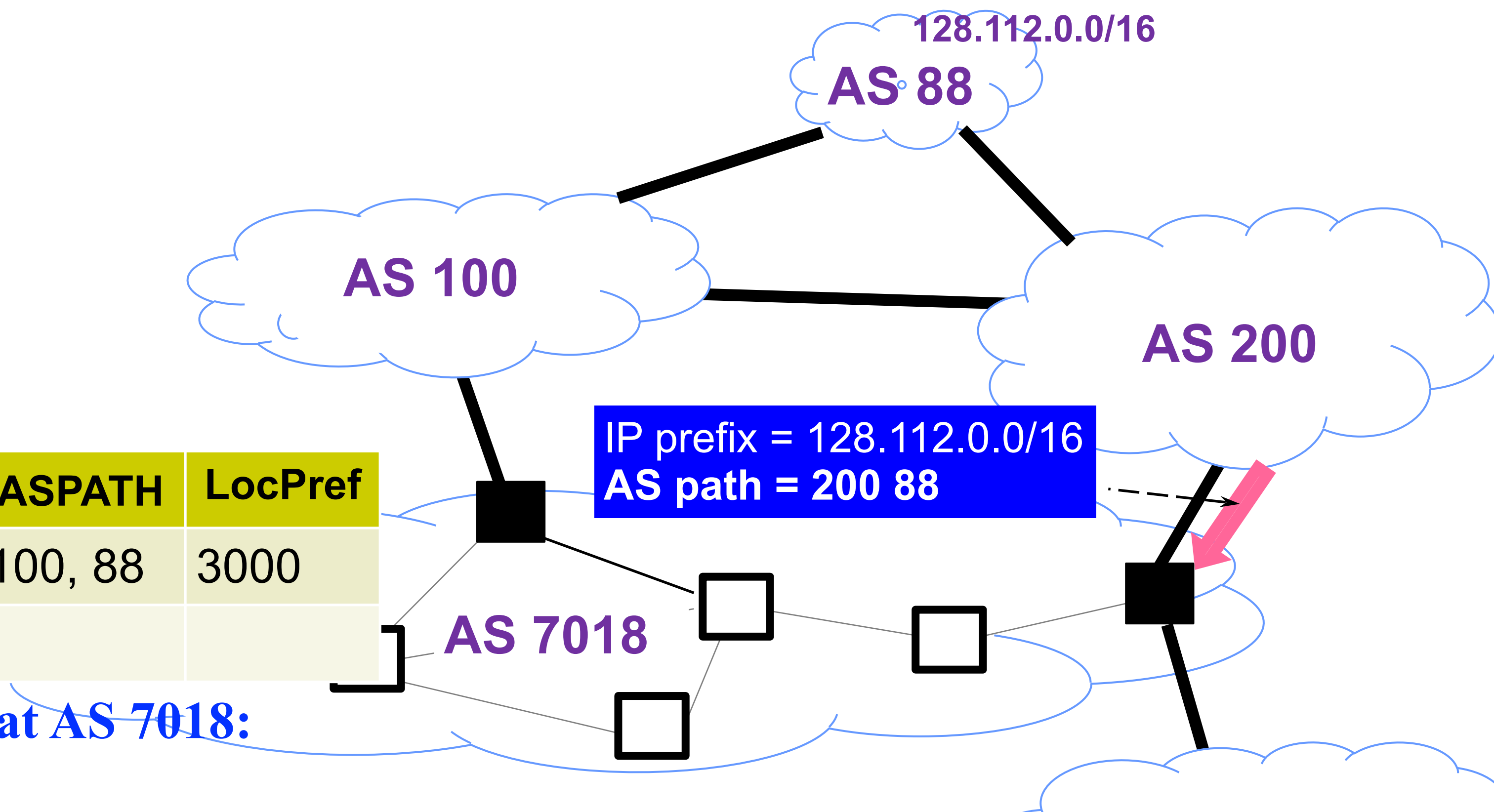

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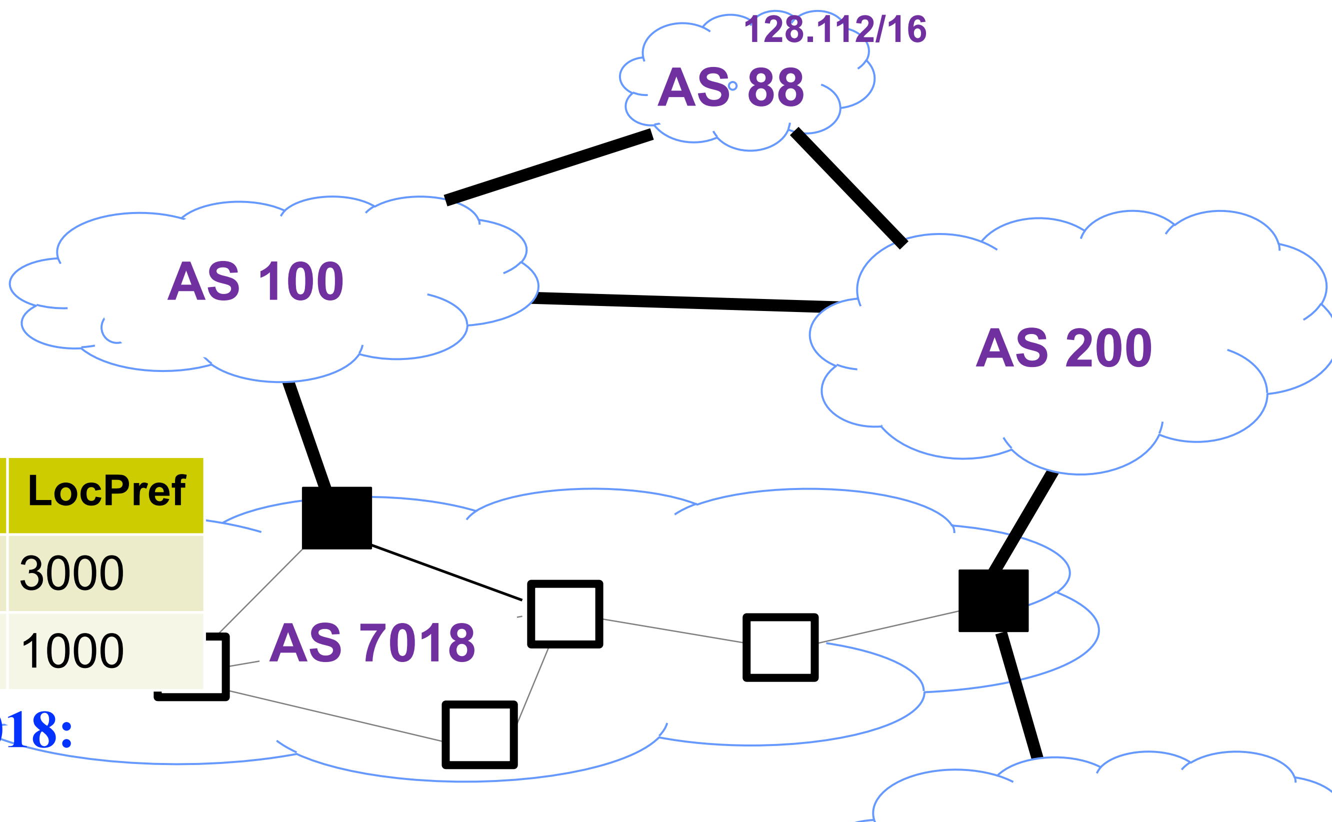

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BGP table at AS 7018:

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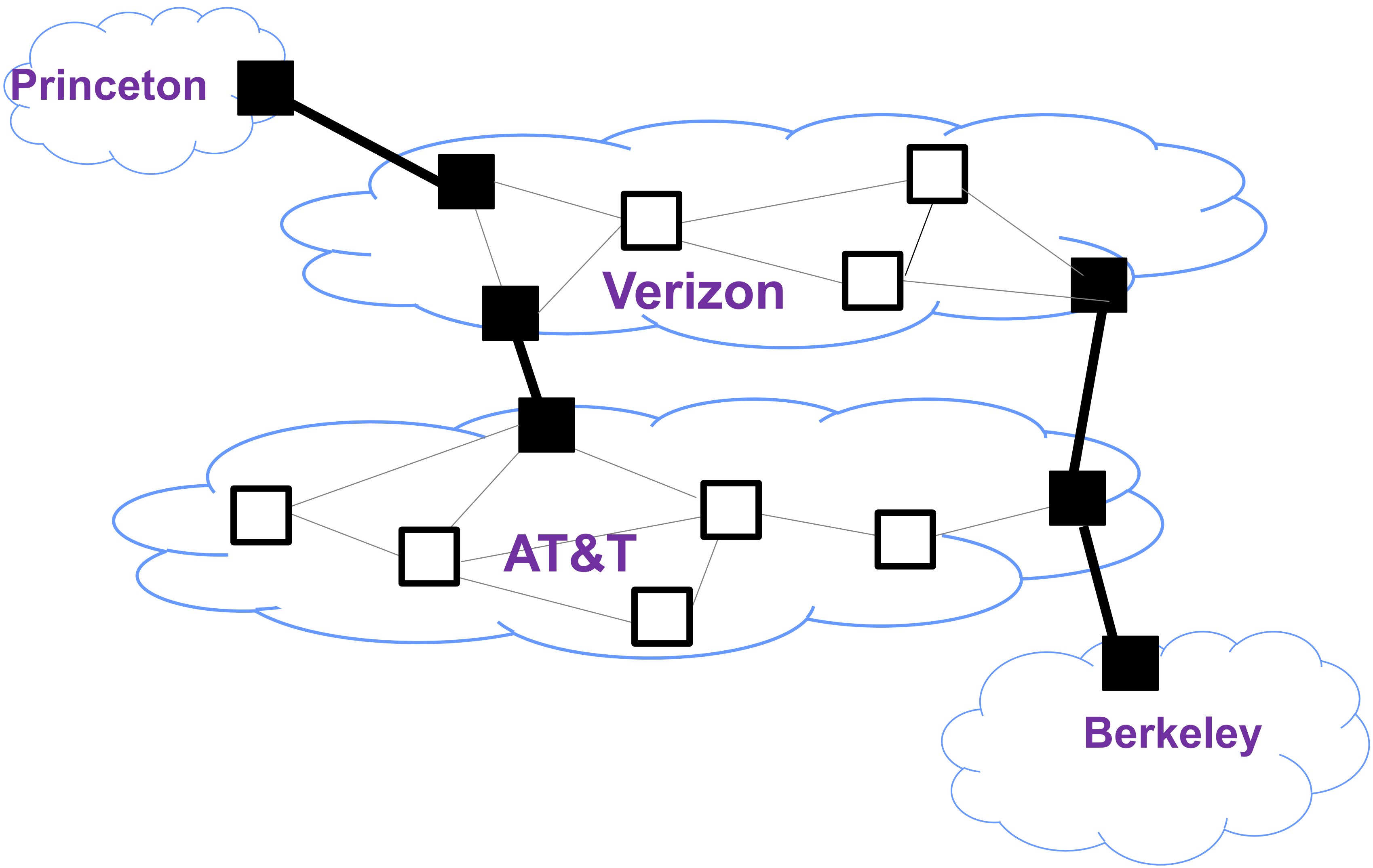

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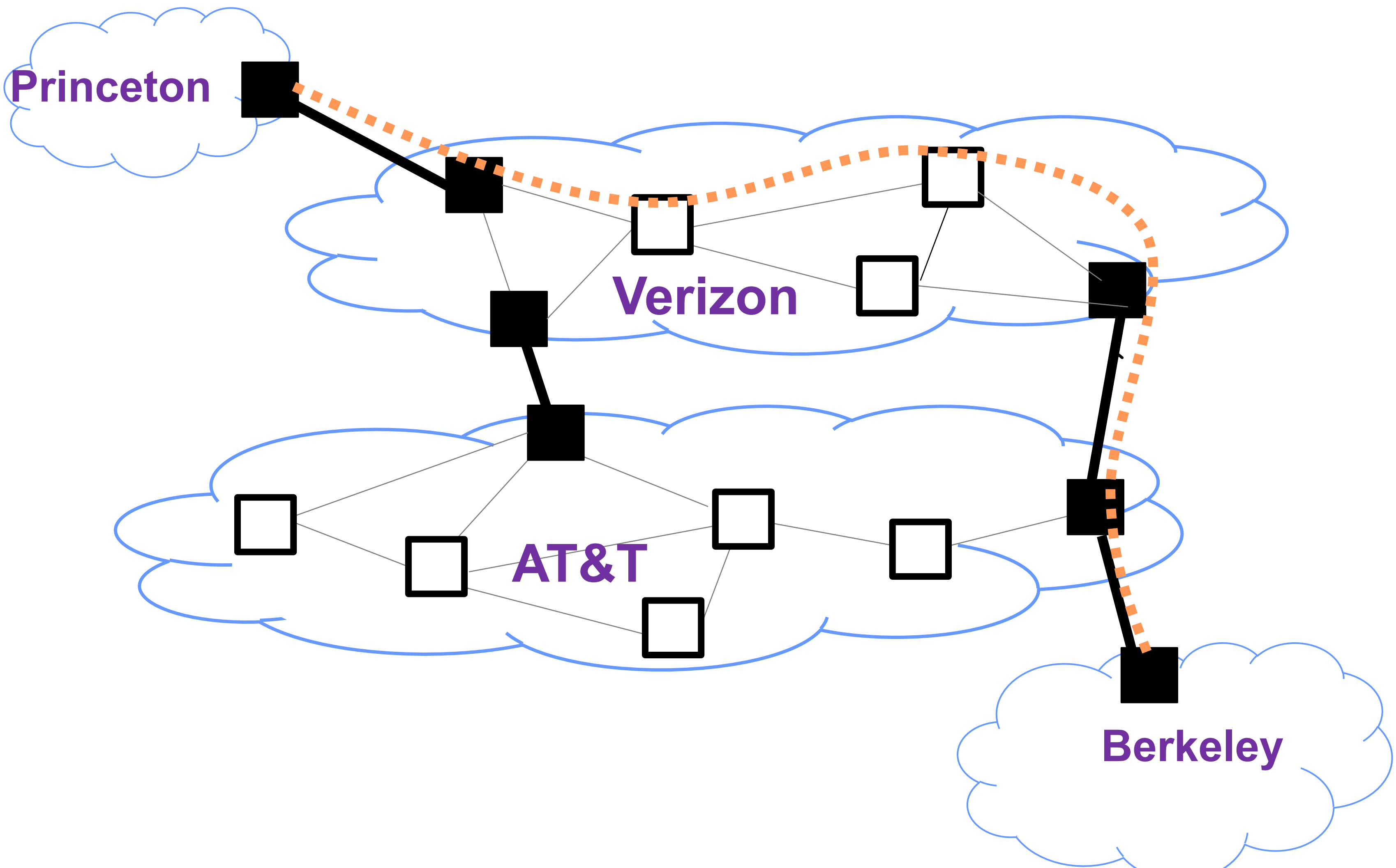

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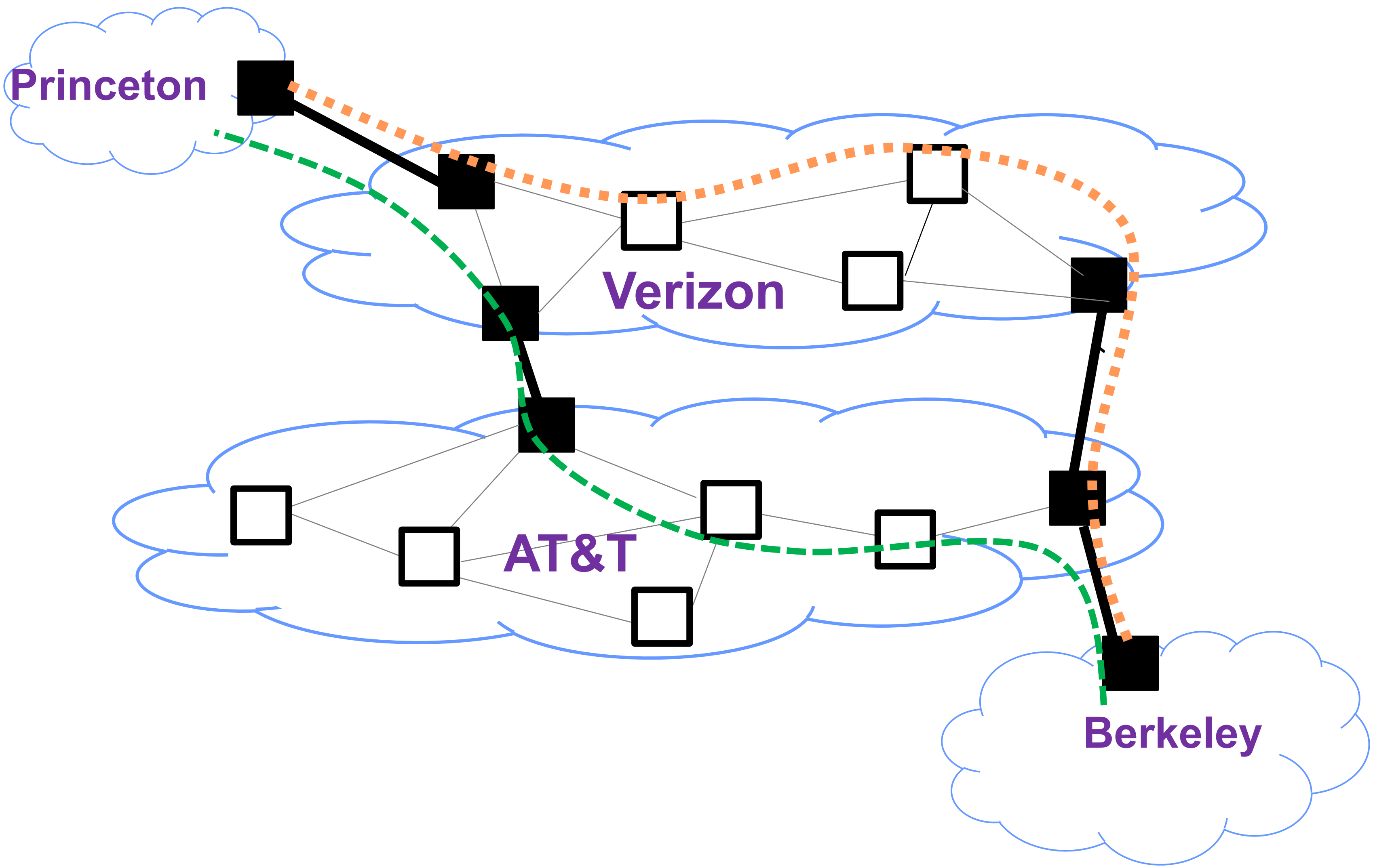

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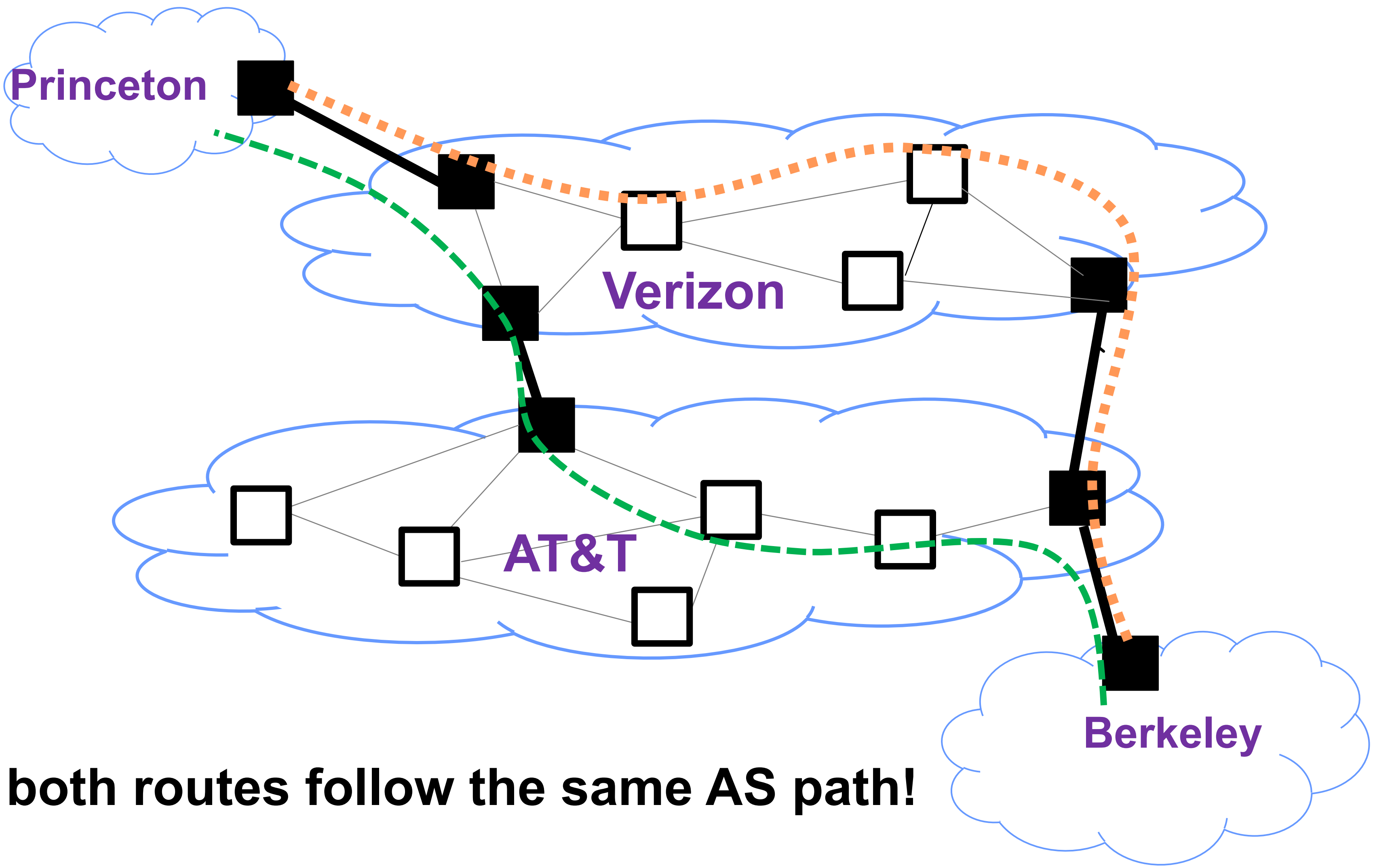

