Routing #2

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cs168.io

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Last Time

- Talked about what a router *is* and why we need/want them.
- Defined routing and forwarding.
- Thought about what makes routing *valid*
- Demonstrated human-based routing and forwarding.

Plan for today

- Types of routing protocols.
- More about *Distance-Vector* routing protocols.

Inter-domain and Intra-domain routing

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- The Internet is a network of networks.
    - How we route traffic on one may not be the best way on another (why?)

Inter-domain and Intra-domain routing

- The Internet does not have a single giant routing protocol.

- The Internet is a network of networks.
  - How we route traffic on one may not be the best way on another (why?)
  - Networks differ!
    - Physical size, number of hosts, number of routers, bandwidth, latency, failure rate, topology, support staff size, when they were built, $ available…

- So…
  - Let individual networks choose how to route *inside* their network (intradomain)
  - …have all networks agree on how to route *between* each other (inter-domain)

Intra-Domain Routing

- ~Within a single network.
    - Technically an “autonomous system”.
    - Run by one operator.
    - Some different protocol requirements – reachability to all different nodes, and to use all capacity efficiently.
    - Base protocols are often called *Interior Gateway Protocols* or IGPs.
        - A number are used actively today – OSPF, IS-IS are the most common.

Inter-domain Routing

- Routing between networks.
  - Between autonomous systems really.
  - Used to make many networks into the Internet.
  - Protocols are called Exterior Gateway Protocols (EGPs).
  - There is only one – all ASes must agree.

- The Internet has used BGP since the 1990s.

Choosing Routing Protocols

- Interior and Exterior (intra- and inter-domain) is a convenient shorthand.

- In practice, the lines are more blurred.
  - BGP is used inside some networks as well as at the edges.

- Comes down to what information needs to be propagated and what type of routing decision is needed.
  - We’ll cover BGP in more depth later.

- We’ll understand the general difference between *Distance-Vector* and *Link-State* protocols.

Least-Cost Routing

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- What did we minimise in the activity last time?
    - Number of people who handled the envelope – the *hop count*

Least-Cost Routing

- What else might we minimise?

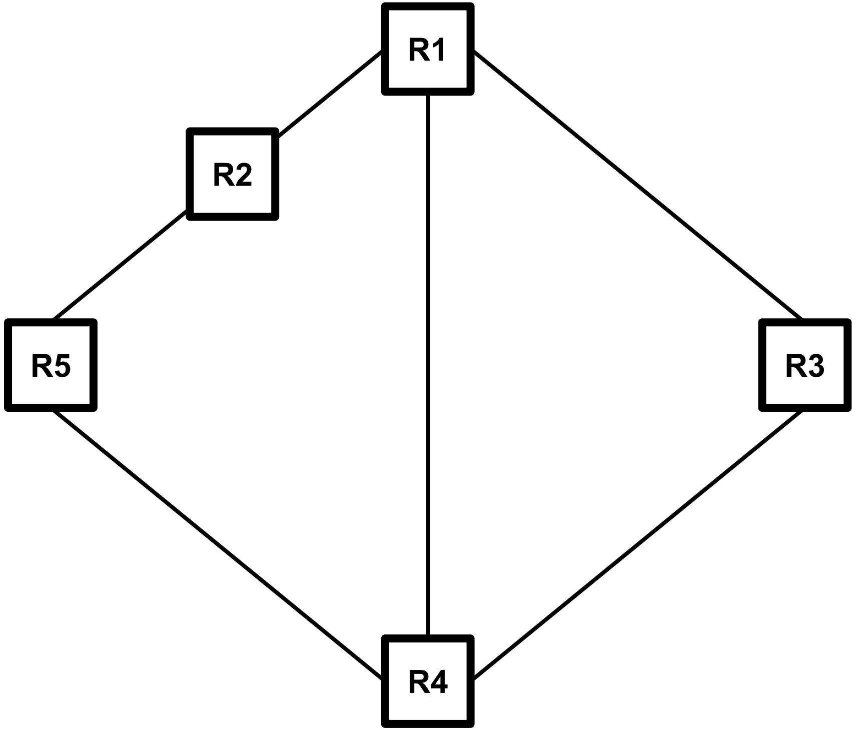
Least-Cost Routing

- What else might we minimise?
    - Price
    - Propagation delay
    - Distance
    - Unreliability
    - Bandwidth constraints

- Metrics can be arbitrarily chosen.
    - We can generically refer to this as “cost”.

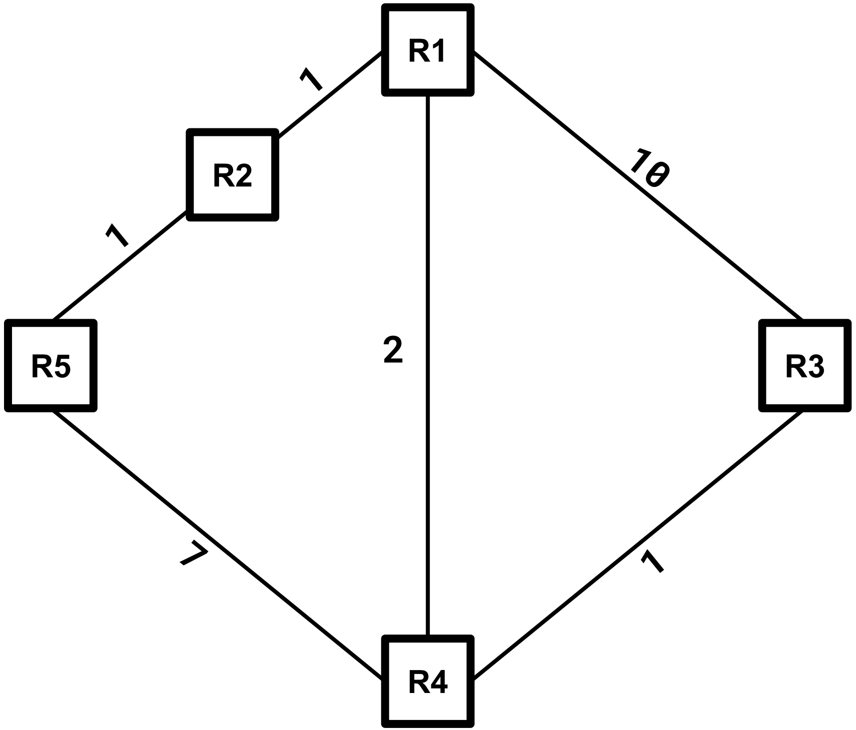
Least-Cost Routing

- For a specific network topology, say…



Least-Cost Routing

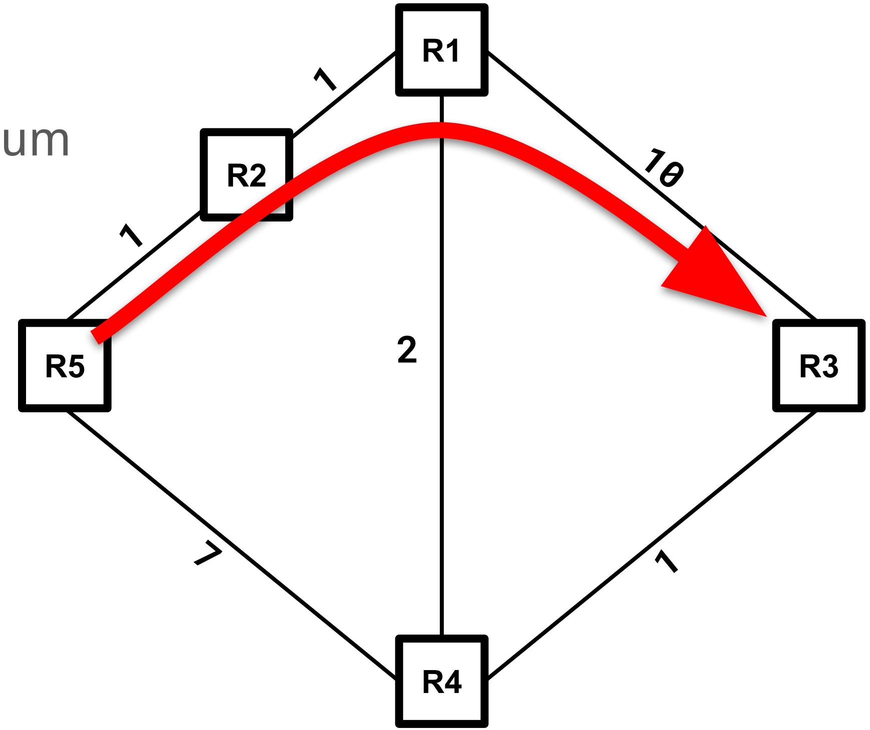
- For a specific network topology, say…
- A cost is associated with each edge.