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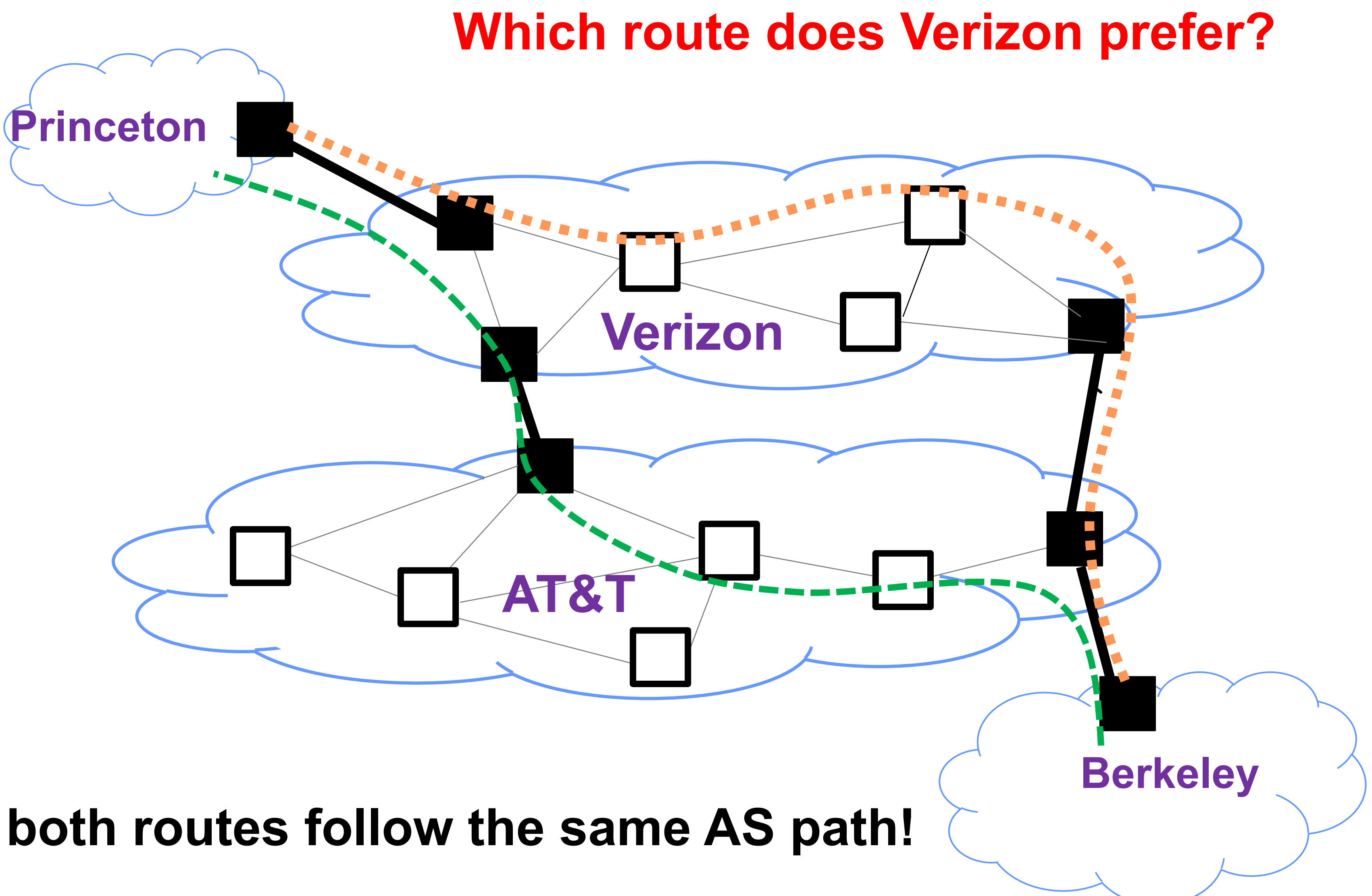
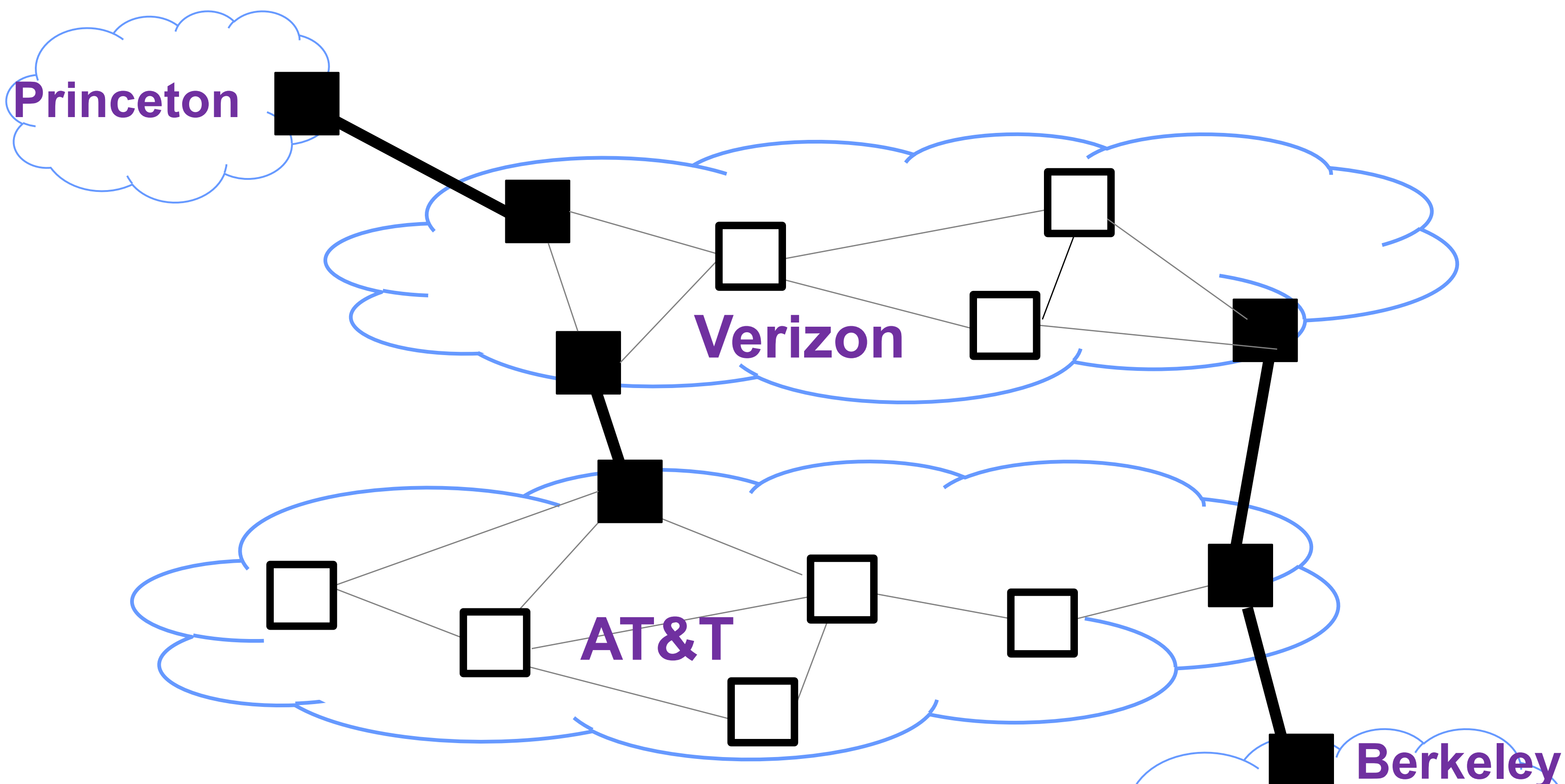


Note: both routes follow the same AS path!

Attributes (3) : `MED`

- MED = “Multi-Exit Discriminator”
- Used when ASes are interconnected via 2 or more links to specify how close a prefix is to the link it is announced on

Attributes (3) : MED



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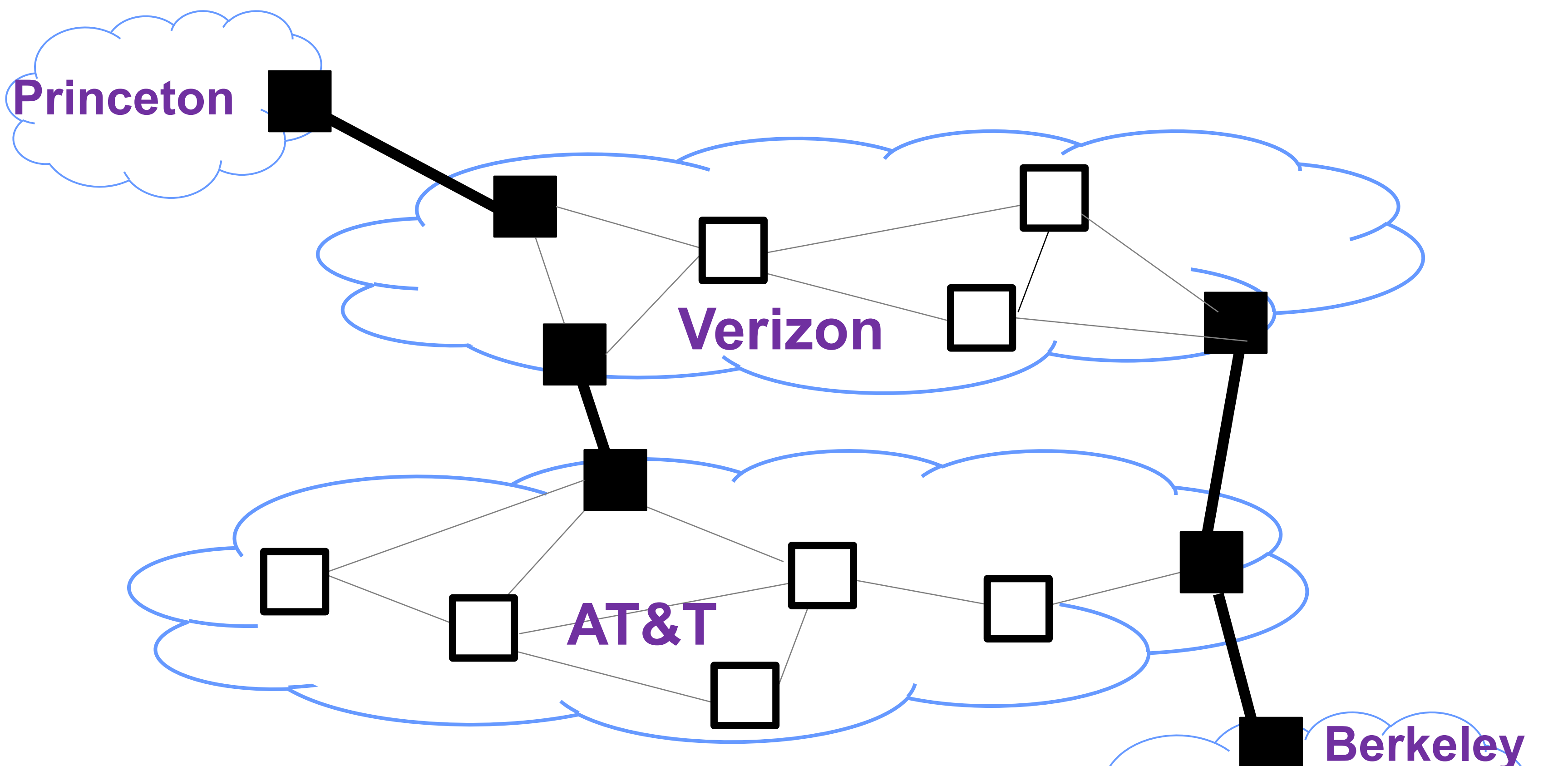

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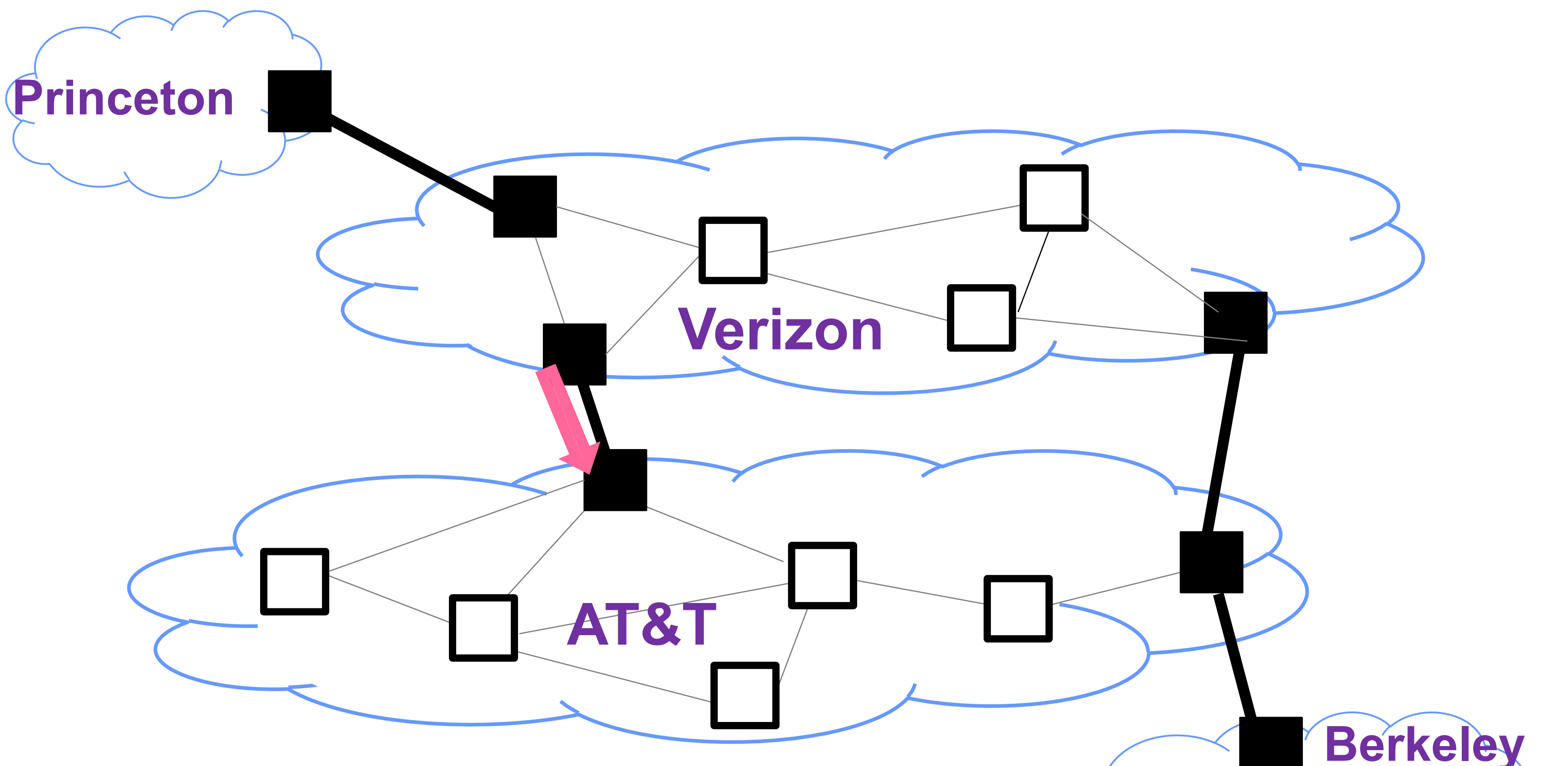

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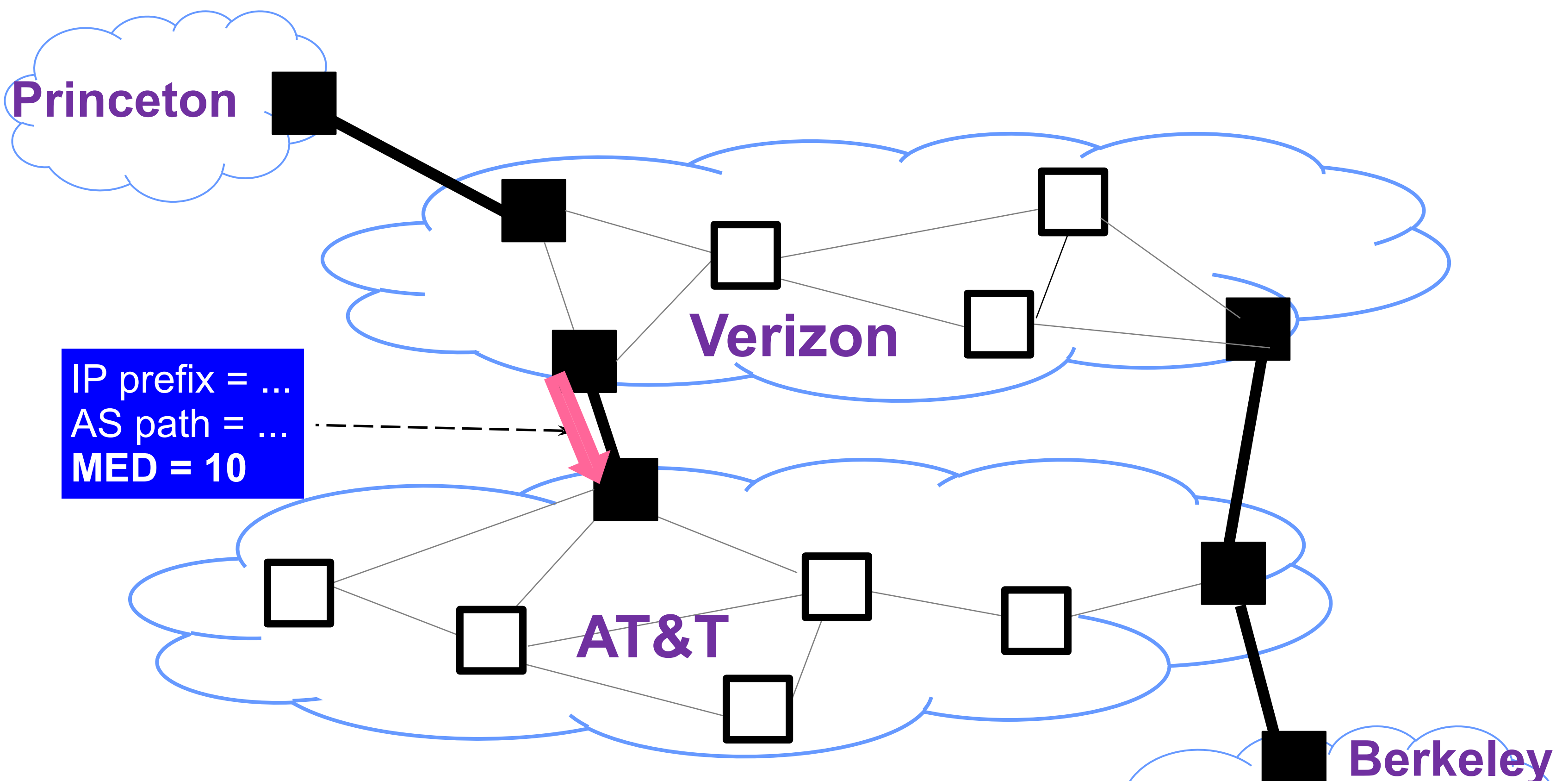

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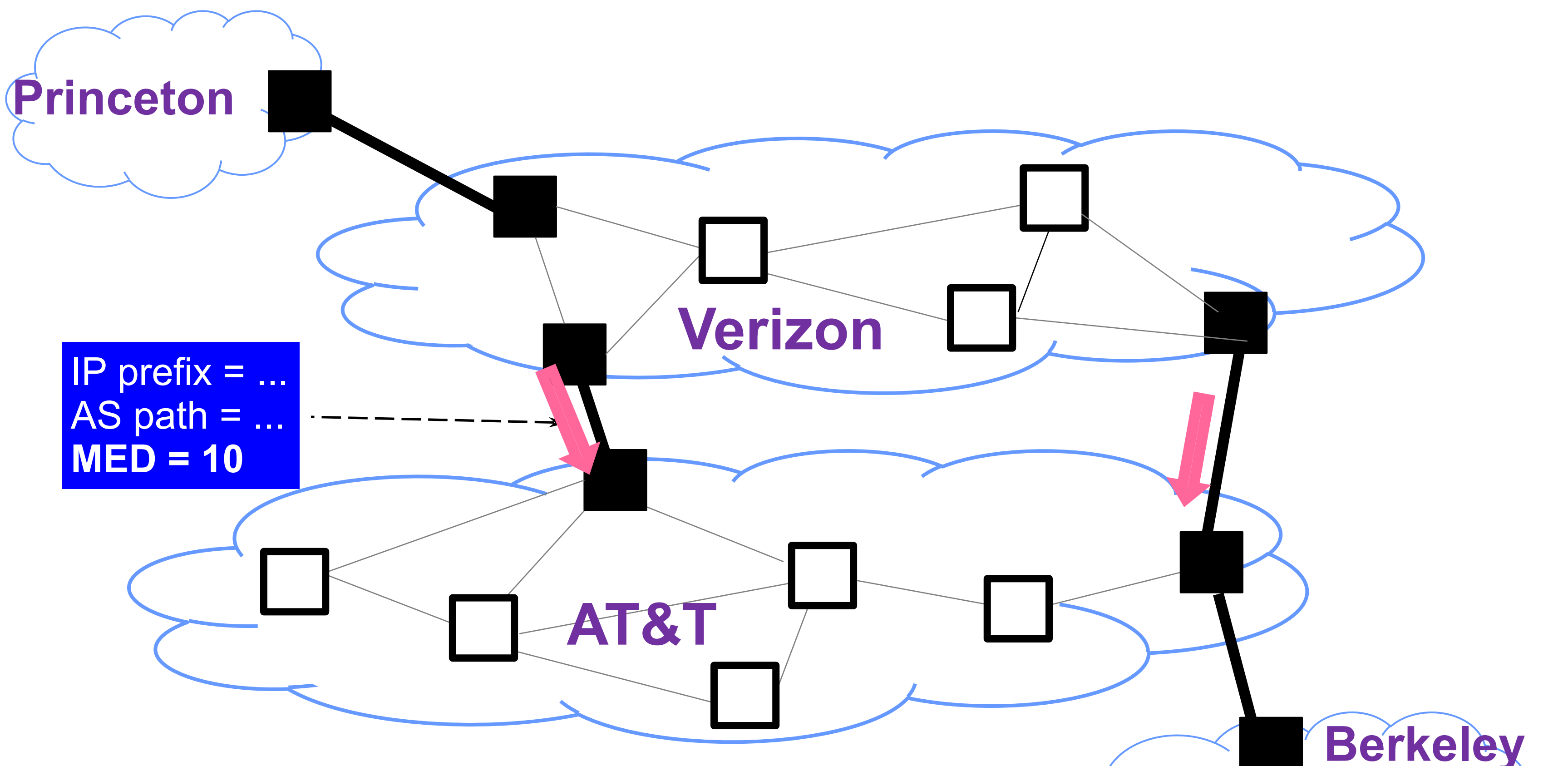