Least-Cost Routing

R5→R3 Cost: 12

- For a specific network topology, say…
- A cost is associated with each edge.
- And we find the path with the smallest sum



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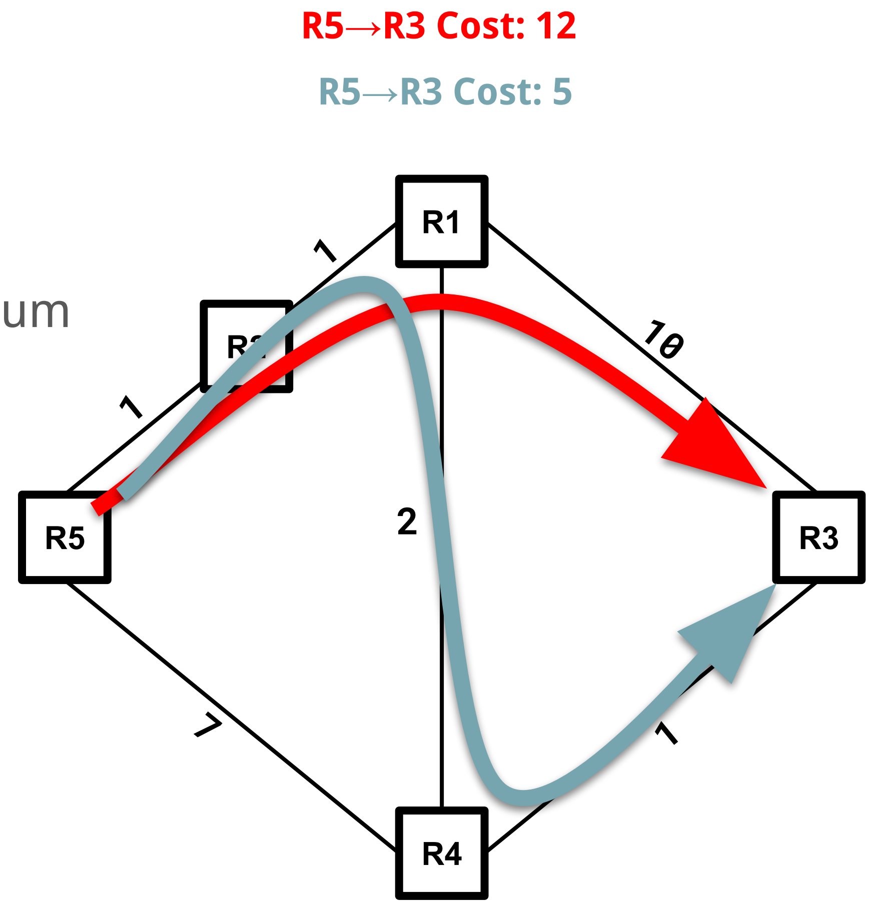

Least-Cost Routing

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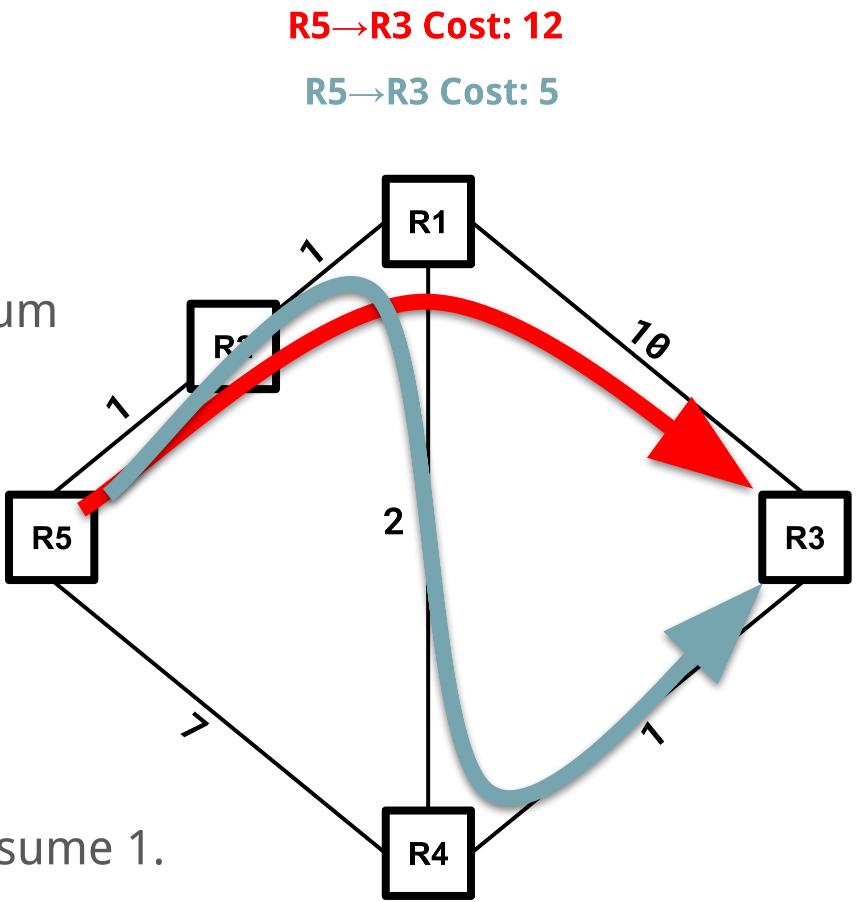

- In our activity:
  - Every edge had a cost of 1
  - Hence we minimised for the fewest edges
  - ⇒ fewest number of hops.

- Generally, if an edge cost is not given, assume 1.

Where do the costs come from?

- Local to a router.
  - Each router knows the cost of its own links.

- Costs are always positive integers.
  - Can’t traverse an edge and make a path cheaper!

- Costs are almost always symmetrical.
  - A→B generally costs the same as B→A.
  - Some rare exceptions.

- In practice, generally configured by an operator.
- Some protocols allow for autoconfiguration.

Are least cost routes good routes?

- Least-cost routes are an easy way to avoid loops.
  - No (sensible) metric is minimised by traversing a loop.
- Least-cost routes are destination based.
- They form a spanning tree.

“Simple” Route Types

“Connected”/”Direct” Routes

- Sometimes we need to be able to route to things that we’re actually connected to directly.

- Host A is directly connected to router 1.
    - These routes are created simply because we tell a router something about its configuration.

- Often created manually by operators.

“Static” Routes

- Routes that we aren’t necessarily directly connected to – but we always want to be there.

- “Static” because they don’t change and there’s no routing protocol used to discover them.

- Again, often manually created by an operator.

Distance-Vector Routing

Distance-Vector Routing Protocols

- Long history on the Internet and ARPANET.

- The prototypical D-V protocol is RIP.

- Strong relationship to the Bellman-Ford shortest path algorithm.
  - Our exercise was a version of Bellman-Ford.
  - With some tweaks to make it a useful routing protocol.

- We'll talk about how such a protocol actually works today.

Bellman-Ford and our In-Class Routing

```
def bellman_ford (dst, routers, links):
  distance = {}; nexthop = {}

  for each r in routers:
    distance[r] = INFINITY
    nexthop[r] = None
  distance[dst] = 0

  for _ in range(len(routers)-1):
    for (r1,r2,dist) in links:
      if distance[r1] + dist < distance[r2]:
        distance[r2] = distance[r1] + dist
        nexthop[r2] = r1

  return distance, nexthop
```

From our exercise - **magic number**

From our exercise - **best friend**

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Accept the offer and update our best friend

But we didn't do this in a loop…
We did it in parallel.

Bellman-Ford and our In-Class Routing

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And we did this asynchronously - there was no strict order amongst you.