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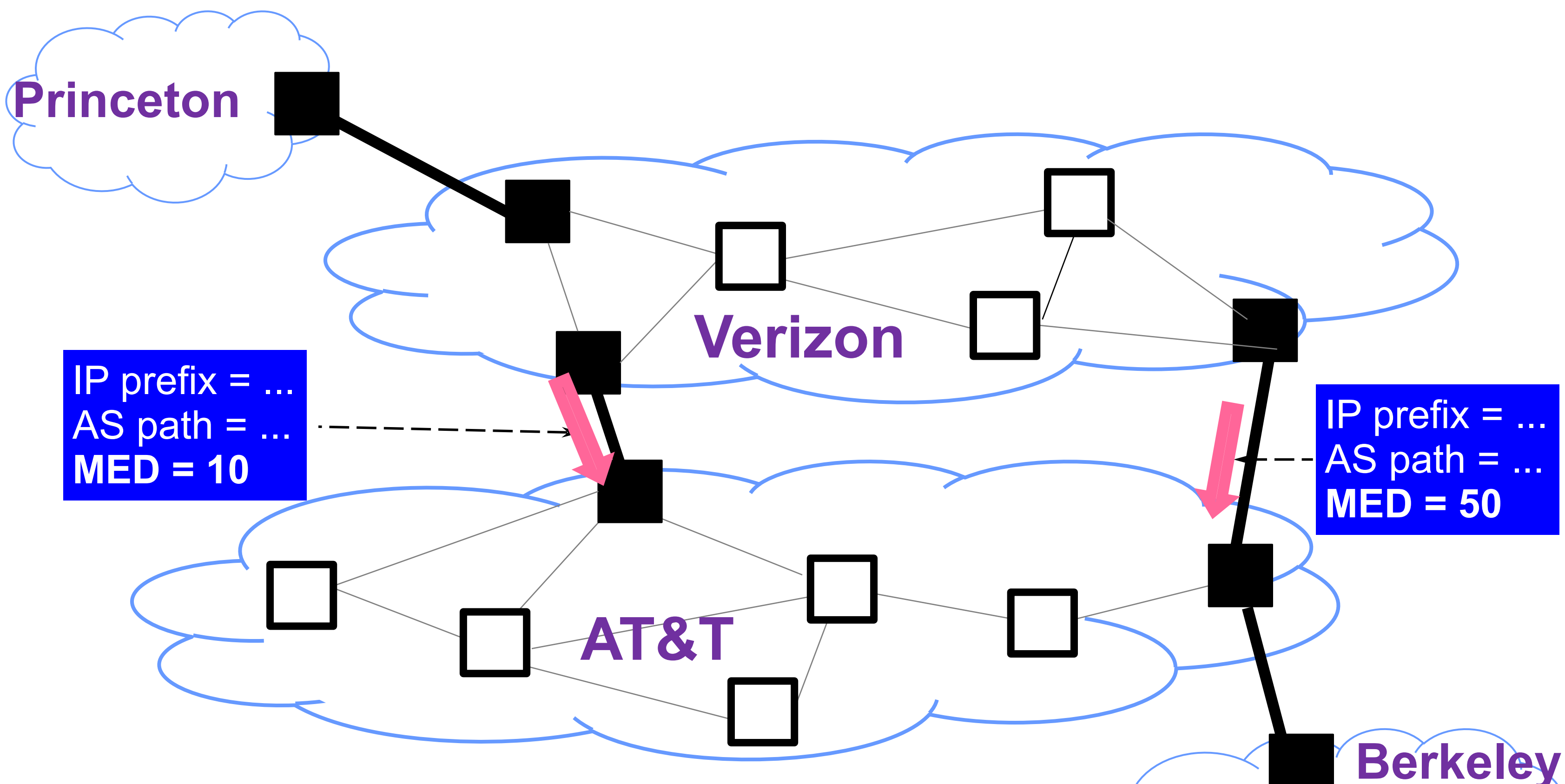

Attributes (3) : MED

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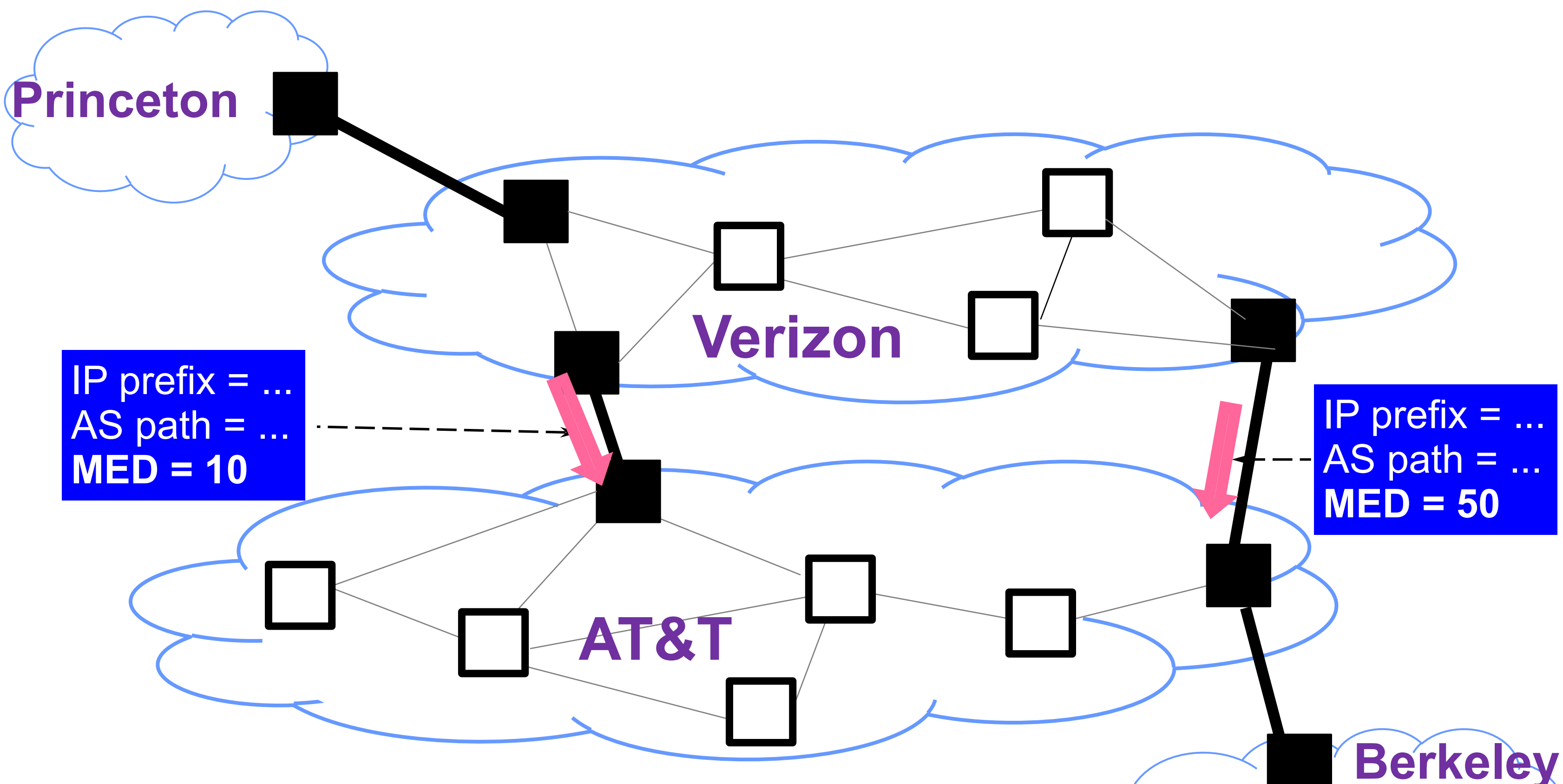
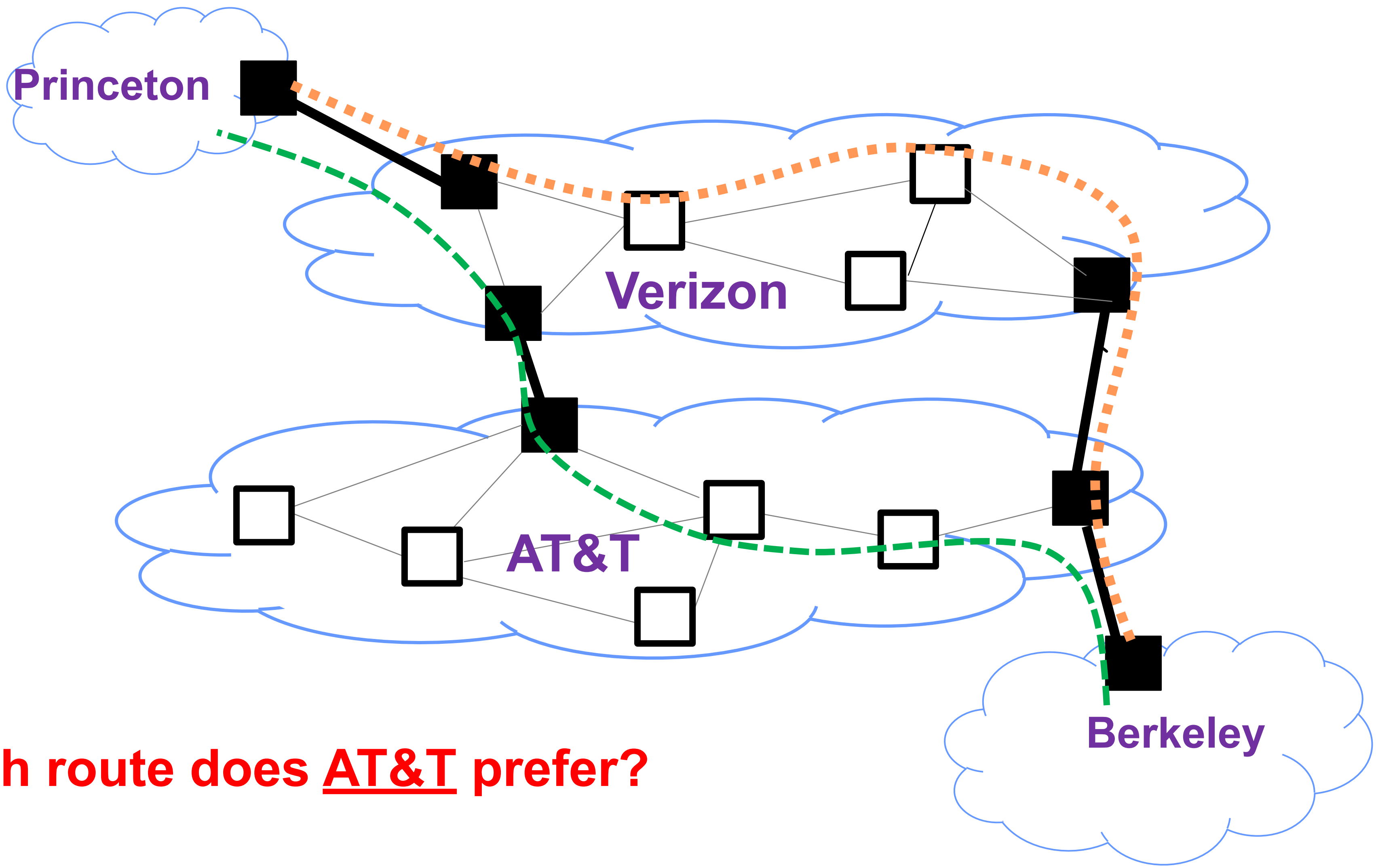
- AS receiving prefix (optionally!) uses MED to select link



More reality...



Which route does **AT&T** prefer?

Attributes (4): IGP cost

- Local to an AS
- Each router selects its closest border router
  - Closest based on IGP cost
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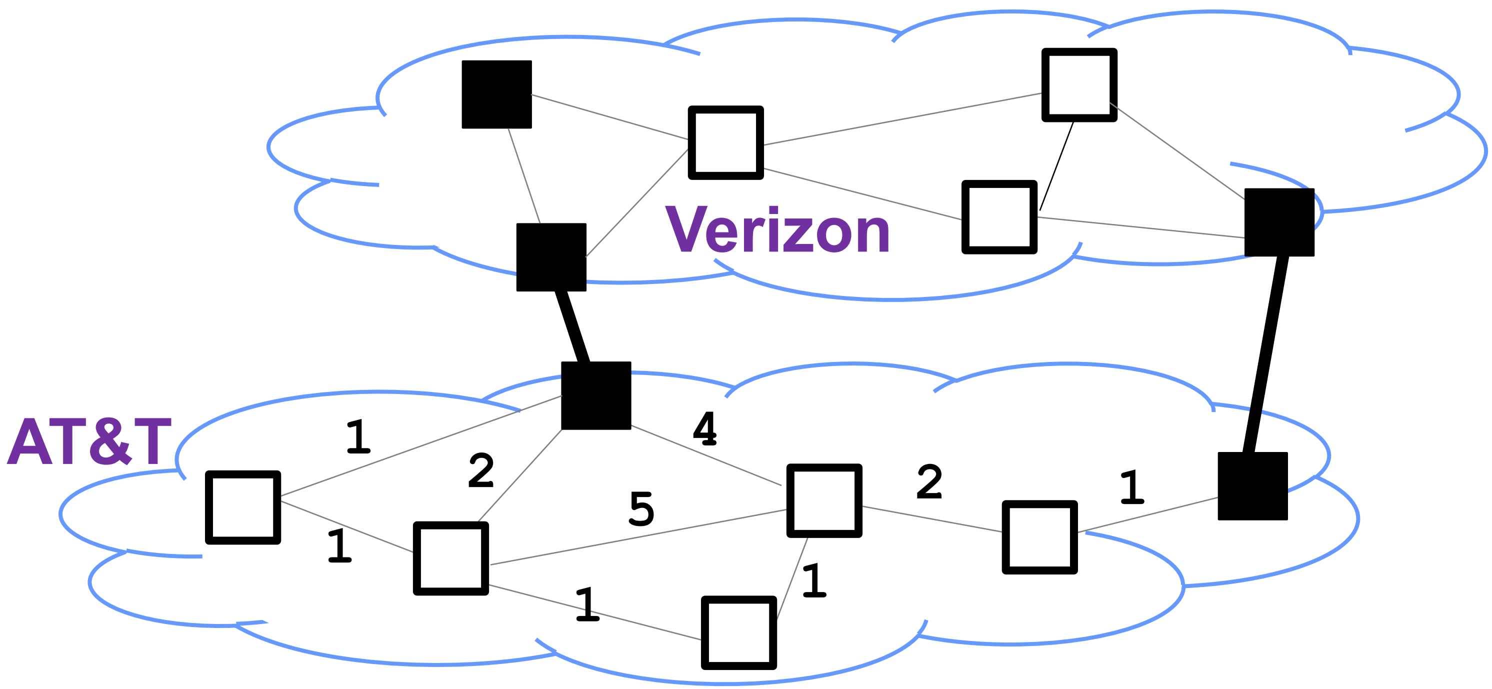

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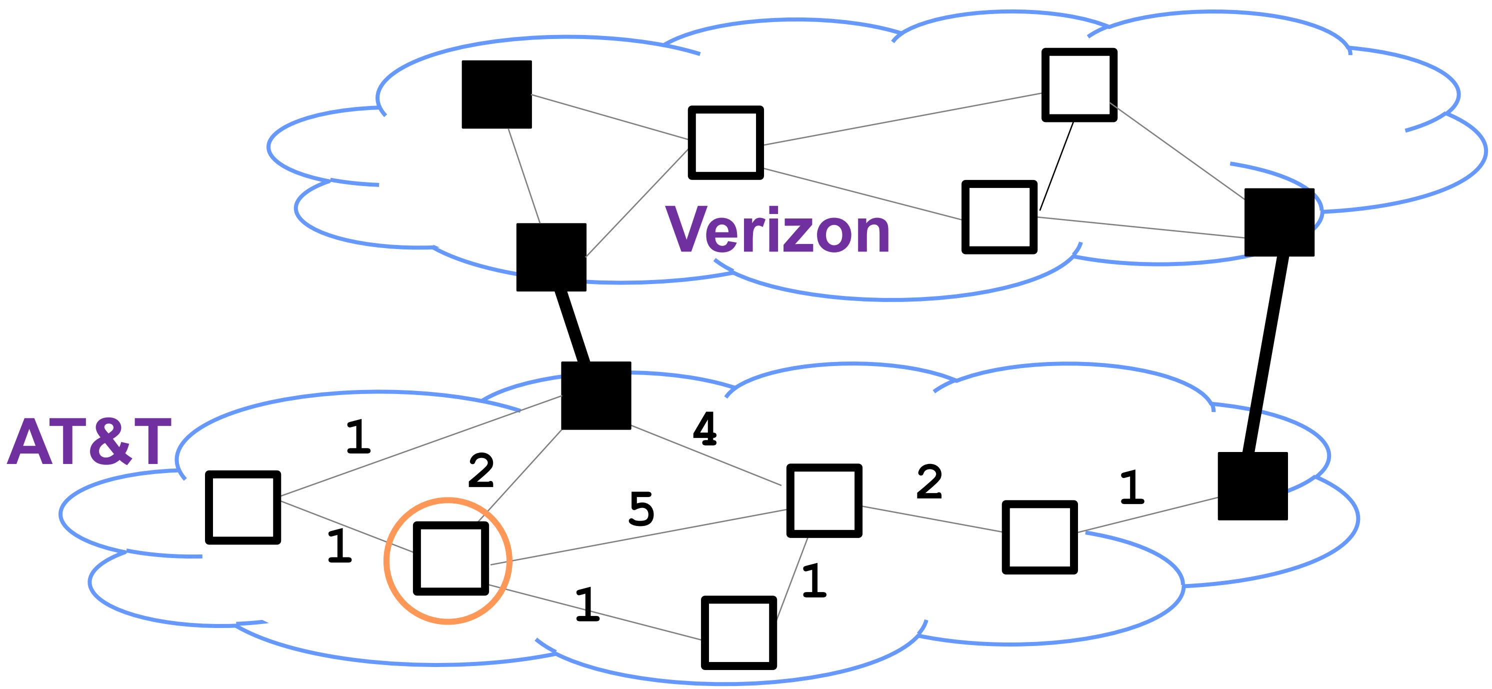

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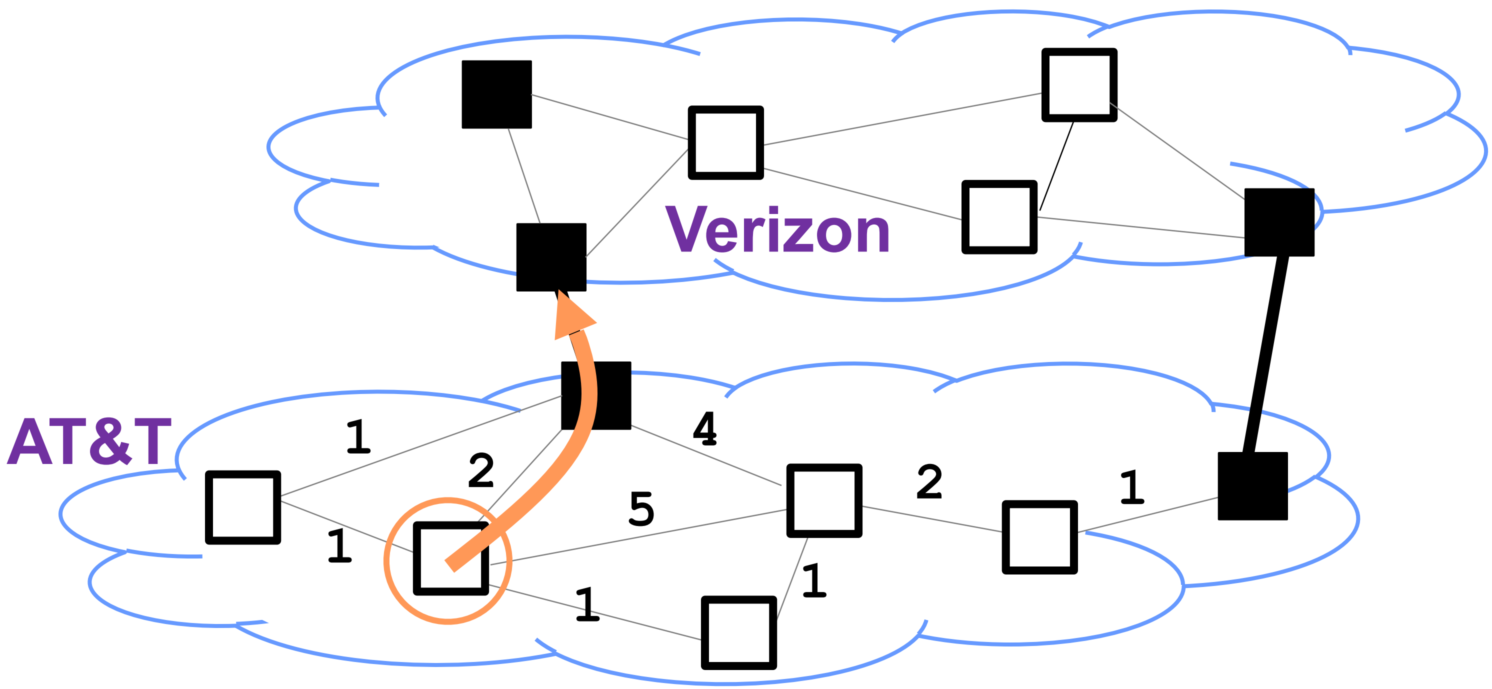