Bellman-Ford and our In-Class Routing

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  dist

  for
    di
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  dist

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  return distance, nexthop
```

And no-one iterated through all the people in the room…

we self-terminated when we *converged*.

From our exercise - **magic number**

m our exercise - **best friend**

Start with infinity as the cost, except for our destination

As we get new offers, compare them to our current cost.

Accept the offer and update our best friend

Building a Distance-Vector Protocol

- The same core approach as Bellman-Ford.
- Thinking about your table…

Your Table	
Dst	***NextHop, Distance***
Sarah	Person in front of me, 14

Building a Distance-Vector Protocol

Your Table	
Dst	***NextHop, Distance***
Sarah	Person in front of me, 14

- Person to your left tells you “I can reach Sarah in 7”.
  - We call this communication **advertising a route** with distance/cost = 7.
- You updated your table…
  - With the cost + 1 (distance to Sarah, plus the distance to your neighbour)
  - If the cost was less than the one in your table.

Building a Distance-Vector Protocol

Your Table	
Dst	***NextHop, Distance***
Sarah	~~Person in front of me, 14~~ Person to my left, 8

- Person to your left tells you "I can reach Ian in 7".
  - We call this communication **advertising a route** with distance/cost = 7.
- You updated your table…
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  - If the cost was less than the one in your table.

Building a Distance-Vector Protocol

Your Table	
Dst	***NextHop, Distance***
Sarah	~~Person in front of me, 14~~ Person to my left, 8

- Person in front tells you, “I can reach Rachel in 3”.
    - Rachel?

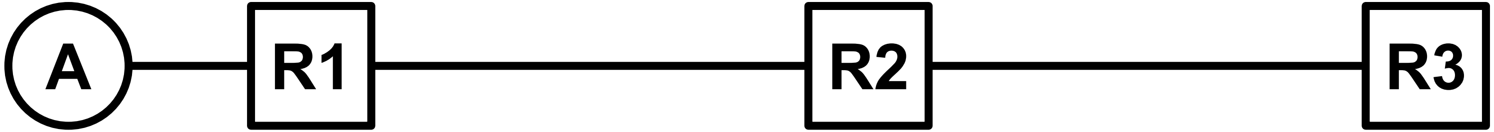
Building a Distance-Vector Protocol

Your Table	
Dst	***NextHop, Distance***
Sarah	~~Person in front of me, 14~~ Person to my left, 8
Rachel	Person in front of me, 4

- Add a new row (for a new destination) Rachel.
- Using the same cost logic.
  - Cost to Rachel plus the distance to your neighbour = 3+1 = 4
- We can keep doing this for all destinations we hear about.

Distance-Vector

Dst	*Nxt,Cost*



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Distance-Vector

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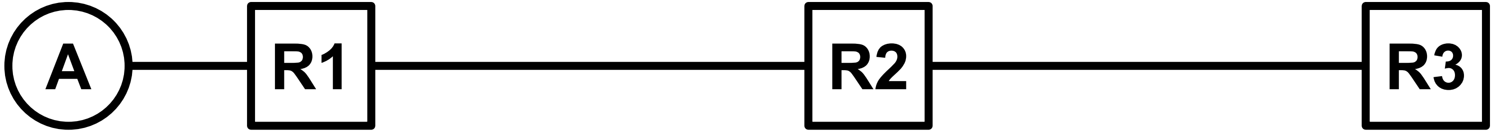
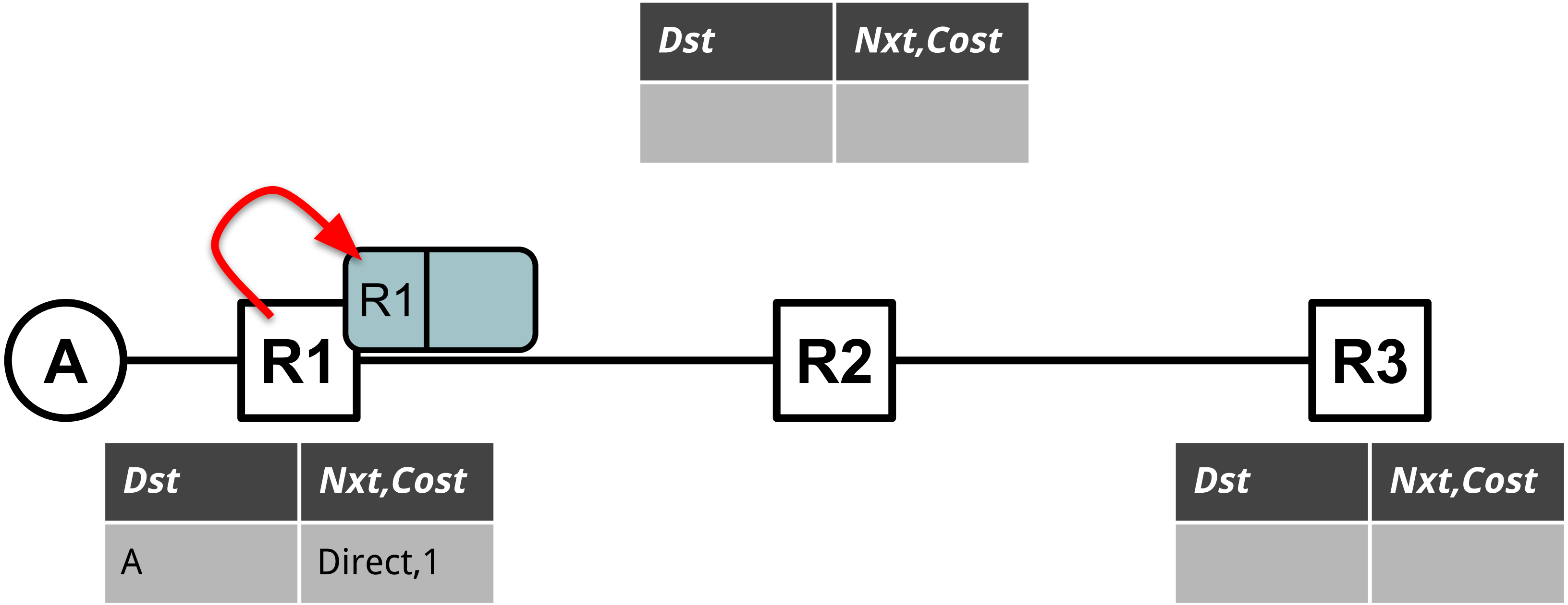


Dst	*Nxt,Cost*
A	Direct,1

Dst	*Nxt,Cost*

Distance-Vector



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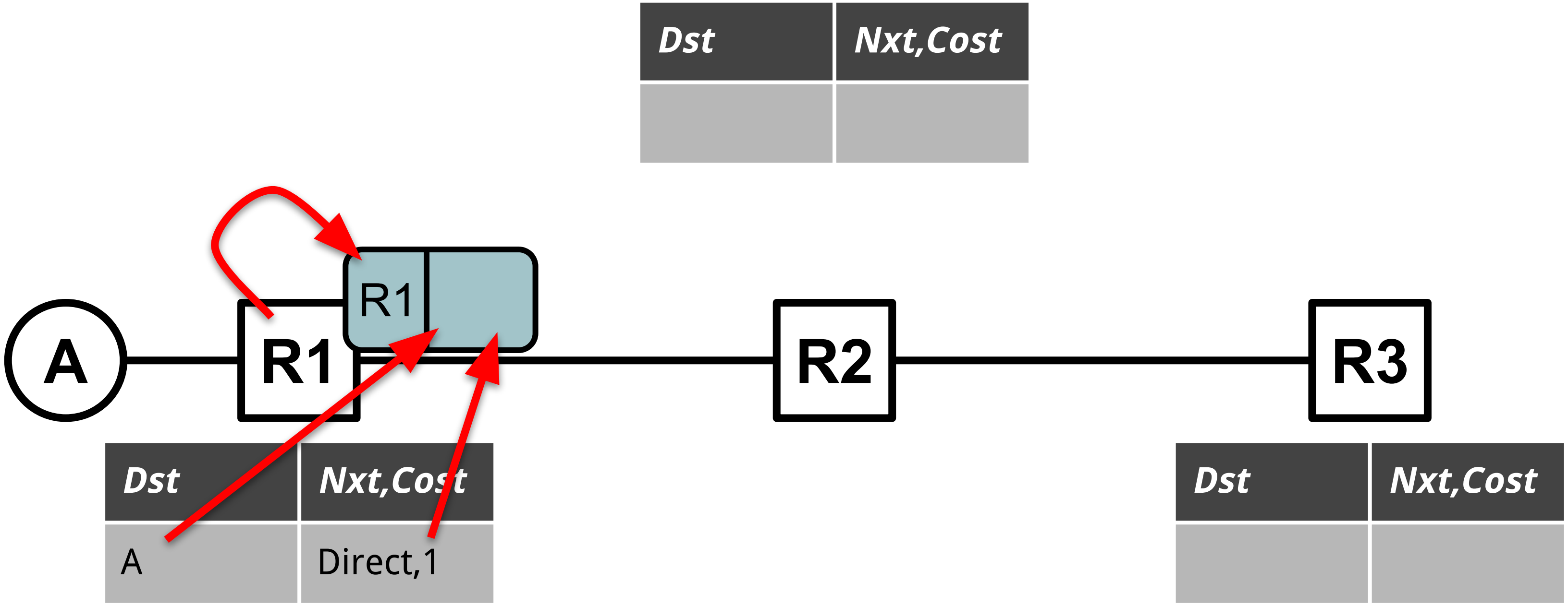

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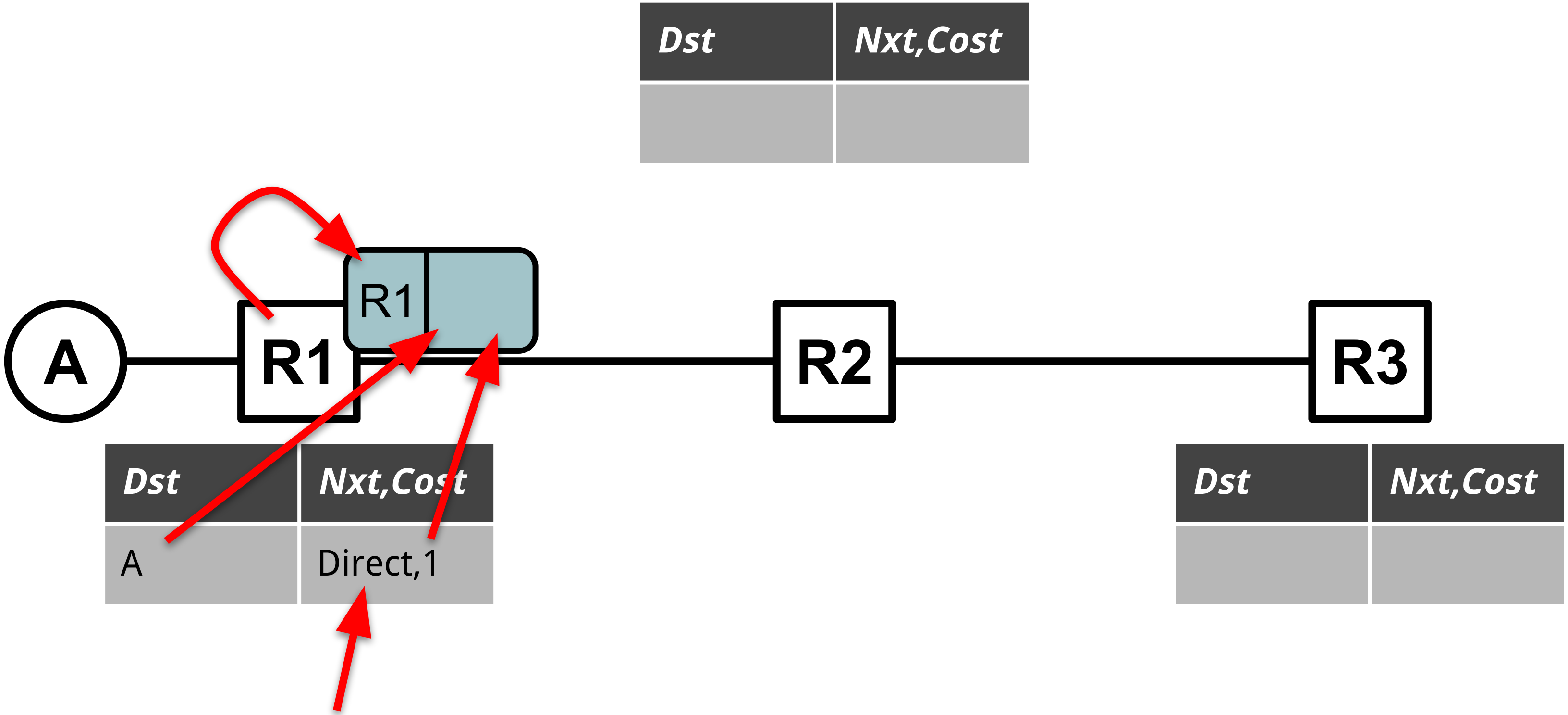
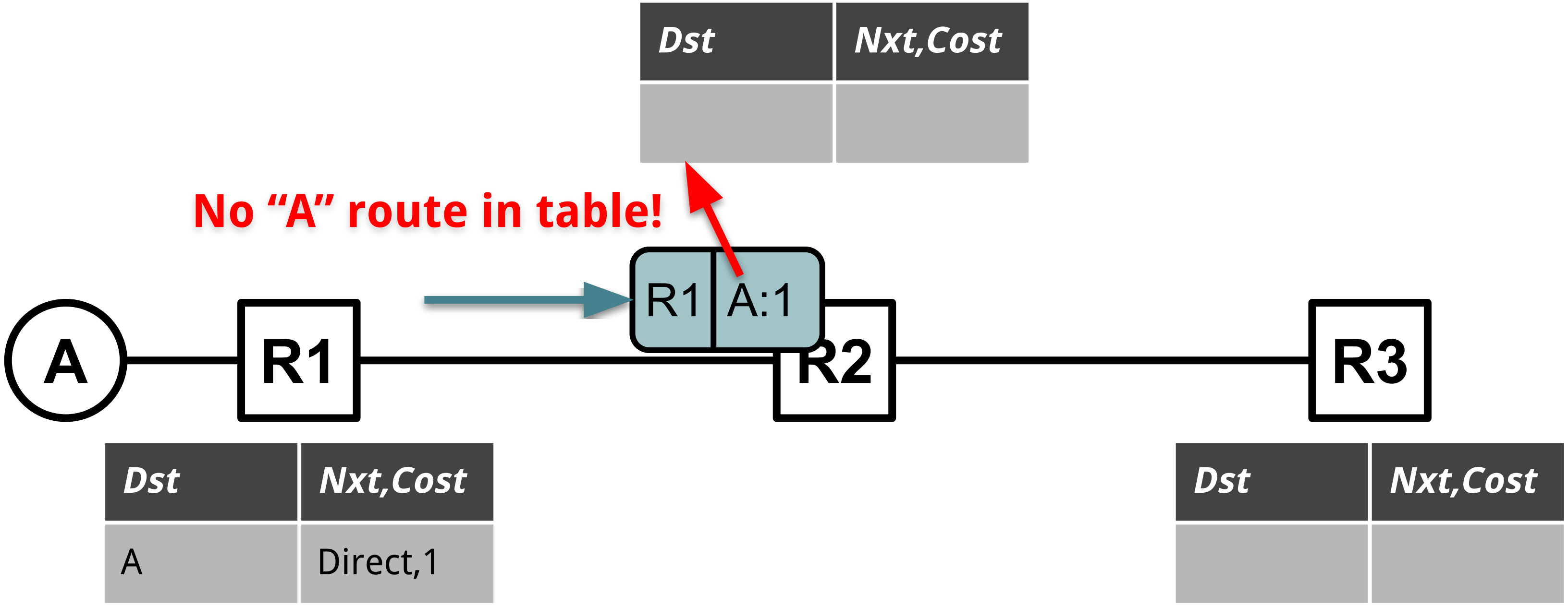


Only R1 needs to know its own next hop!

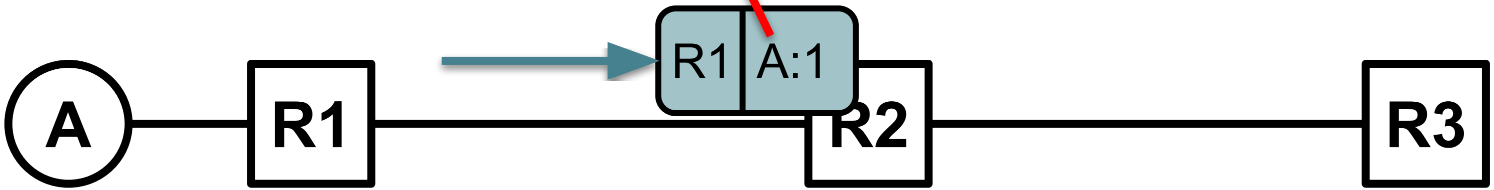
Distance-Vector



Distance-Vector

Dst	Nxt,Cost
A	

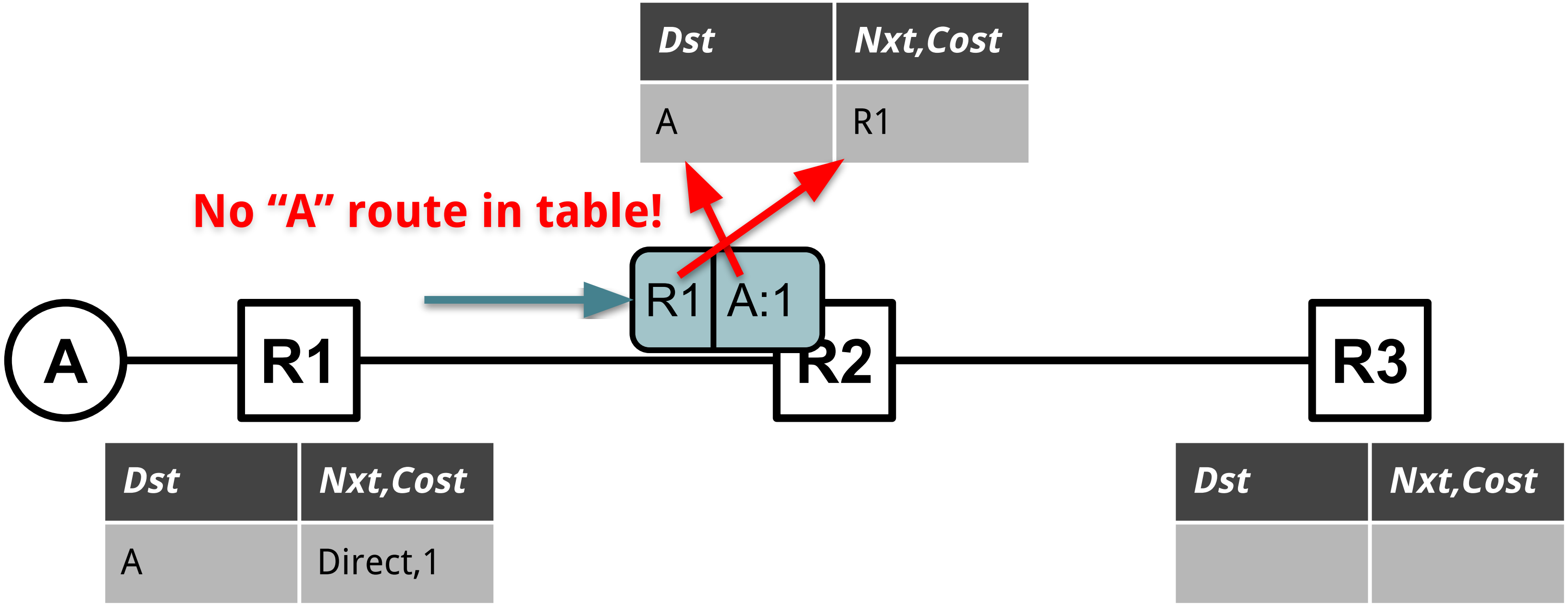
No “A” route in table!



Dst	Nxt,Cost
A	Direct,1

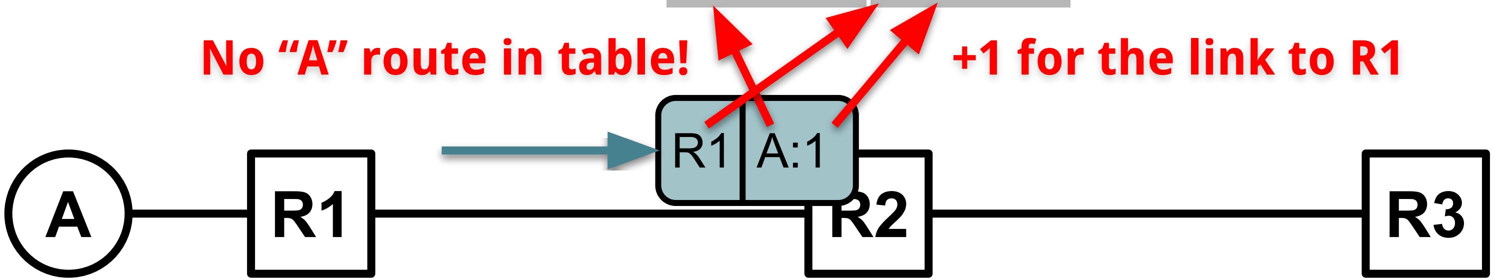
Dst	Nxt,Cost

Distance-Vector



Distance-Vector

Dst	Nxt,Cost
A	R1,2



Dst	Nxt,Cost
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Dst	Nxt,Cost

Distance-Vector

Dst	*Nxt,Cost*
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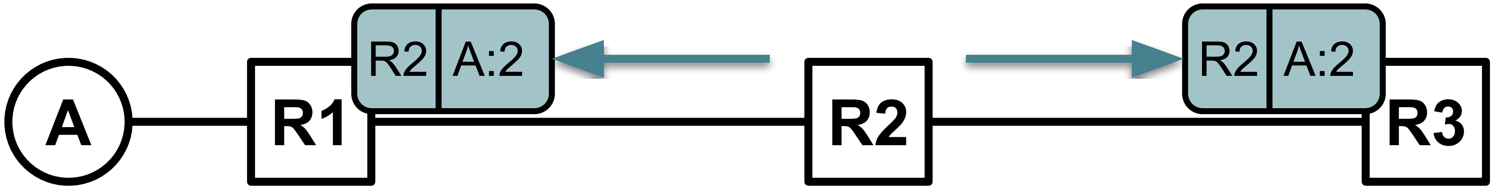

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Distance-Vector

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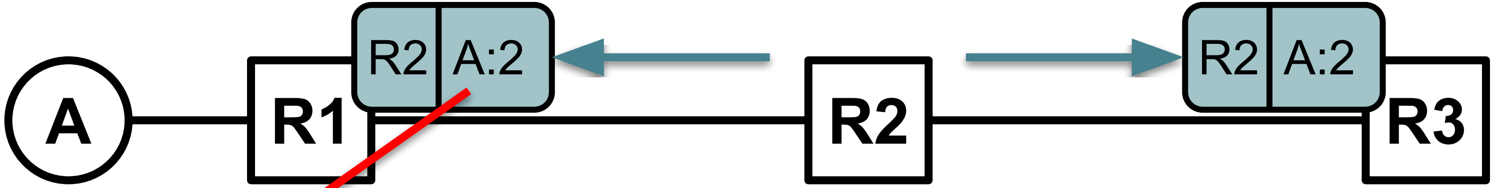

Dst	Nxt,Cost
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2+1 = 3

Dst	Nxt,Cost

Distance-Vector

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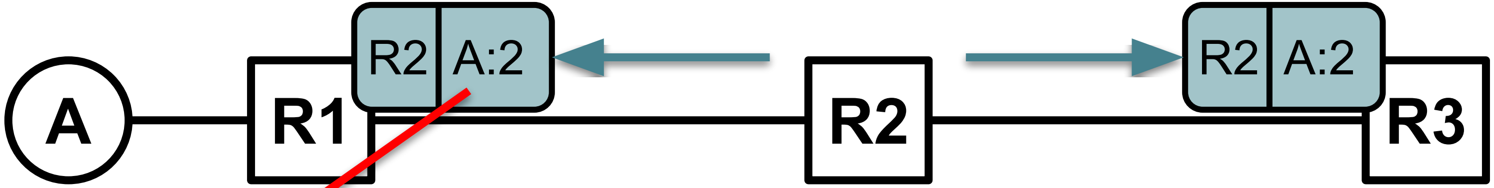

Dst	Nxt,Cost
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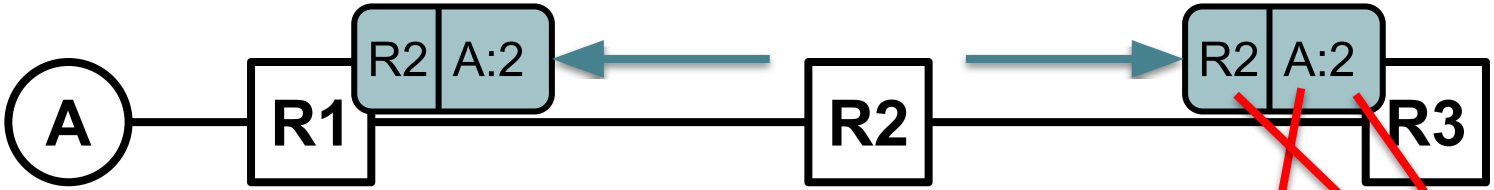
2+1 = 3
Worse than current route
⇒ do not adjust.

Dst	Nxt,Cost

Distance-Vector

Dst	Nxt,Cost
A	R1,2



Dst	Nxt,Cost
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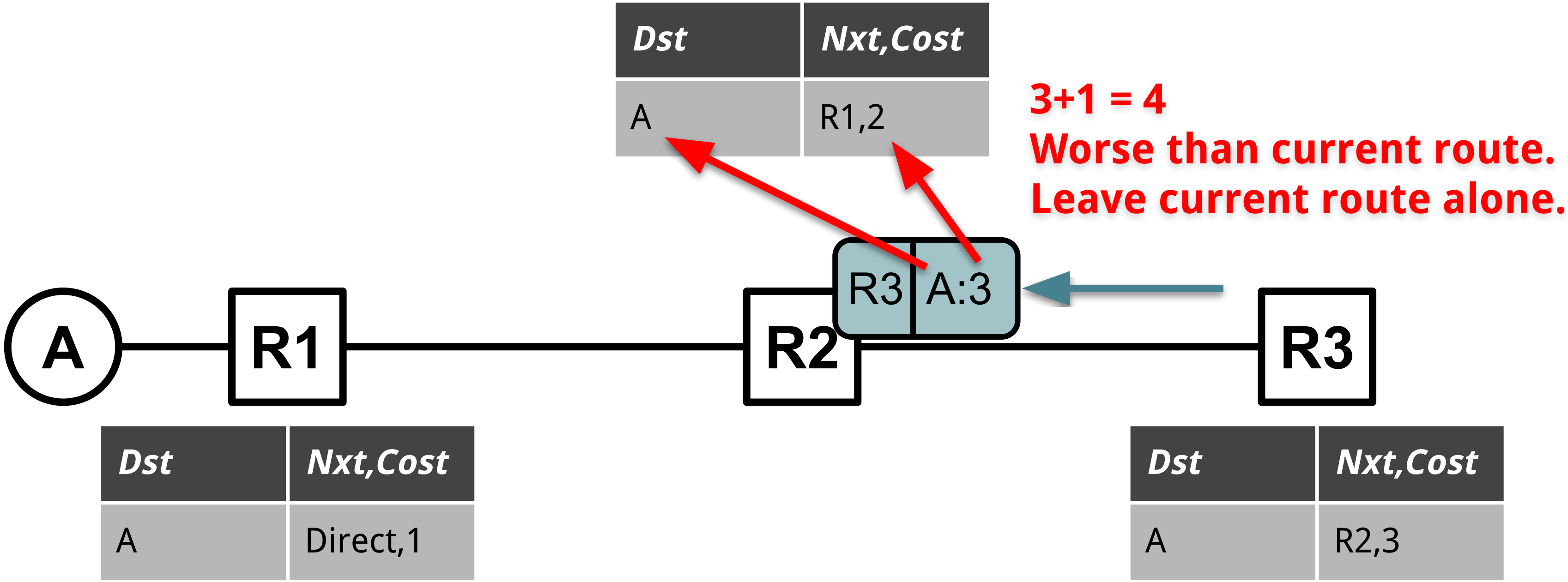