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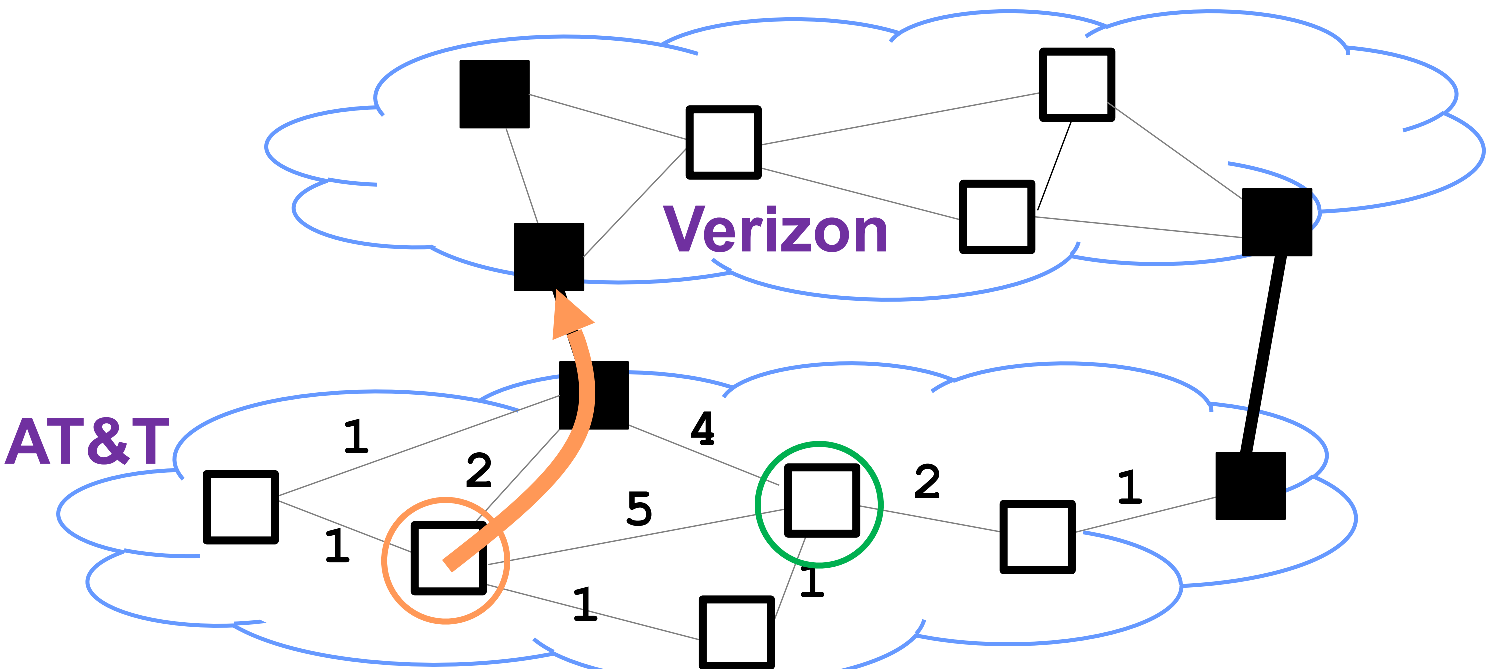

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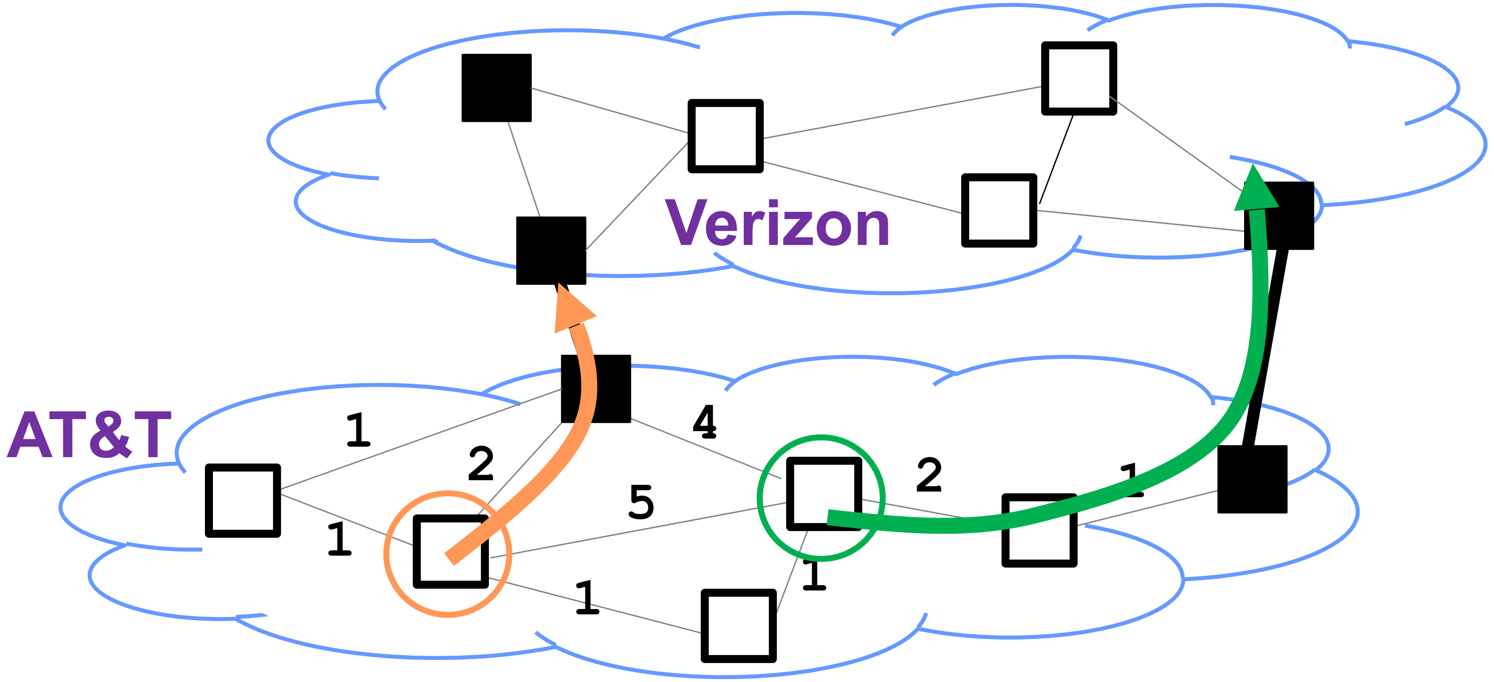

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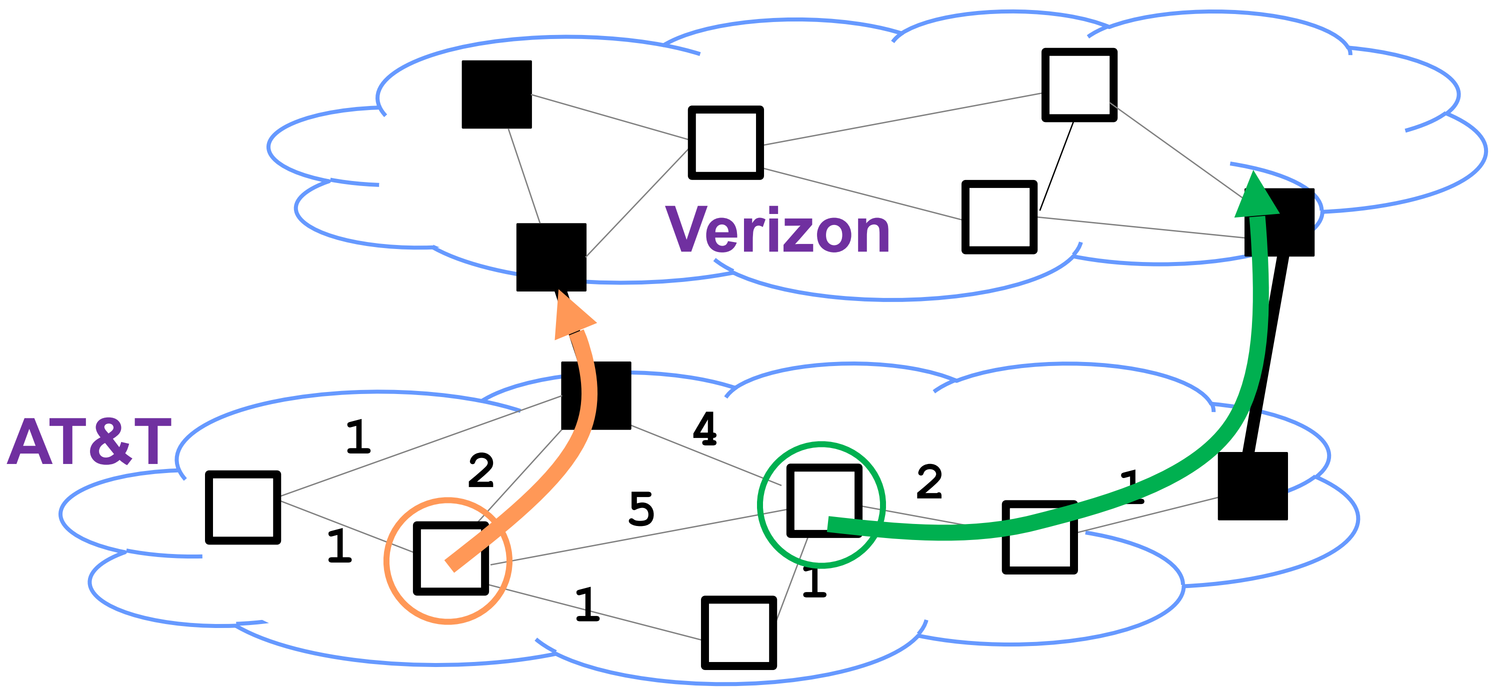

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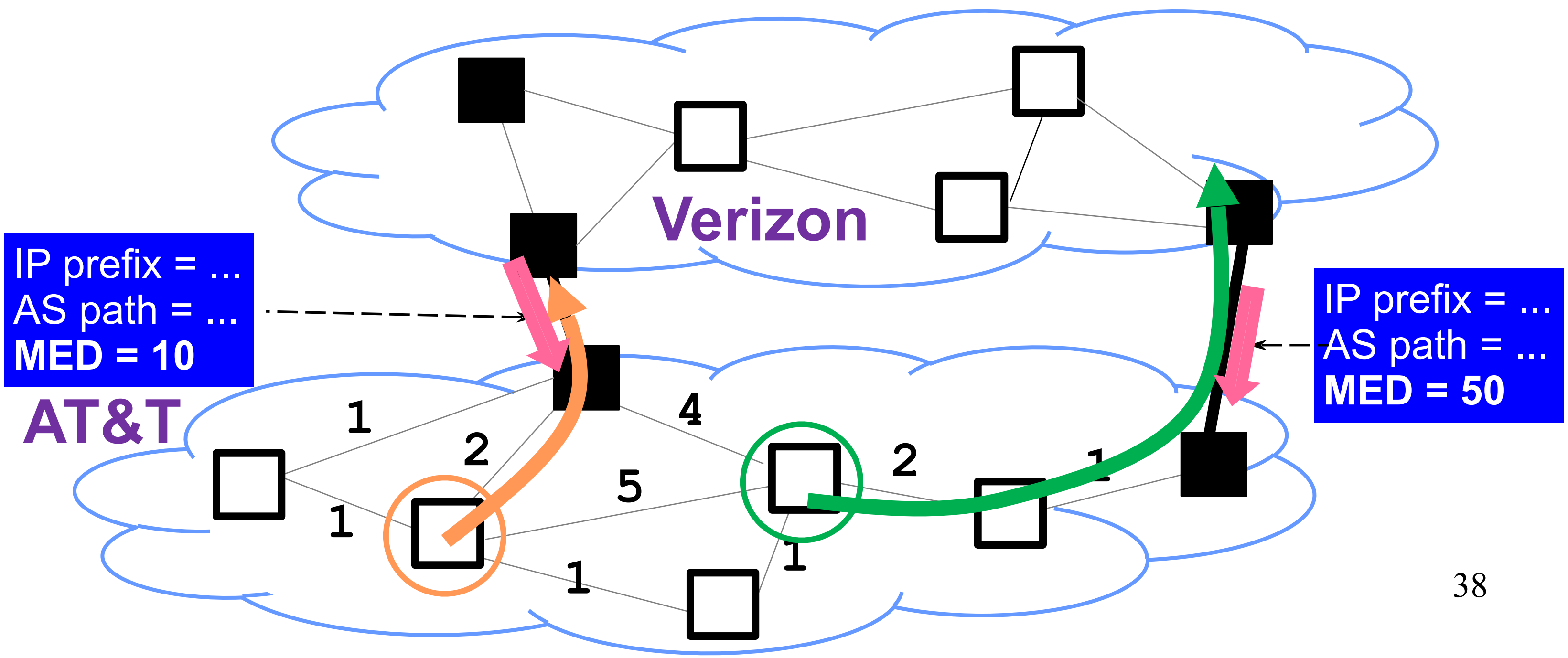

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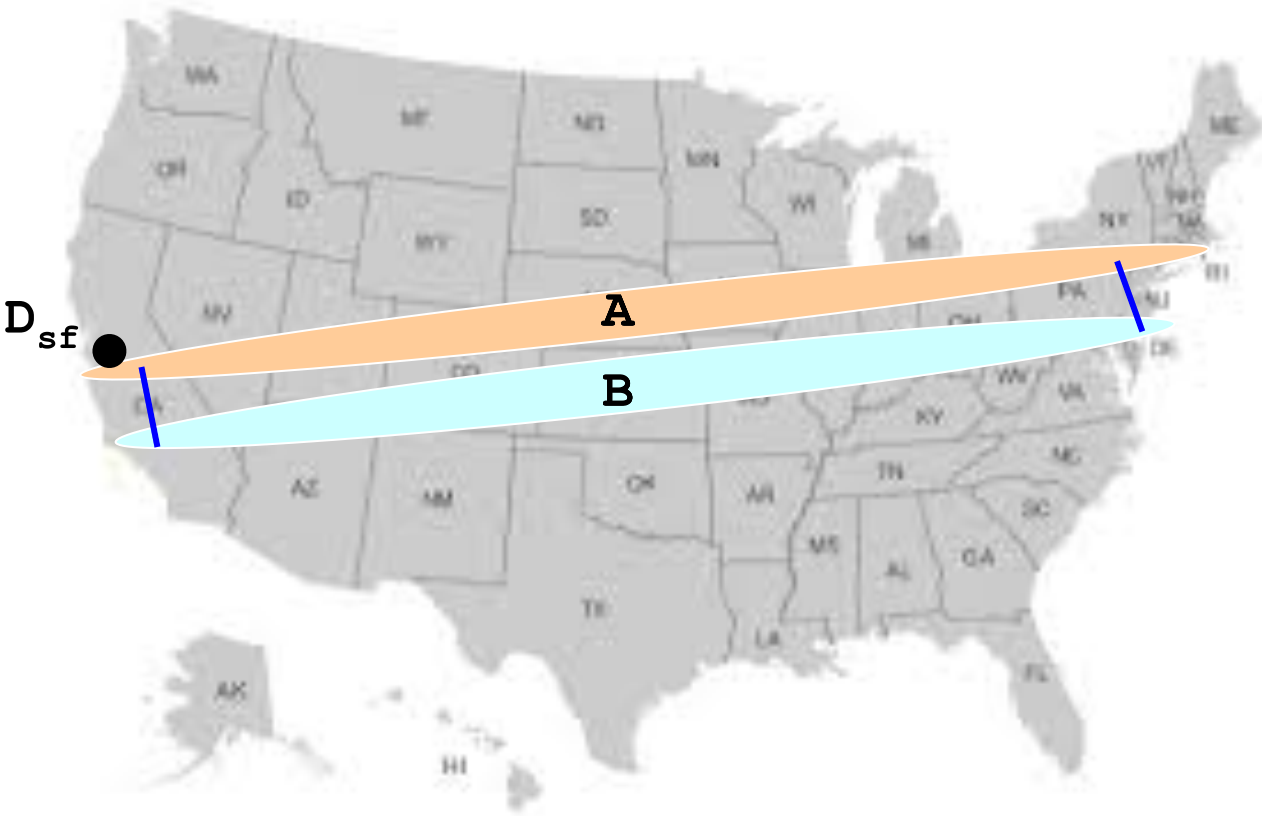

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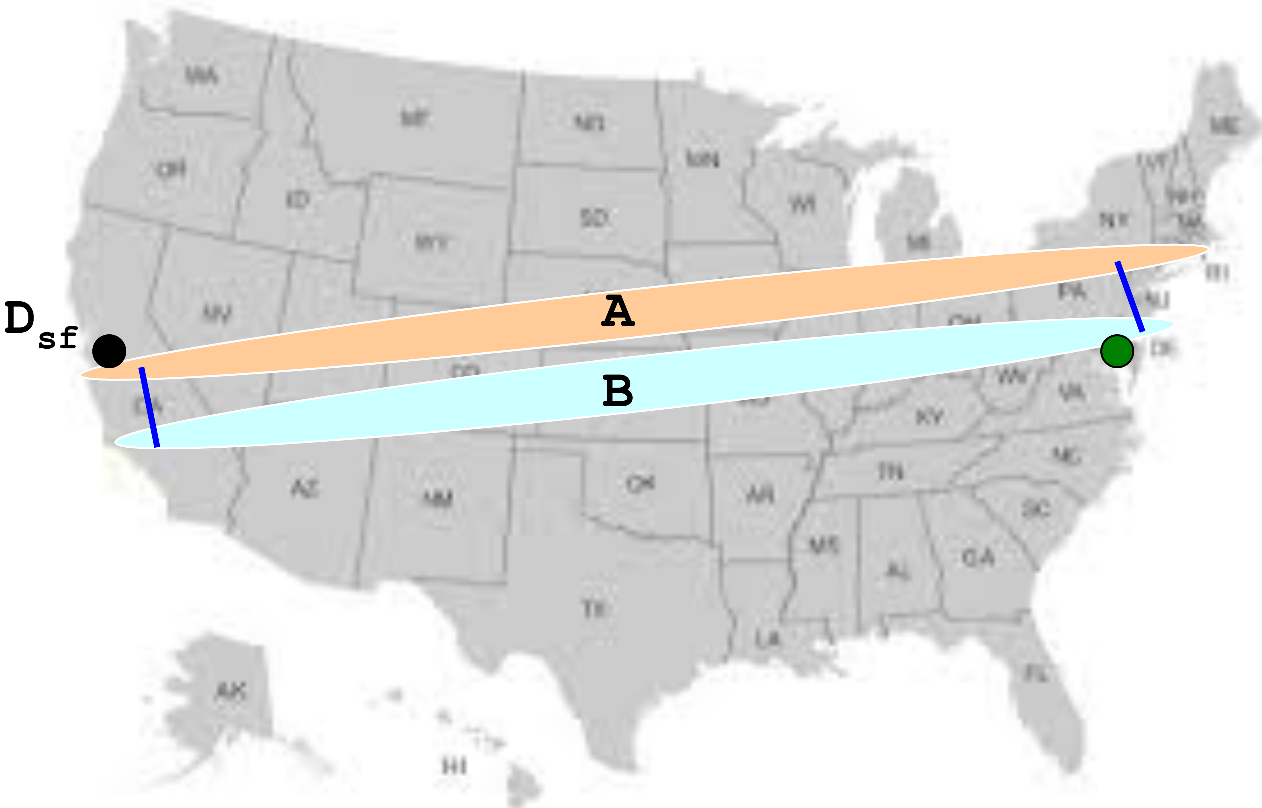

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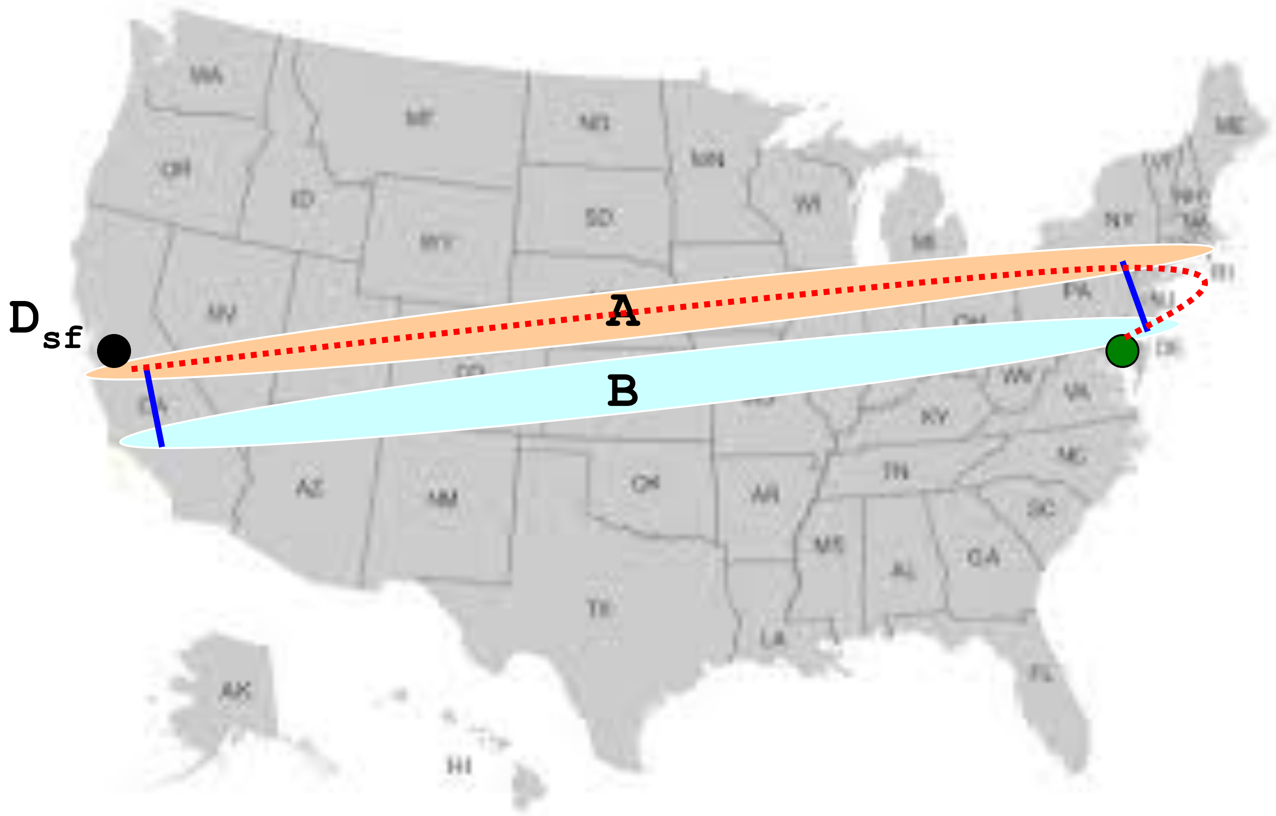

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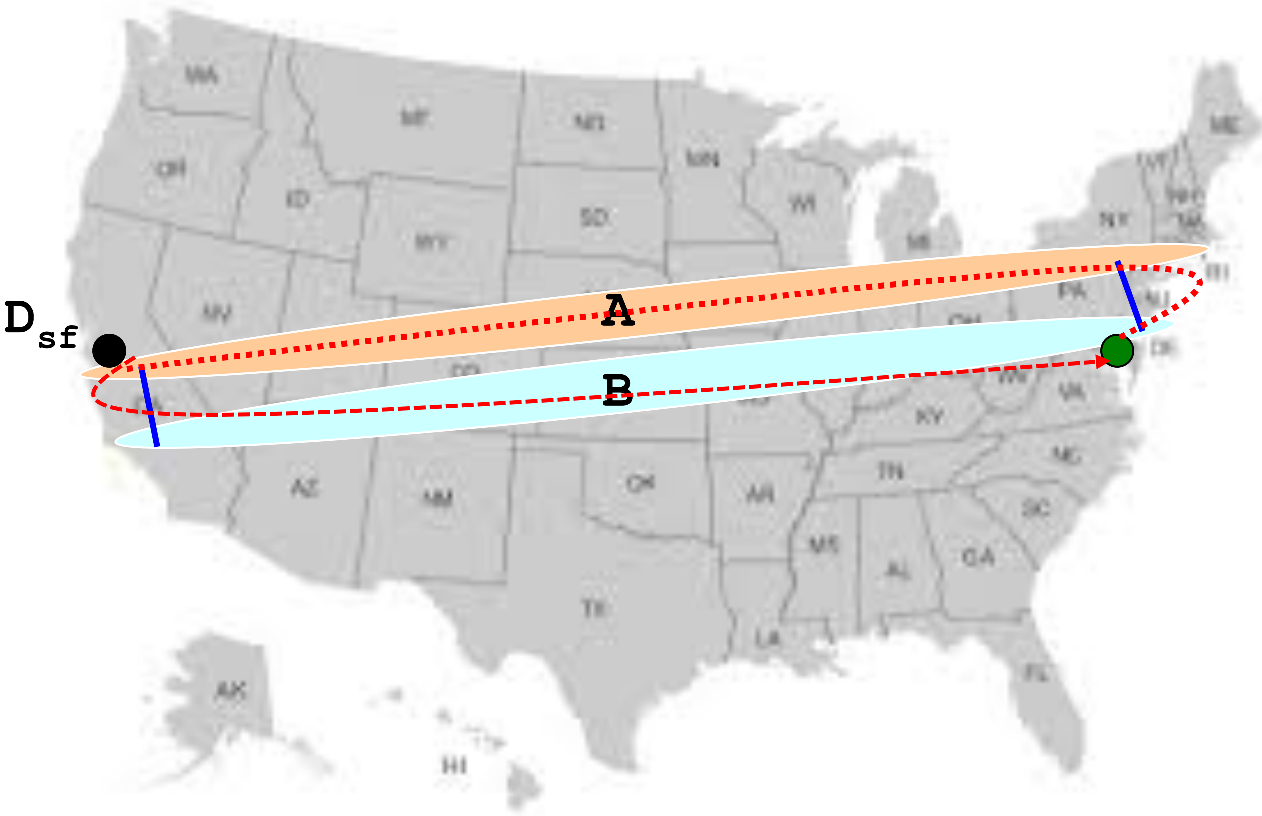

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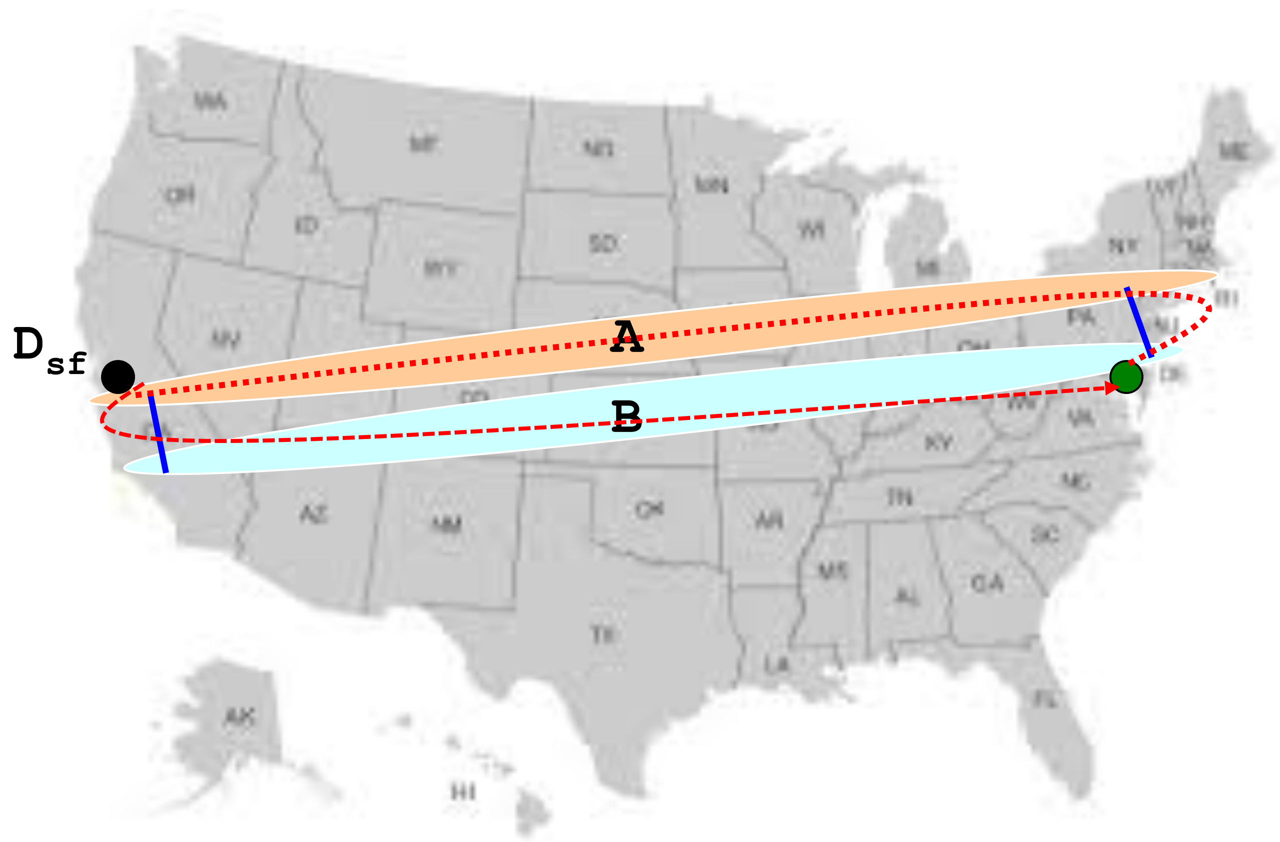

Can lead to asymmetric paths!

Closing the loop... Typical Selection Policy

- In decreasing order of priority
  - make/save money
  - maximize performance
  - minimize use of my network bandwidth
  - …
  - …

Closing the loop...
Typical Selection Policy

- In decreasing order of priority
  - make/save money: LOCAL PREF (cust > peer > provider)
  - maximize performance: length of ASPATH
  - minimize use of my network bandwidth: "hot potato", MED
  - …
  - …

Using Attributes

- Rules for route selection in priority order

Priority	Rule	Remarks
1	LOCAL PREF	Pick highest LOCAL PREF
2	ASPATH	Pick shortest ASPATH length
3	IGP path	Lowest IGP cost to next hop (egress router)
4	MED	MED preferred
5	Router ID	Smallest next-hop router's IP address as tie-breaker

Questions?

Outline

- Context
- Goals
- Approach
- Detailed design
- Limitations

Issues with BGP

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- Security

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- Reachability and Convergence
  - Not guaranteed if Gao-Rexford doesn’t hold
  - Example of policy oscillations in discussion section

Questions?

Taking Stock: We've done...

- An end-to-end overview of the Internet arch.

- How L3 works
  - IP addressing and routers
  - Intra-domain routing
  - Inter-domain routing

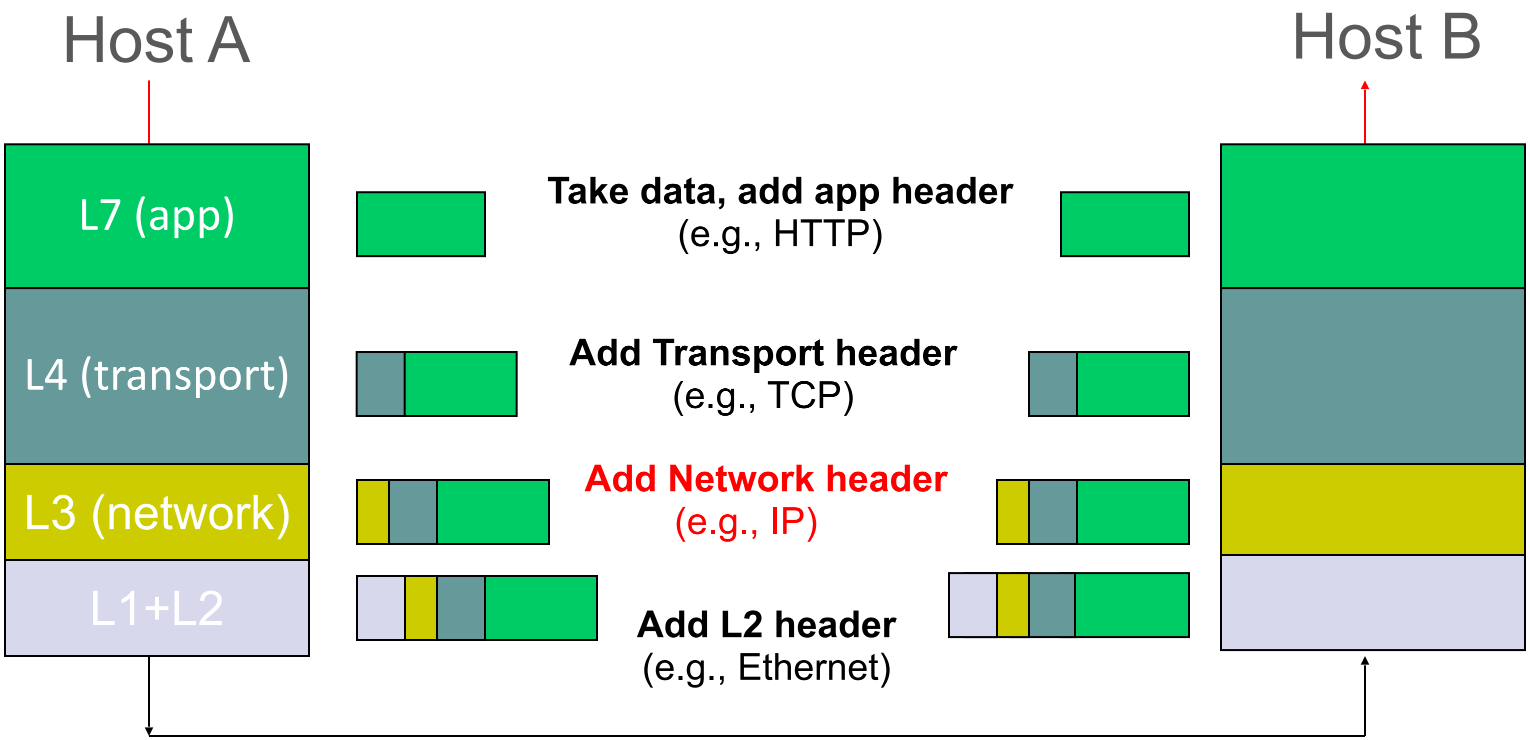
- **Last topic: the IP header**
  - At which point, you'll know how L3 works!

Let’s design the IP header

- **Syntax**: format of an IP packet
  - Nontrivial part: header
  - Rest is opaque payload

- **Semantics**: meaning of IP header fields
  - How they’re processed

Recall: Layering



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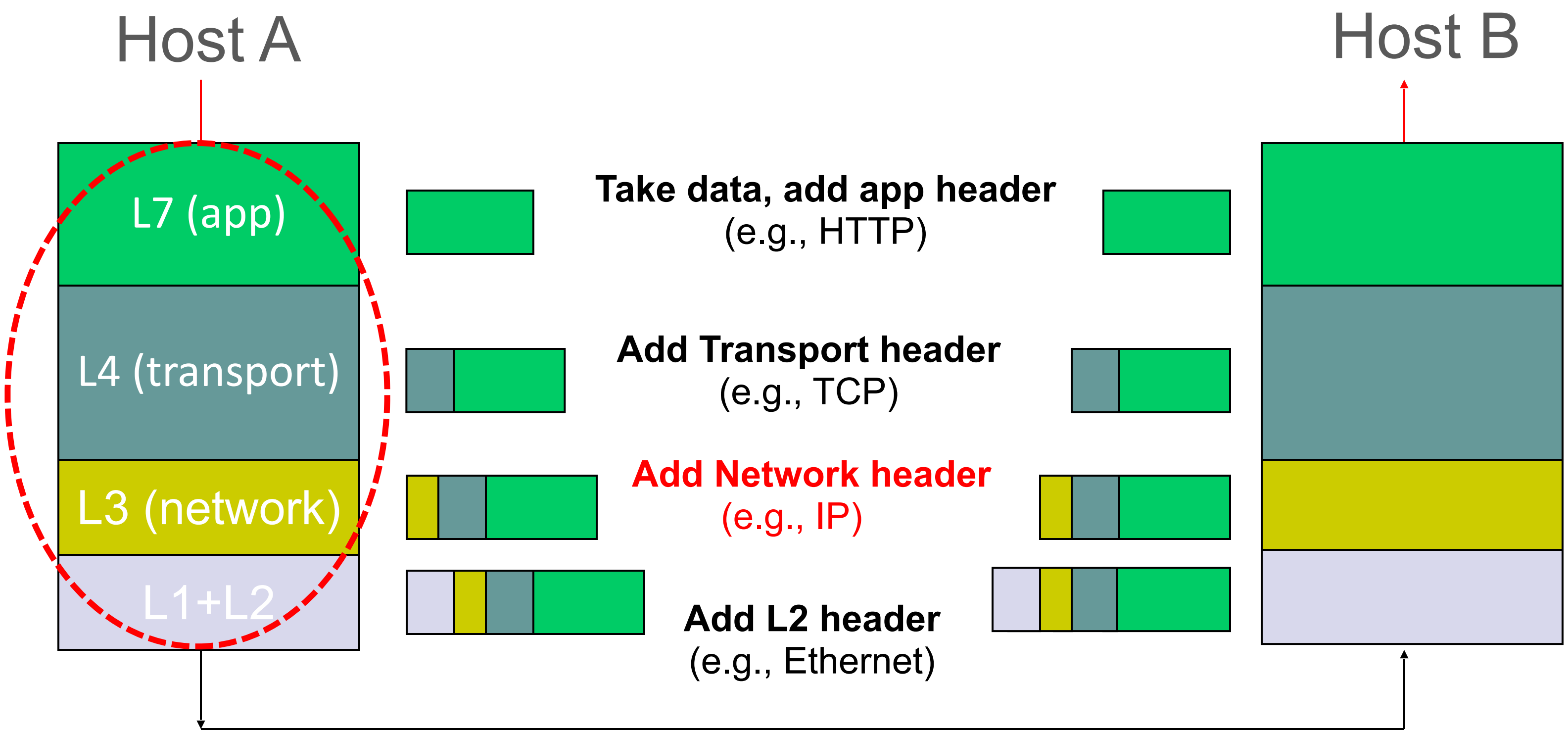
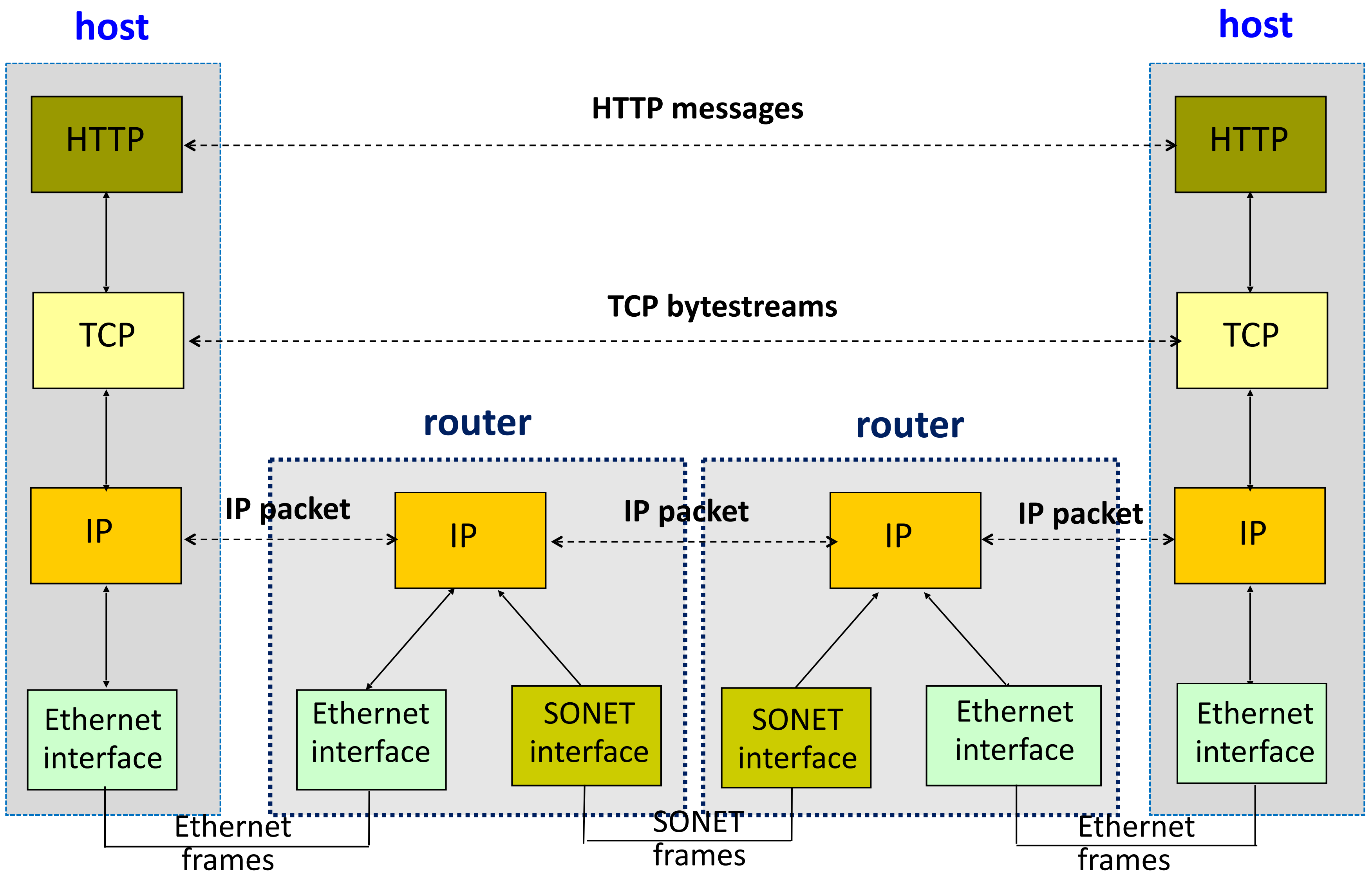


Recall: Hosts *vs.* Routers



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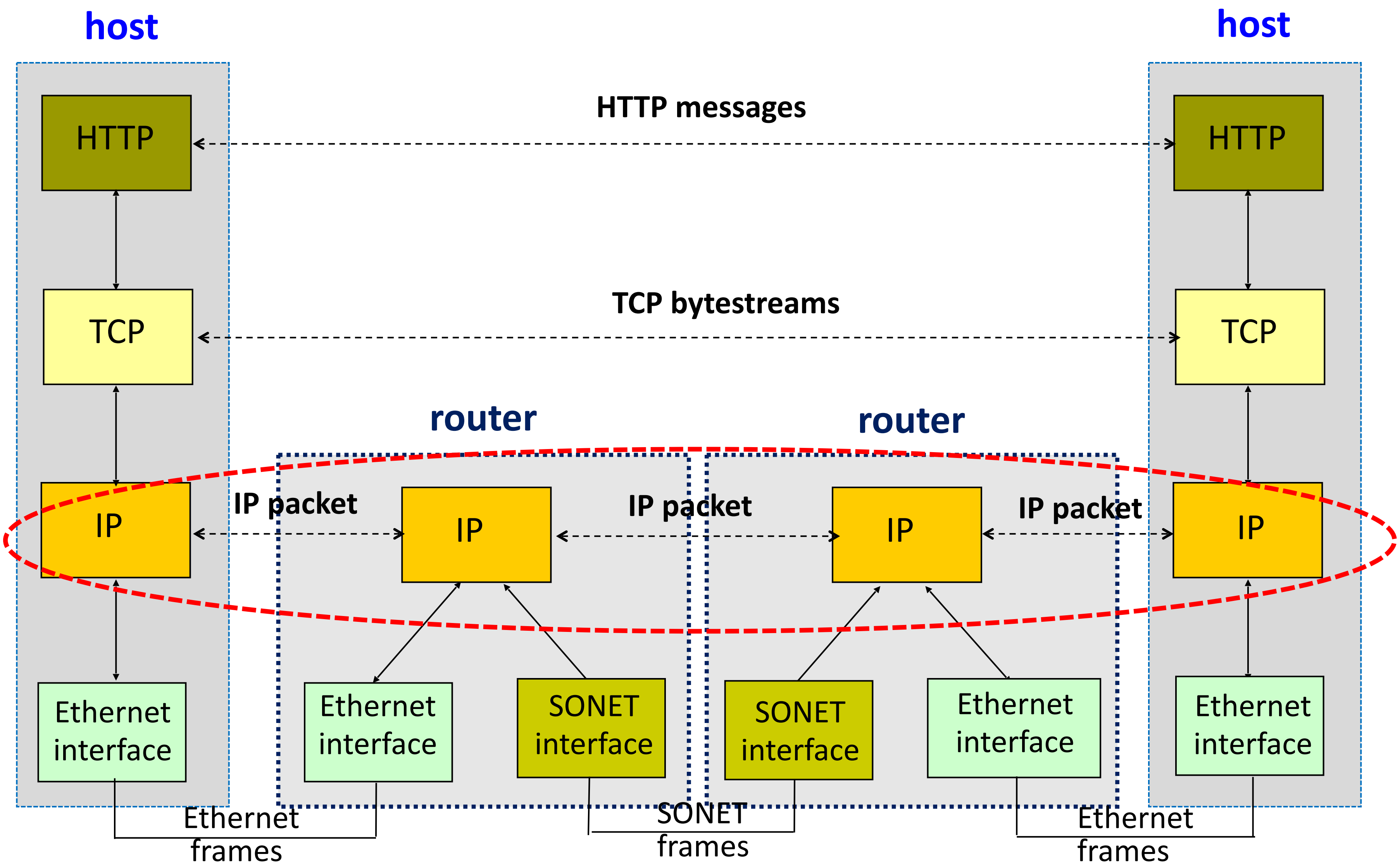

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  - between the source and destination endhosts
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  - what task(s) are we trying to accomplish?
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- Header reflects information needed for basic tasks

What are these tasks?
(at a router, at the destination host)

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- Specify any special handling *(router, dst host)*

Next: what information do we need?