Dst	Nxt,Cost
A	R2,3

Distance-Vector



Distance-Vector

Dst	*Nxt,Cost*
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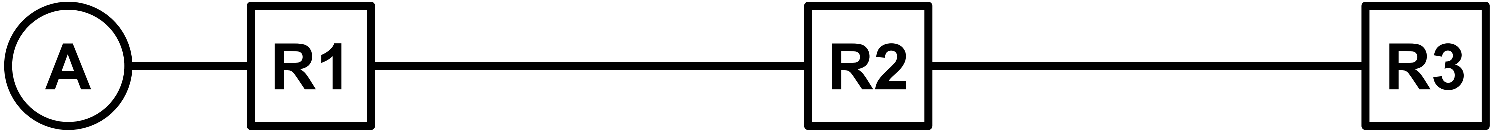


Dst	*Nxt,Cost*
A	Direct,1

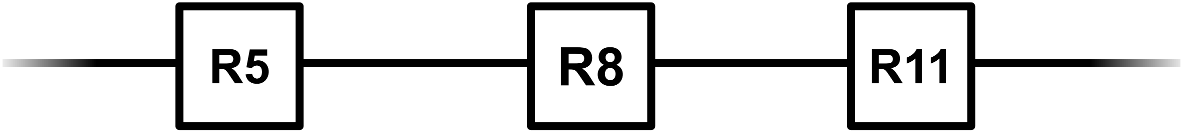
Dst	*Nxt,Cost*
A	R2,3

We've converged! 🥳

Questions?

D-V: An exception to the update rule

- Our logic for when to update a route:
  - If destination not in table -- add to table



Dst	*Nxt,Cost*
F	R5,6

D-V: An exception to the update rule

- Our logic for when to update a route:
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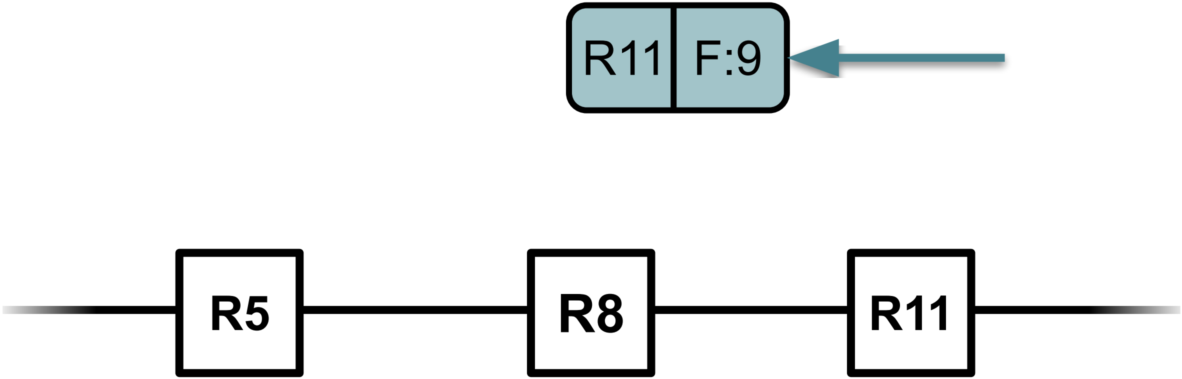

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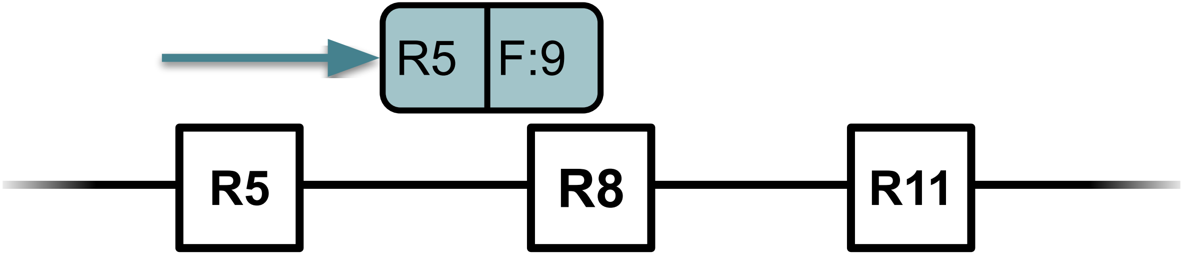

Dst	***Nxt,Cost***
F	R5,6

D-V: An exception to the update rule

- Our logic for when to update a route:
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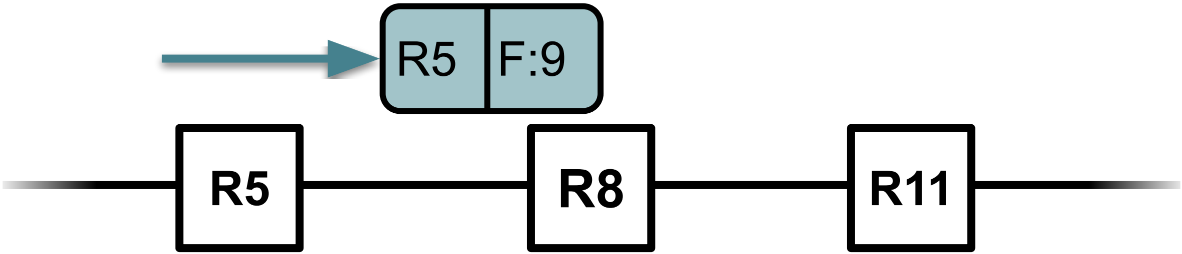
  - If current_route_distance > advertised_distance + distance_to_neighbor -- replace current
  - **If advertiser is current_next_hop -- replace current**



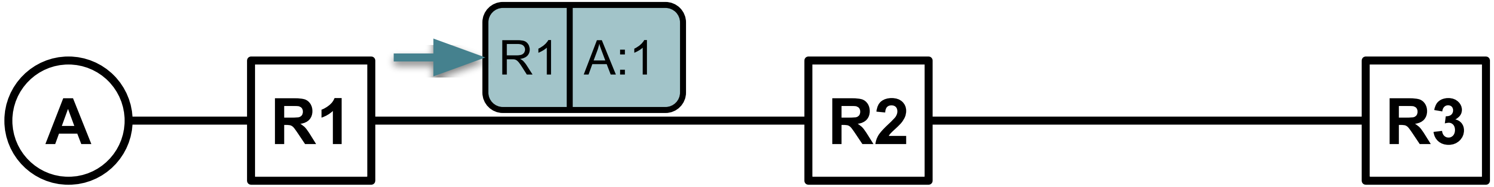
Dst	*Nxt,Cost*
F	R5,**10**

D-V:

Is our D-V protocol reliable?

D-V: Reliability

Dst	*Nxt,Cost*



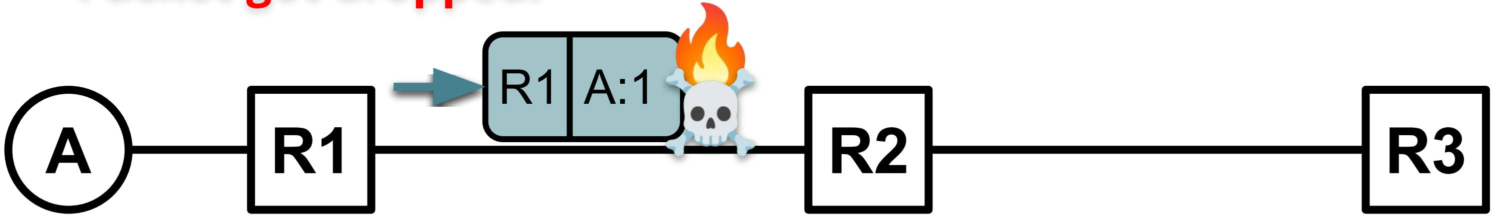
Dst	*Nxt,Cost*
A	Direct,1

Dst	*Nxt,Cost*