Parse Packet Correctly

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- What version of IP?

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- Where does header end?

Parse Packet Correctly

- What version of IP?
- Where does header end?
- Where does packet end?

Deliver packet to the L3 destination

Deliver packet to the L3 destination

- Provide destination address (duh!)

Tell the destination how to handle packet

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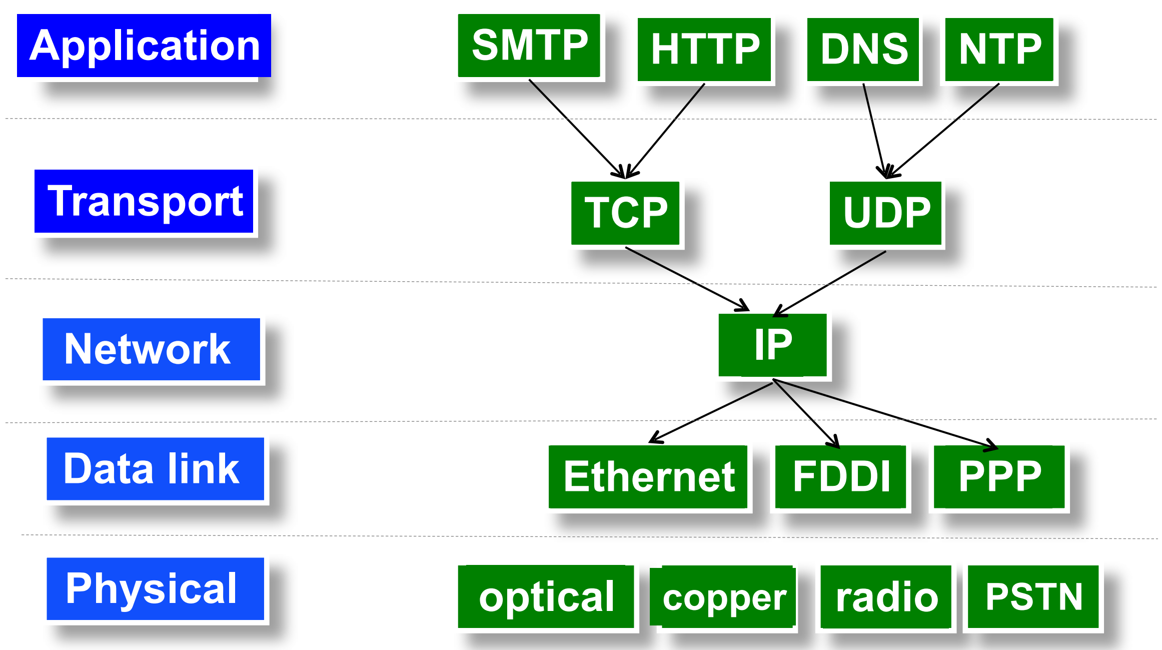

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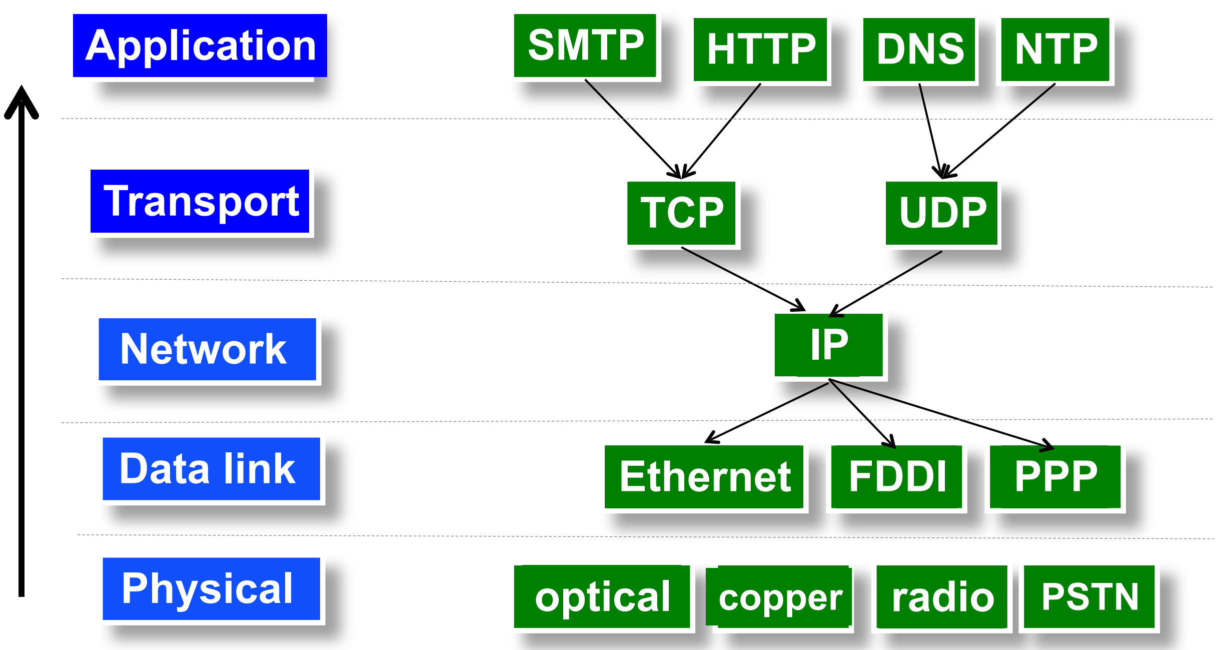

Tell the destination how to handle packet

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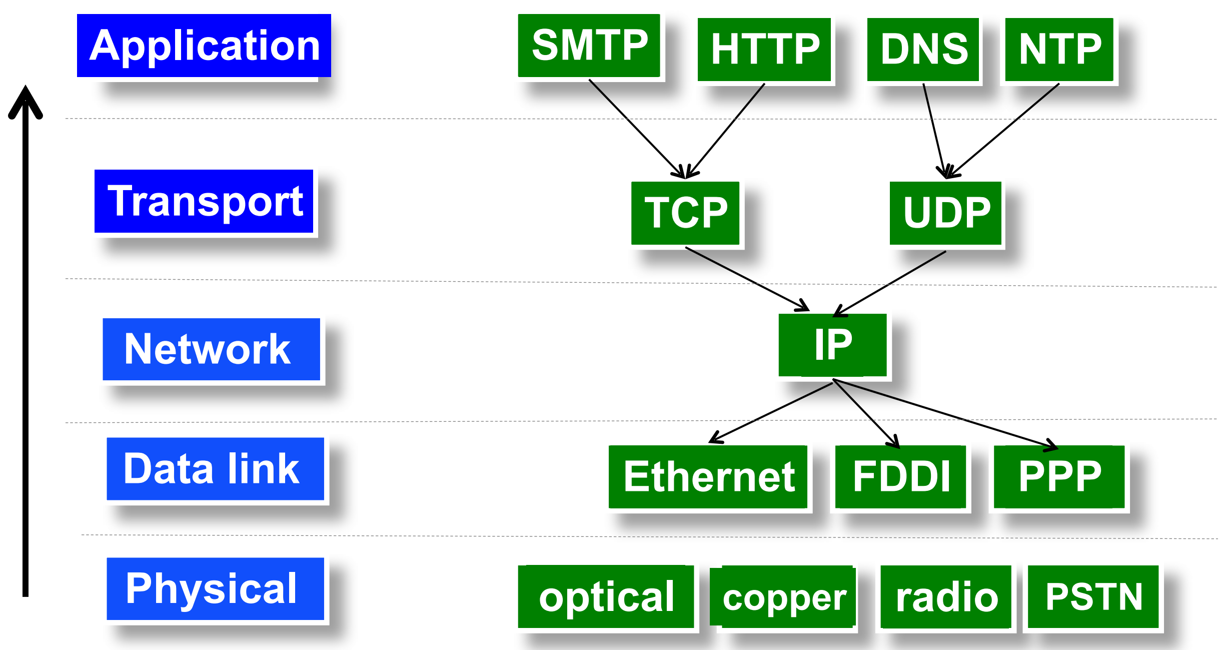
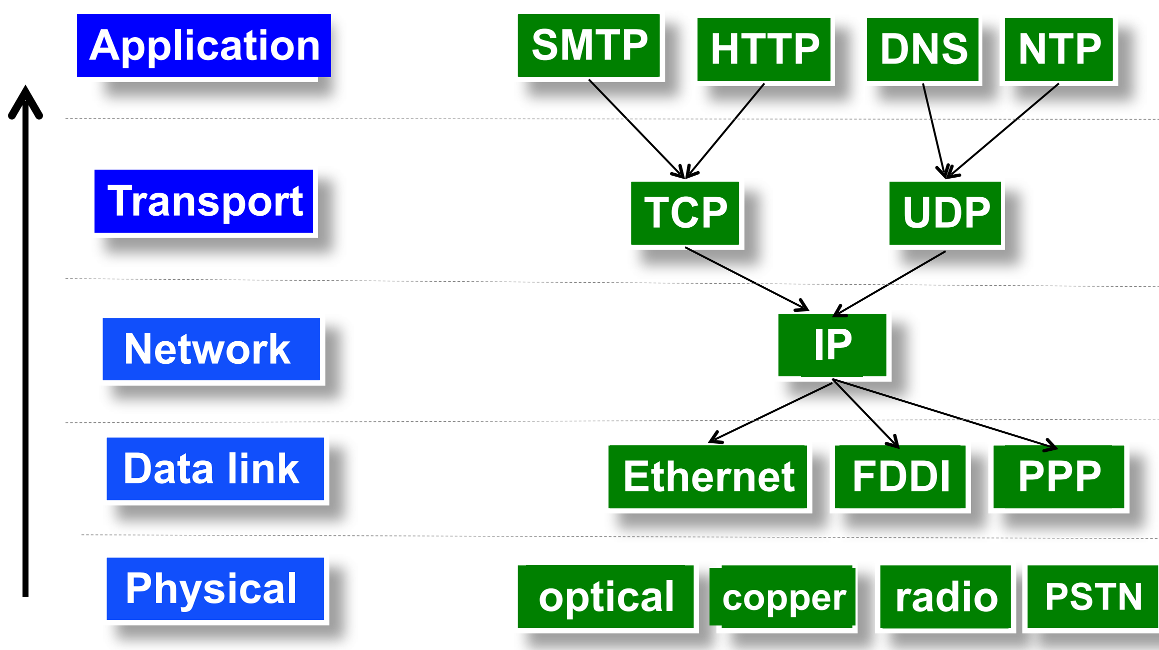


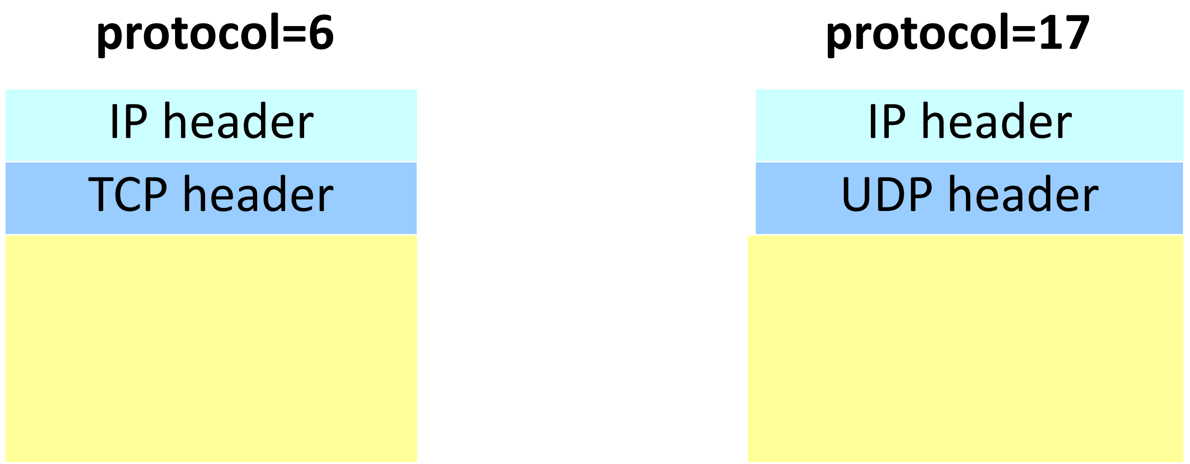
Tell the destination how to handle packet

- Indicate which protocol should handle packet next
- **Protocol** field: identifies the higher-level protocol
  - Important for de-multiplexing at receiving host



Tell the destination how to handle packet

- Protocol field that identifies the L4 protocol for this packet
- Common examples
  - "6" for the Transmission Control Protocol (TCP)
  - "17" for the User Datagram Protocol (UDP)



Get responses back to the source

Get responses back to the source

- *Source IP address*

Where are we …

- Parse packet → *version, header length, packet length*
- Forward packet to the L3 dst → *destination address*
- Tell destination what to do next → *protocol field*
- Get responses back to the source → *source address*

- Deal with problems along the way
- Specify any special handling

What problems?

What problems?

- Loops

What problems?

- Loops
- Corruption

What problems?

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- Packet too large (> MTU)

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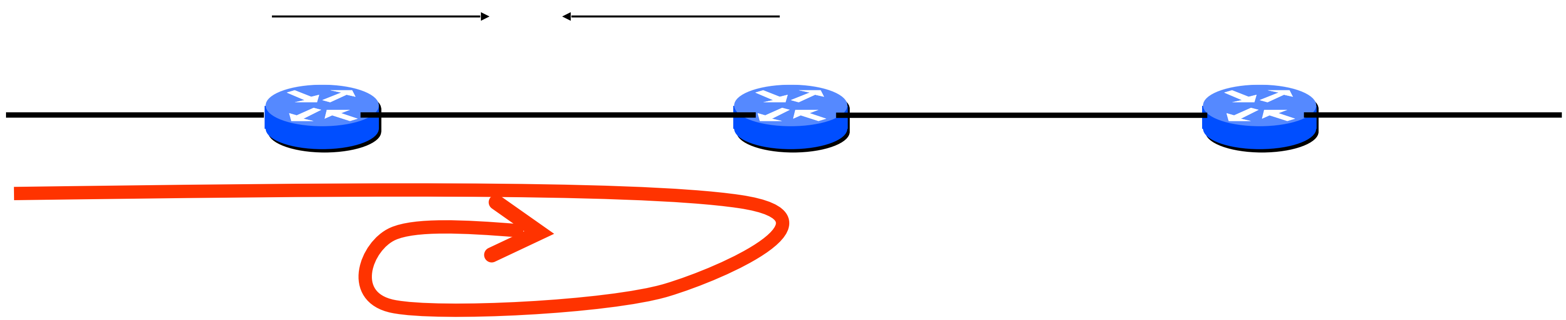
- Forwarding loops cause packets to cycle for a looong time
  - left unchecked would accumulate to consume all capacity



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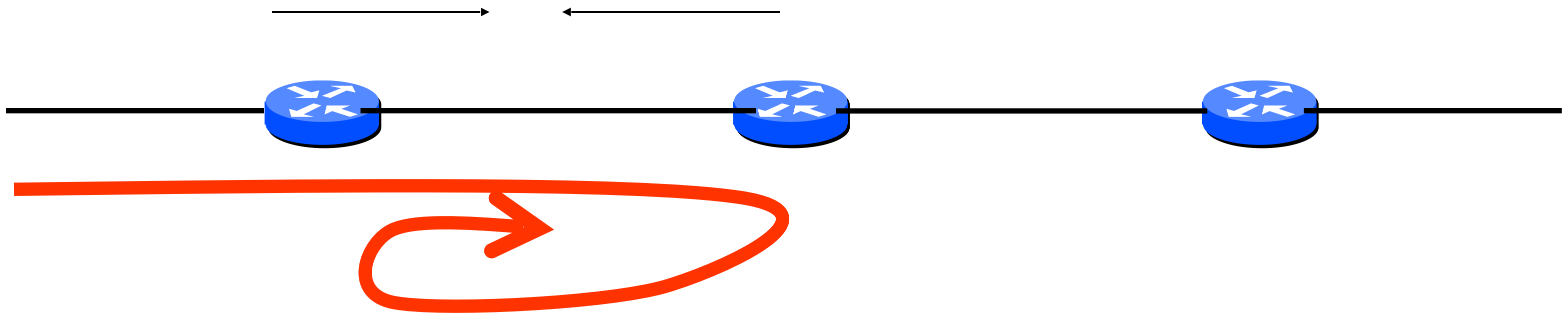

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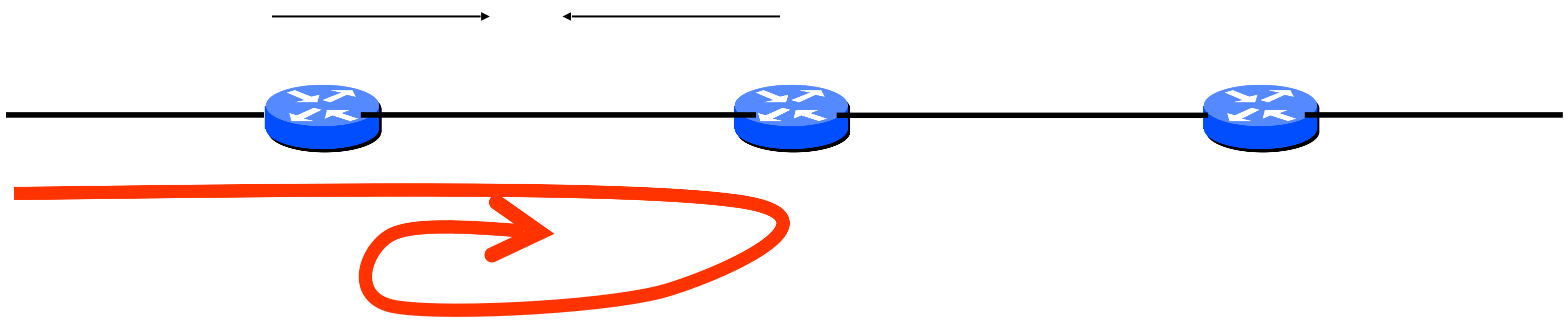

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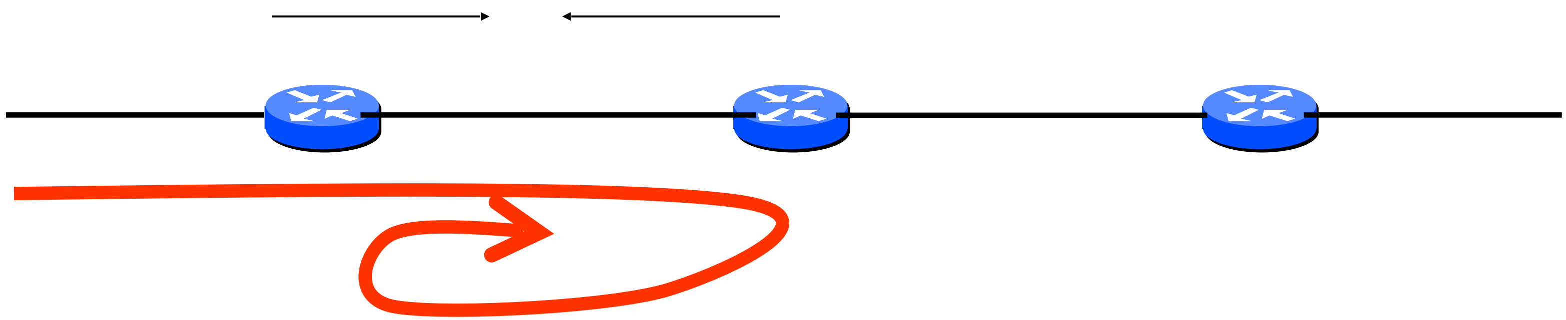

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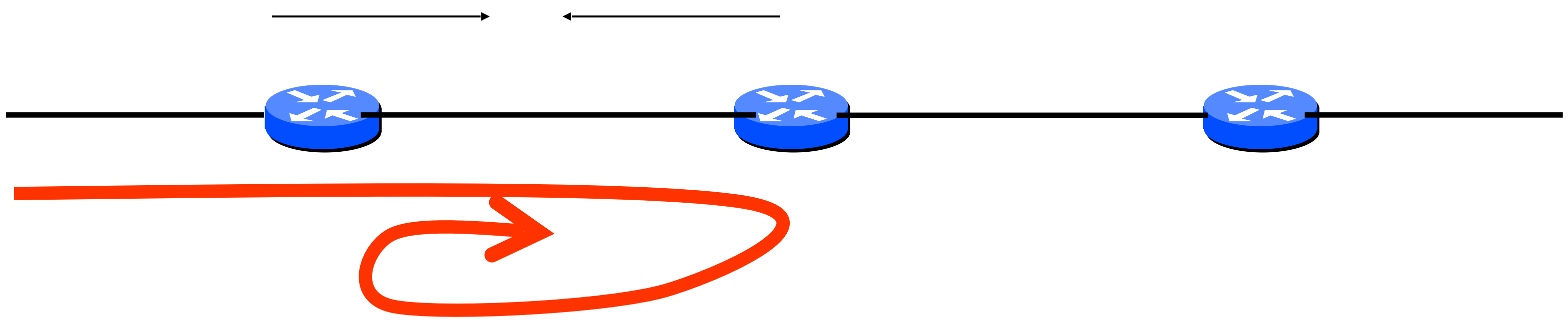

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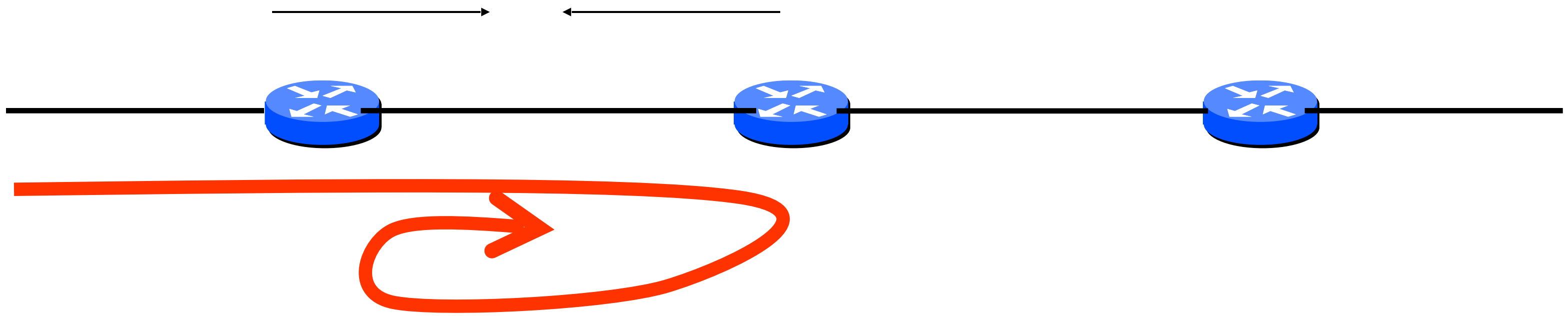

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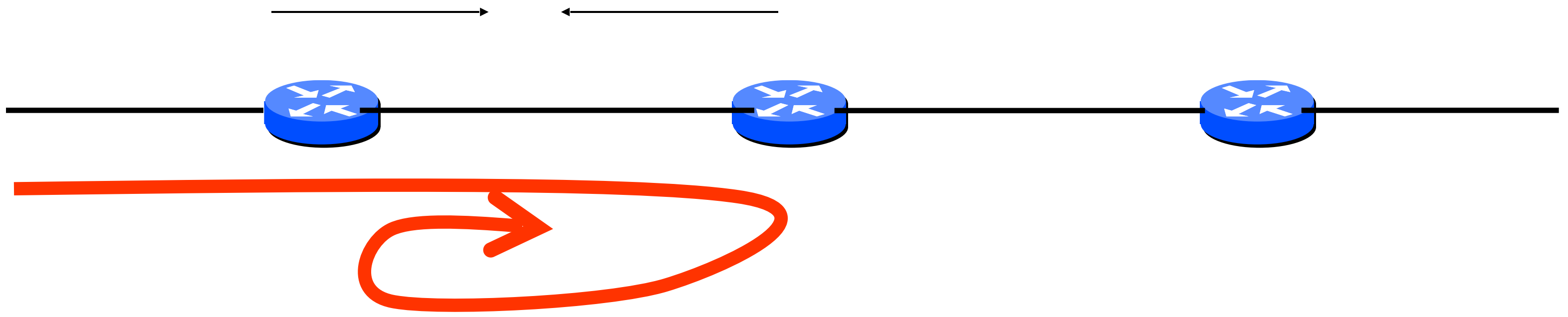

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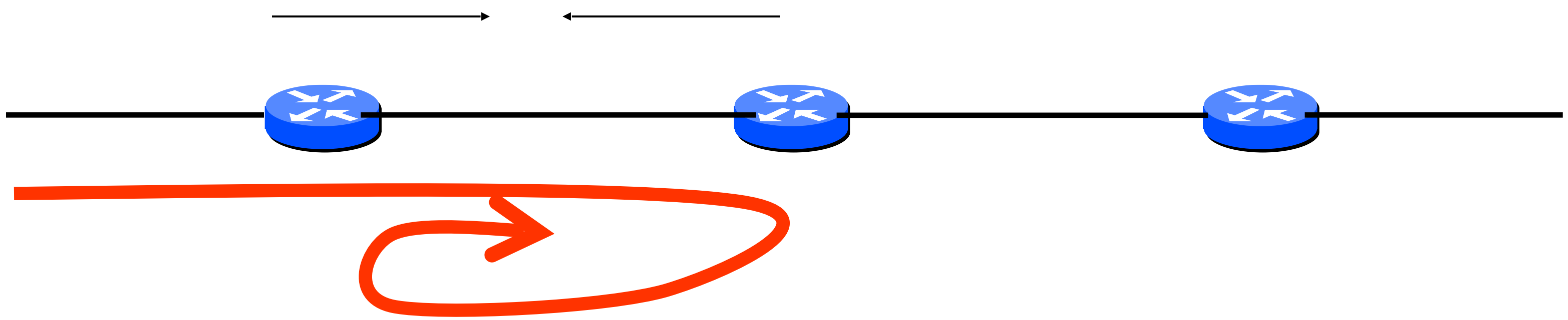

- Time-to-Live (TTL) field
  - decremented at each hop, packet discarded if reaches 0
  - …and “time exceeded” message is sent to the source

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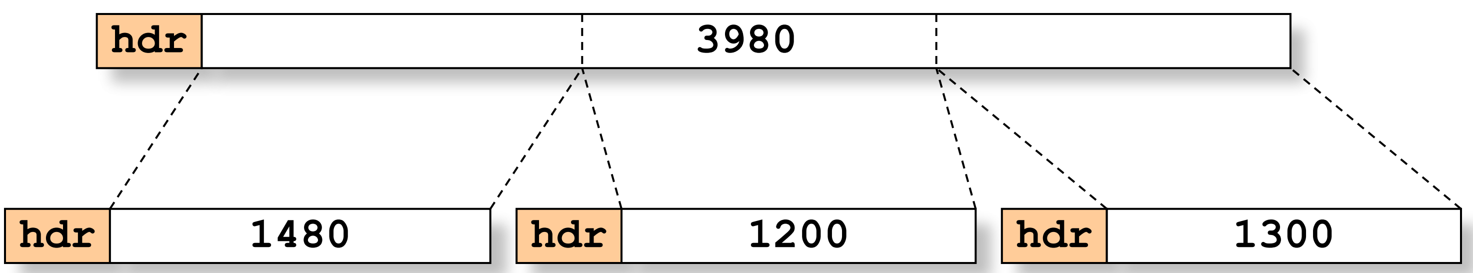

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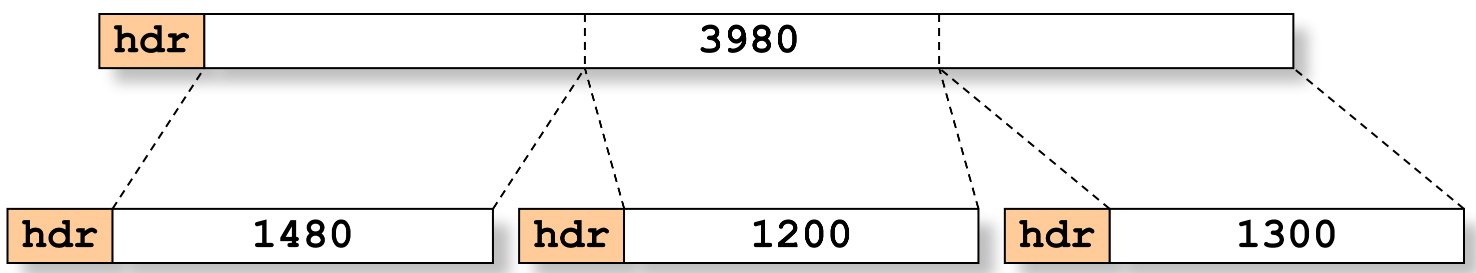

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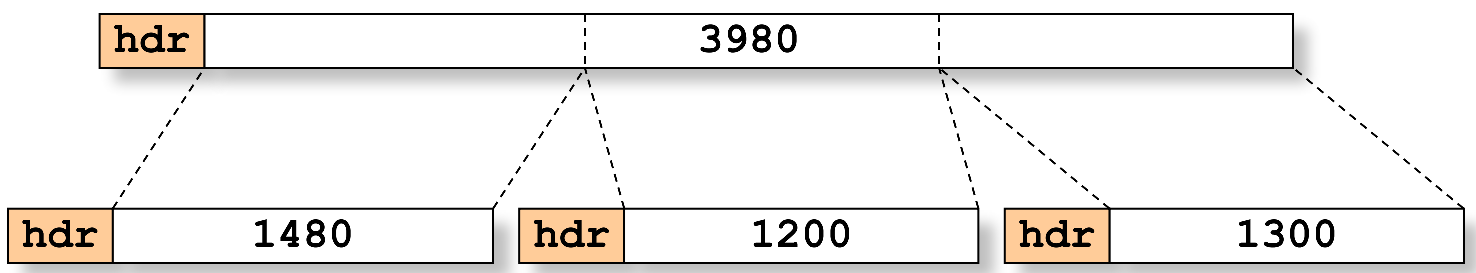

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Details of fragmentation will be covered in section

Where are we …

- Parse packet → *version, header length, packet length*
- Forward packet to the L3 dst → *destination address*
- Tell destination what to do next → *protocol field*
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- Deal with problems along the way
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- “Options”
  - Request advanced functionality for this packet

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- Today:
  - Differentiated Services Code Point (DSCP): traffic “classes”
  - Explicit Congestion Notification (ECN): a later lecture

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- **Examples**
  - Record Route, Source Route, Timestamp, ...
- More complex implementation
  - Leads to variable length headers
  - Often leads to higher processing overheads

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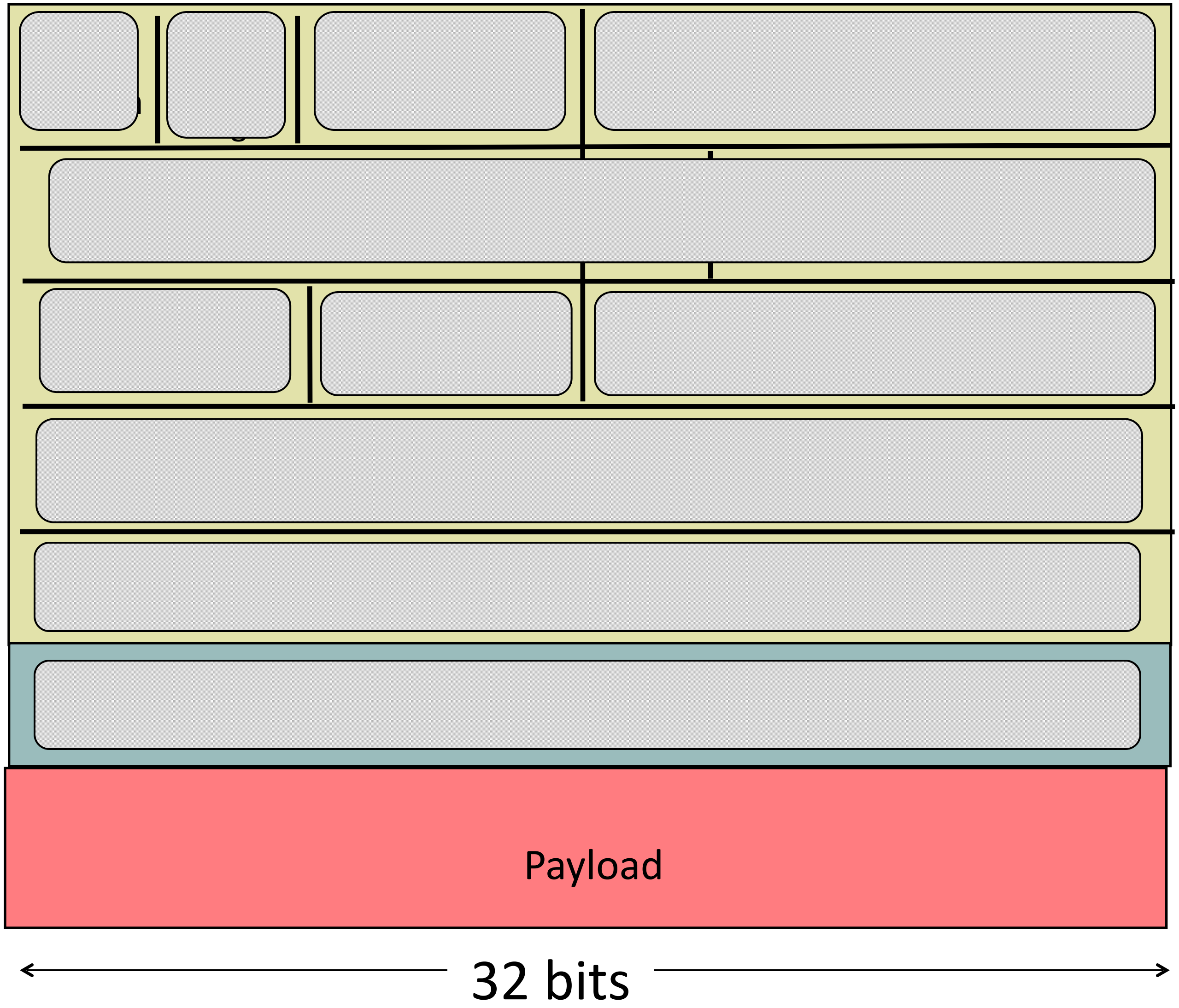

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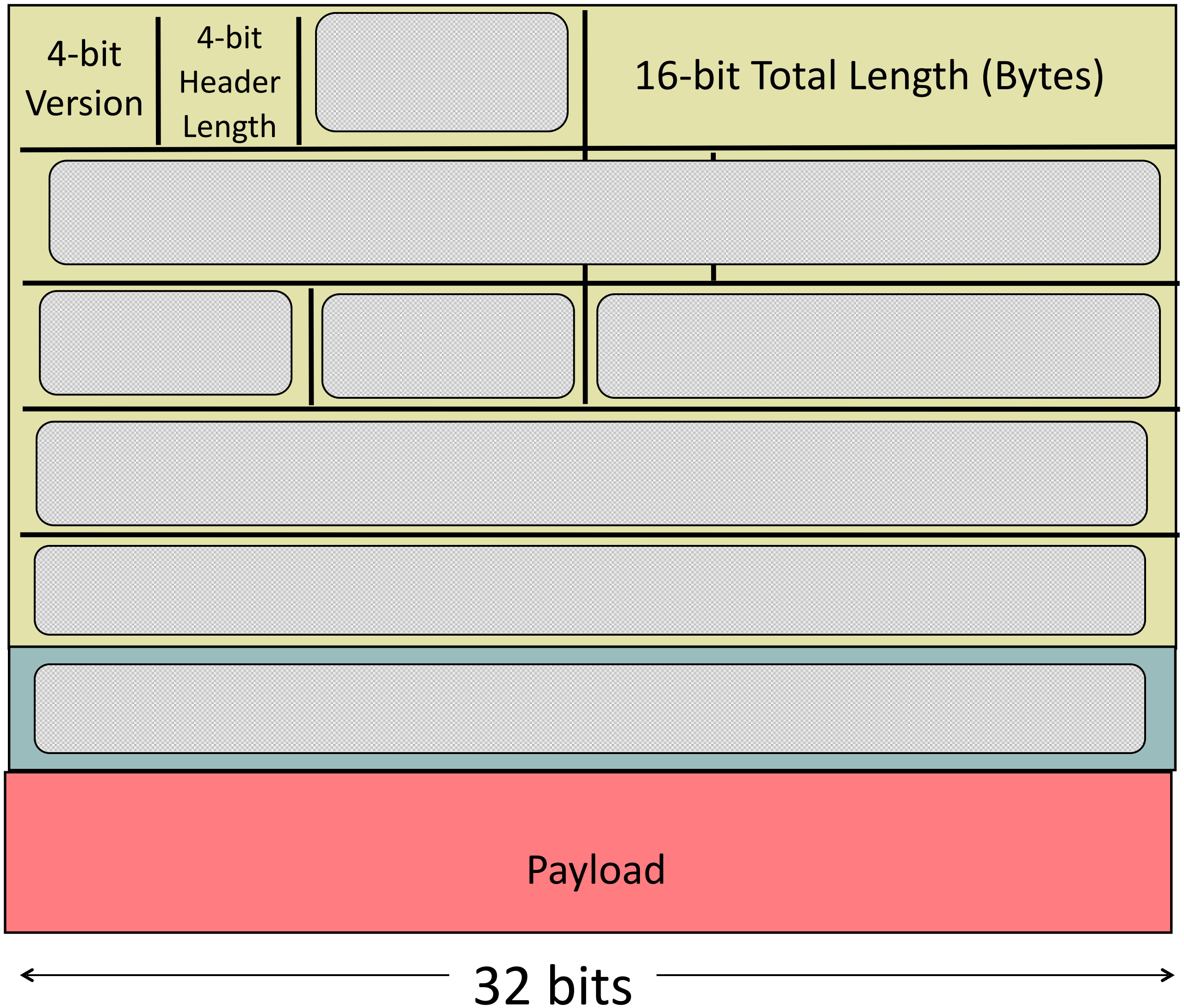

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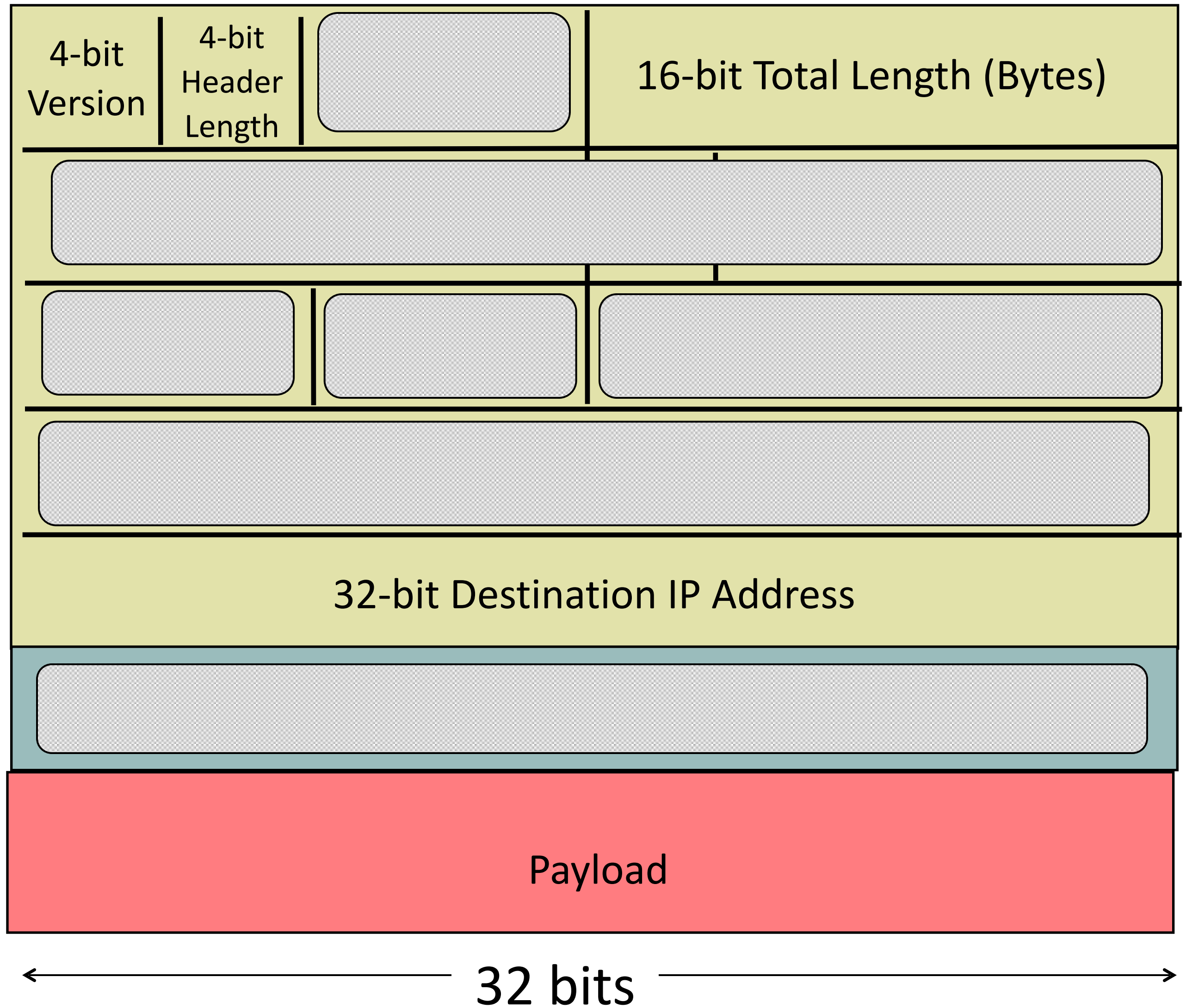

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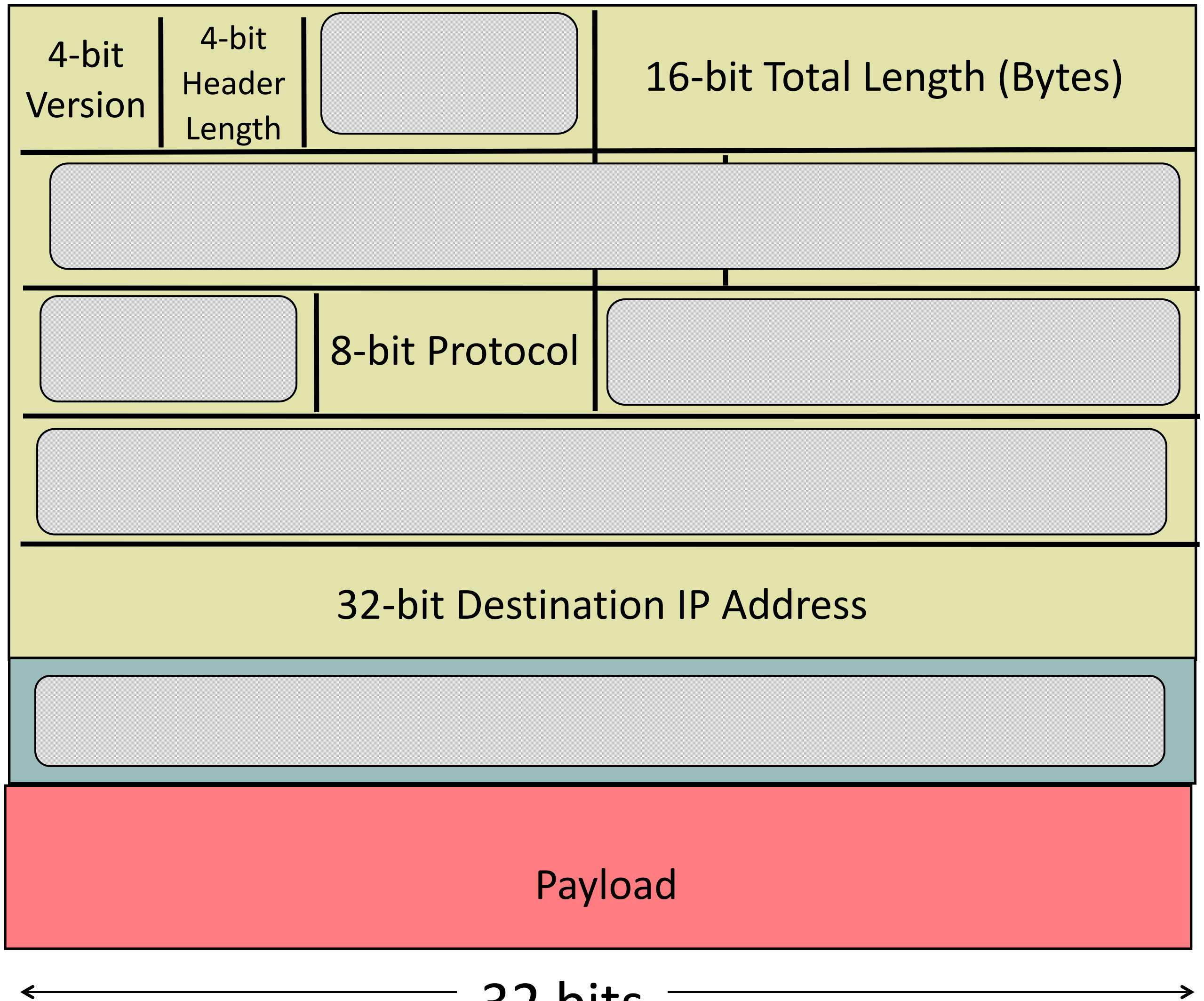

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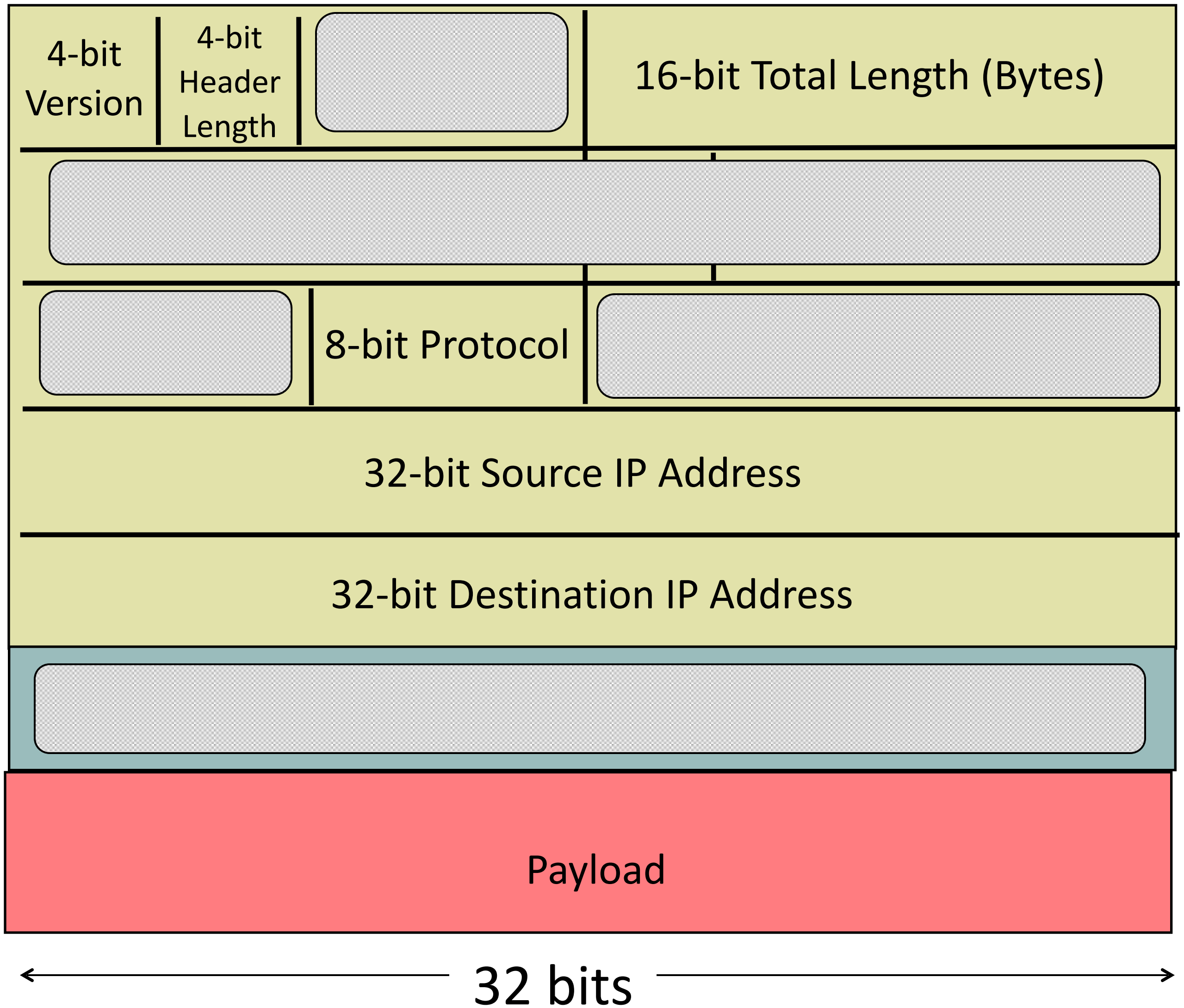

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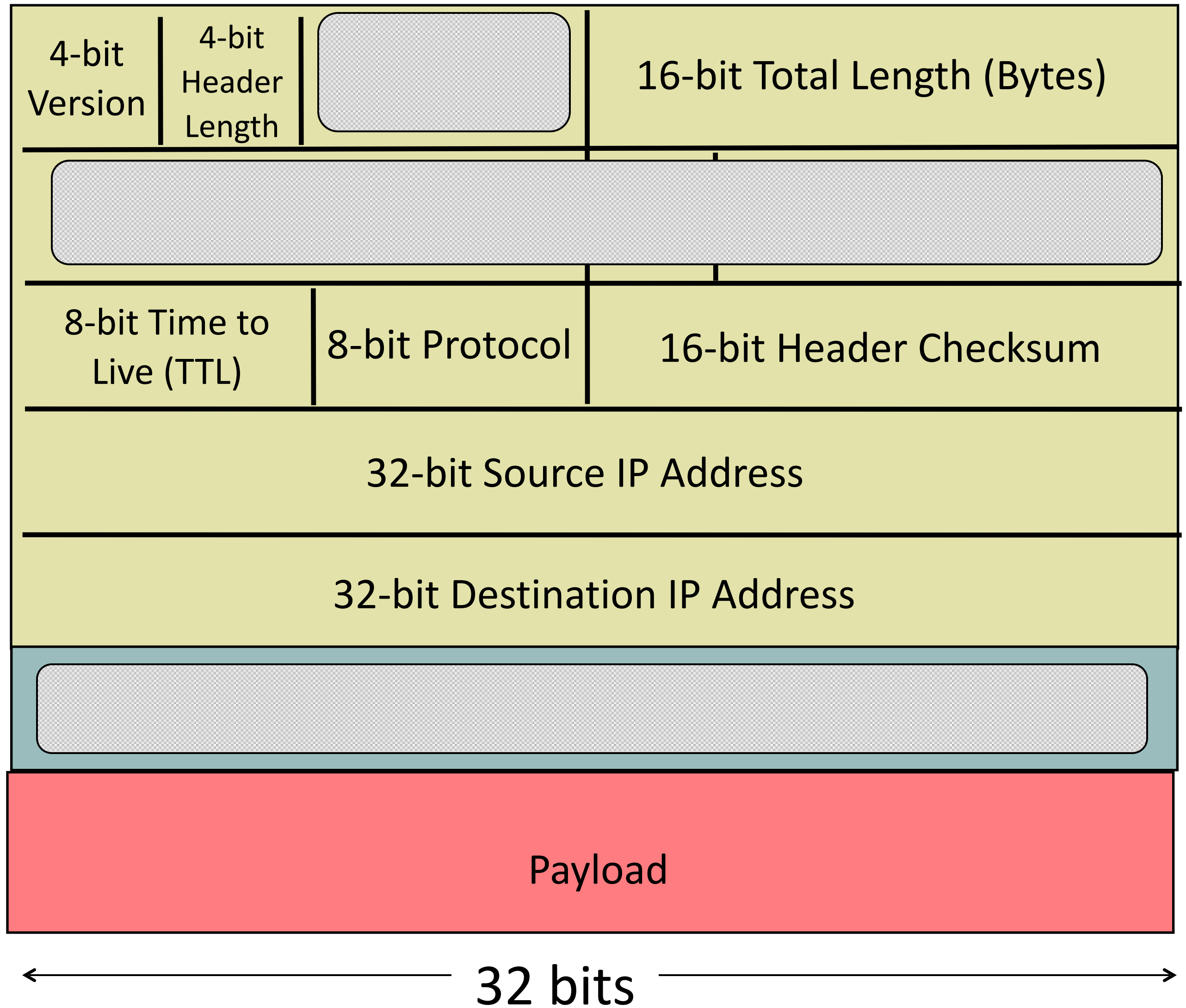

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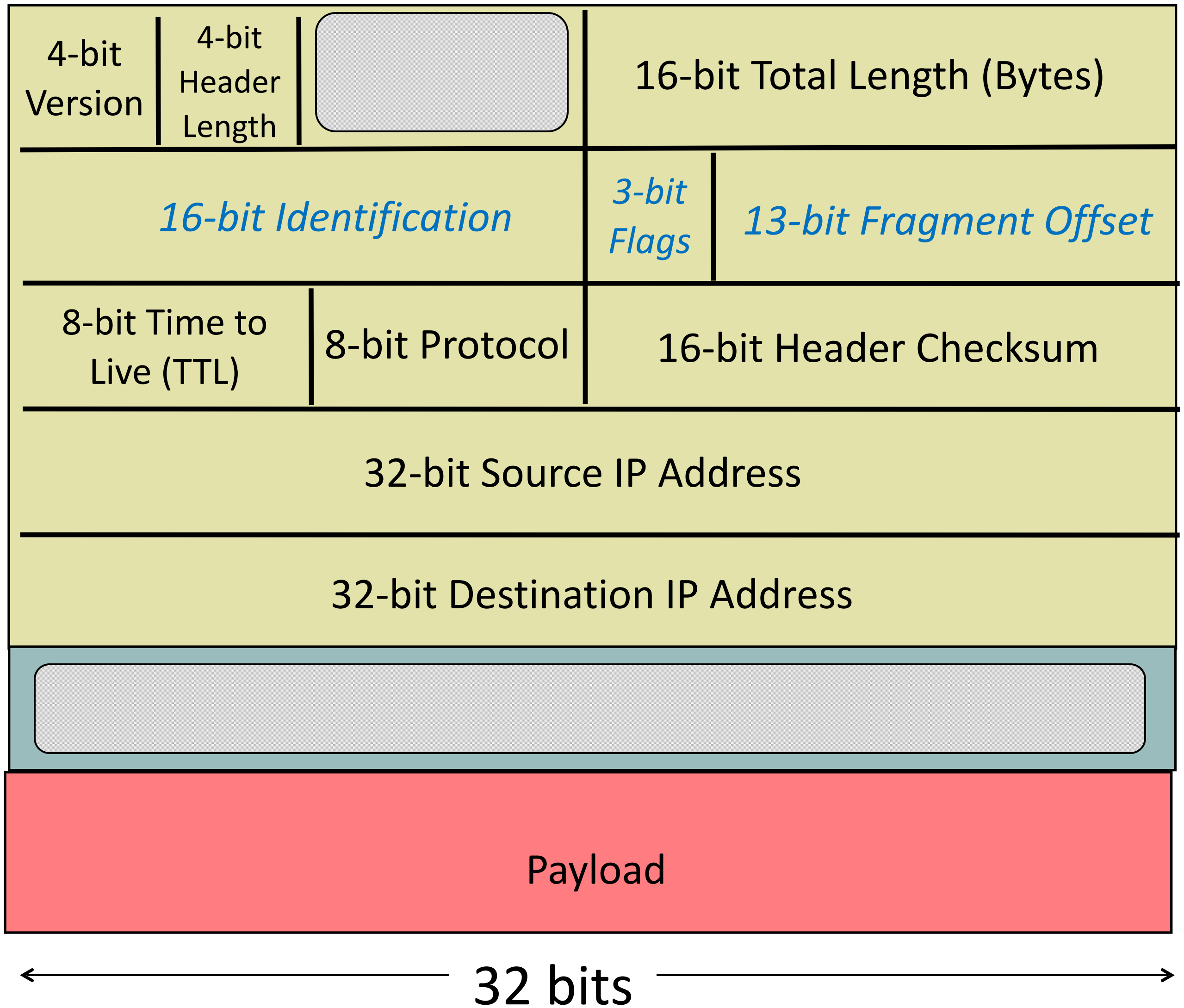

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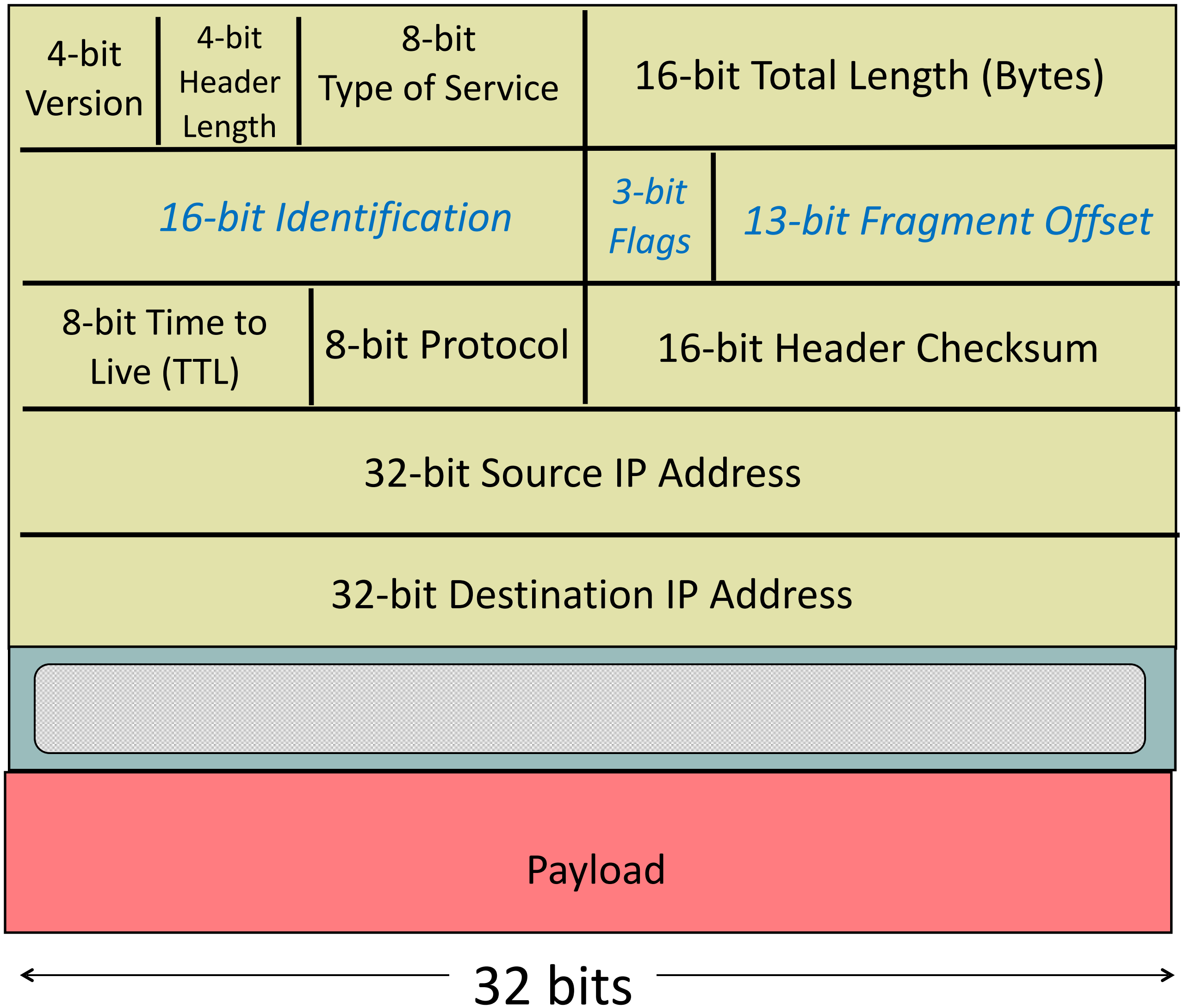

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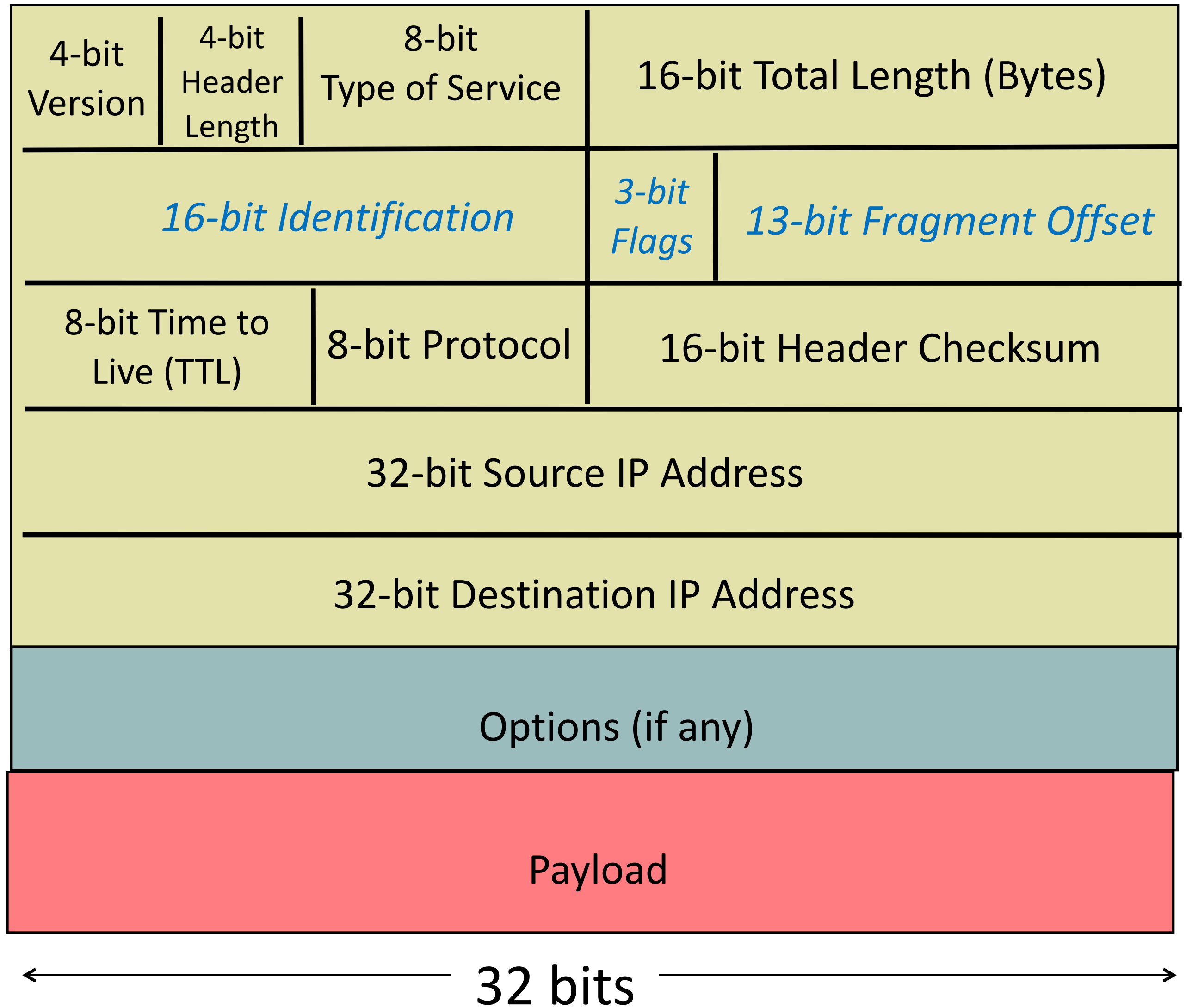

Two remaining topics (next time)

- IPv4 → IPv6
- Security implications of the IP header

Questions?