D-V: Reliability

Dst	Nxt,Cost

Something bad happened!
Packet got dropped!



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D-V: Reliability

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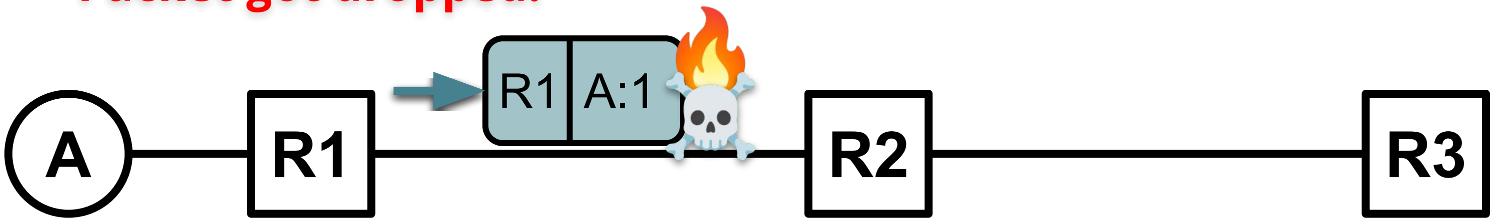


Dst	Nxt,Cost
A	Direct,1

<u>Super simple reliability</u>

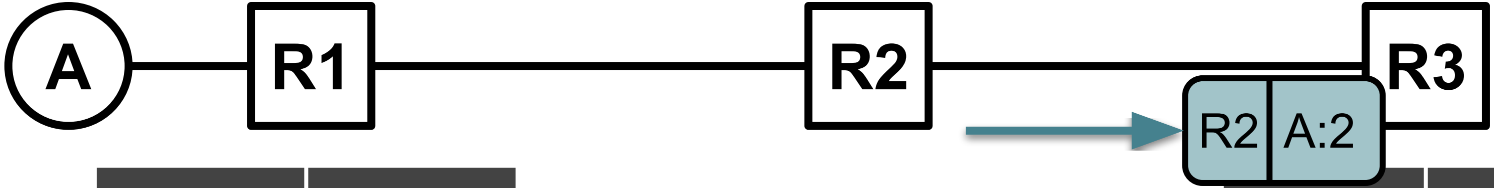
Resend advertisements every X seconds. (X=*advertisement interval*)

This should always work *eventually* (assuming link works at all).
Sending on change (*triggered updates*) acts as an *optimisation*.

Questions?

D-V: Split Horizon

Dst	Nxt,Cost
A	R1,2



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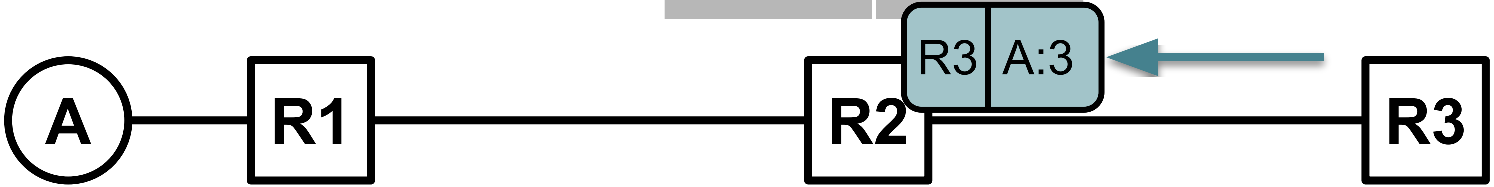
D-V: Split Horizon



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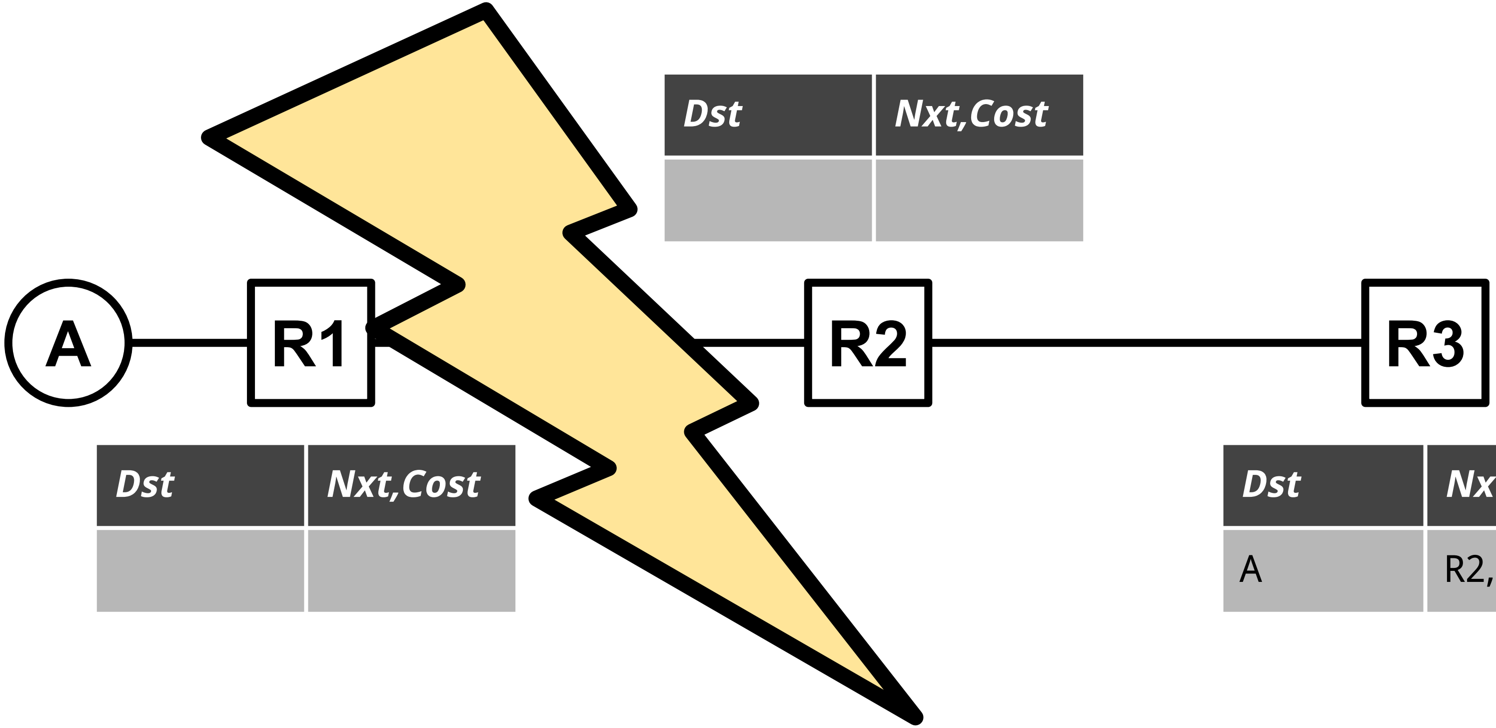
Dst	Nxt,Cost
A	Direct,1

Dst	Nxt,Cost
A	R2,3

D-V: Split Horizon



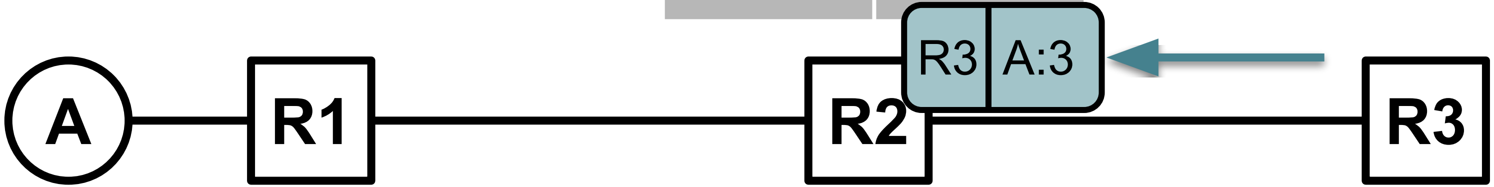
Dst	Nxt,Cost

Dst	Nxt,Cost

Dst	Nxt,Cost
A	R2,3

D-V: Split Horizon

Dst	Nxt,Cost
A	R3, 4



Dst	Nxt,Cost

Dst	Nxt,Cost
A	R2,3

D-V: Split Horizon

Dst	Nxt,Cost
A	R3,4

Dst	Nxt,Cost
A	R2,5

Dst	Nxt,Cost
A	R2,3

Huh?! A is local to R1?!

D-V: Split Horizon

- What is the advantage in advertising a path back to the person who sent it you?

- Telling them about your entry *via them*:
  - Doesn’t tell them anything new.
  - Misleads them into thinking you have an independent path.

D-V: Split Horizon

- What is the advantage in advertising a path back to the person who sent it you?

- Telling them about your entry *via them*:
  - Doesn't tell them anything new.
  - Misleads them into thinking you have an independent path.

- Solution:
  - If you are using a next-hop's path for some destination – don't advertise it to them.
  - Referred to as **Split Horizon**

Questions?

D-V: Counting to Infinity

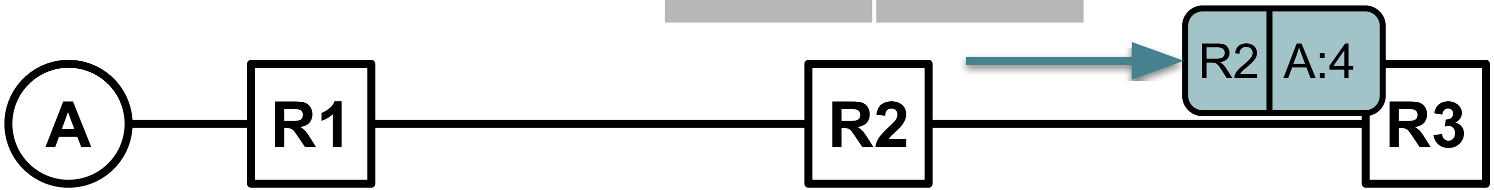
Dst	Nxt,Cost
A	R3,4

Dst	Nxt,Cost
A	R2,5

Dst	Nxt,Cost
A	R2,3

D-V: Counting to Infinity

Dst	Nxt,Cost
A	R3,4



Dst	Nxt,Cost
A	R2,5

Dst	Nxt,Cost
A	R2,~~3~~ 5

D-V: Counting to Infinity

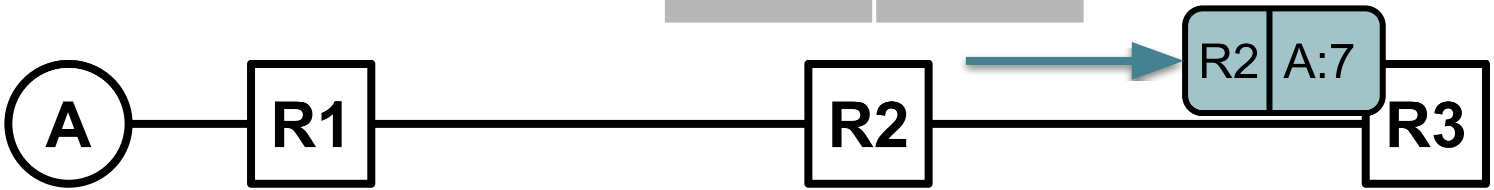
Dst	Nxt,Cost
A	R3,~~4~~ 6

Dst	Nxt,Cost
A	R2,5

Dst	Nxt,Cost
A	R2,5

D-V: Counting to Infinity

Dst	Nxt,Cost
A	R3,6



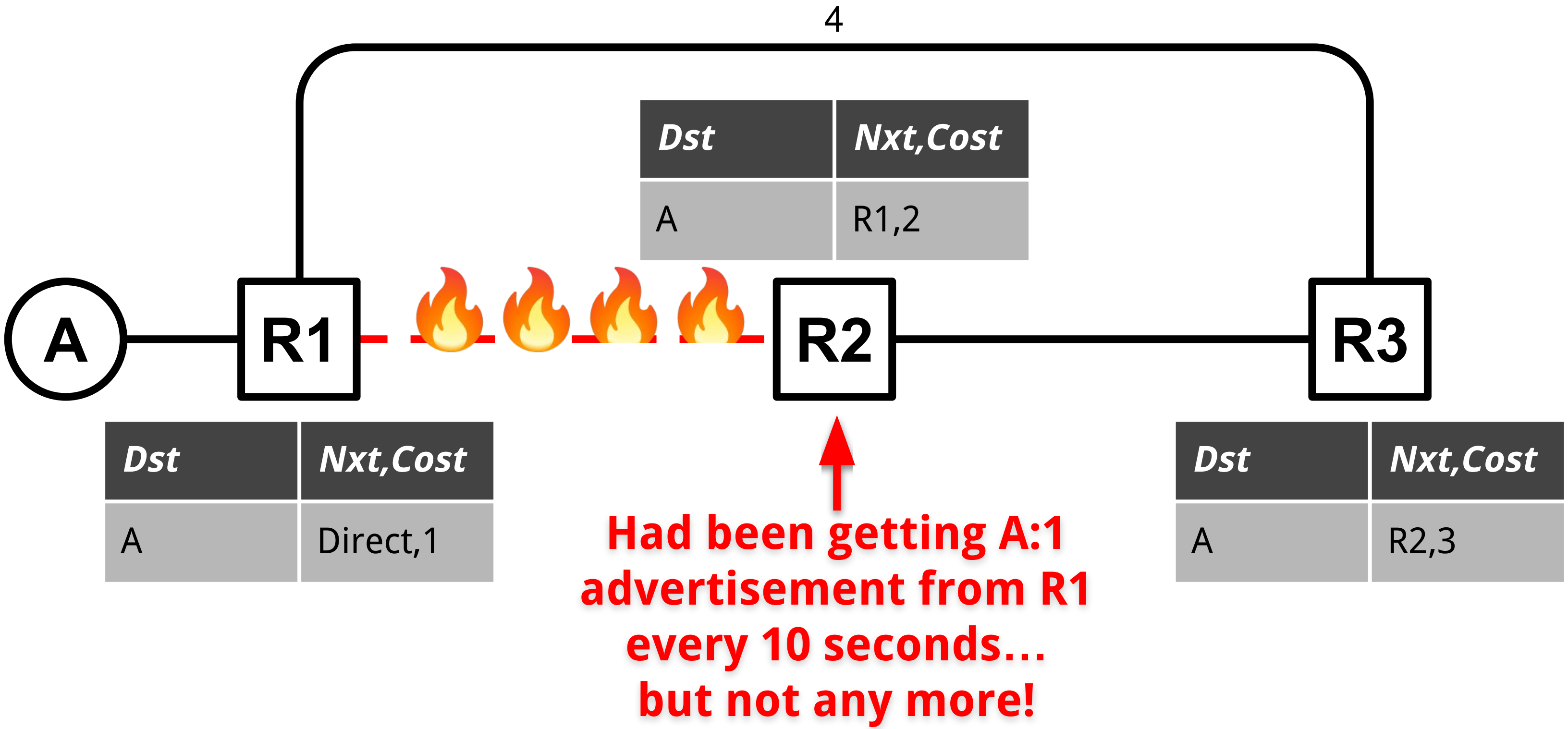
Dst	Nxt,Cost
A	R2,5

Dst	Nxt,Cost
A	R2,~~5~~ 7

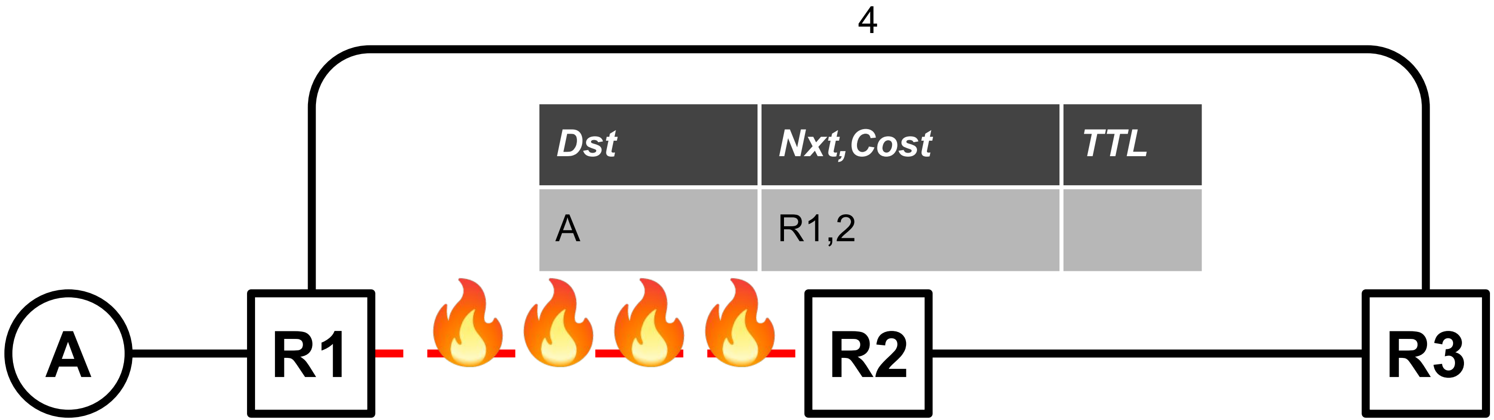
Route costs on R2/R3 *count to infinity*!

Solution: Pick a maximum value (e.g., 16) and stop there.

D-V: Failures


4
Dst
Nxt,Cost
A
R1,2
A
R1
R2
R3
Dst
Nxt,Cost
A
Direct,1
Dst
Nxt,Cost
A
R2,3
Had been getting A:1
advertisement from R1
every 10 seconds…
but not any more!

D-V: Failures



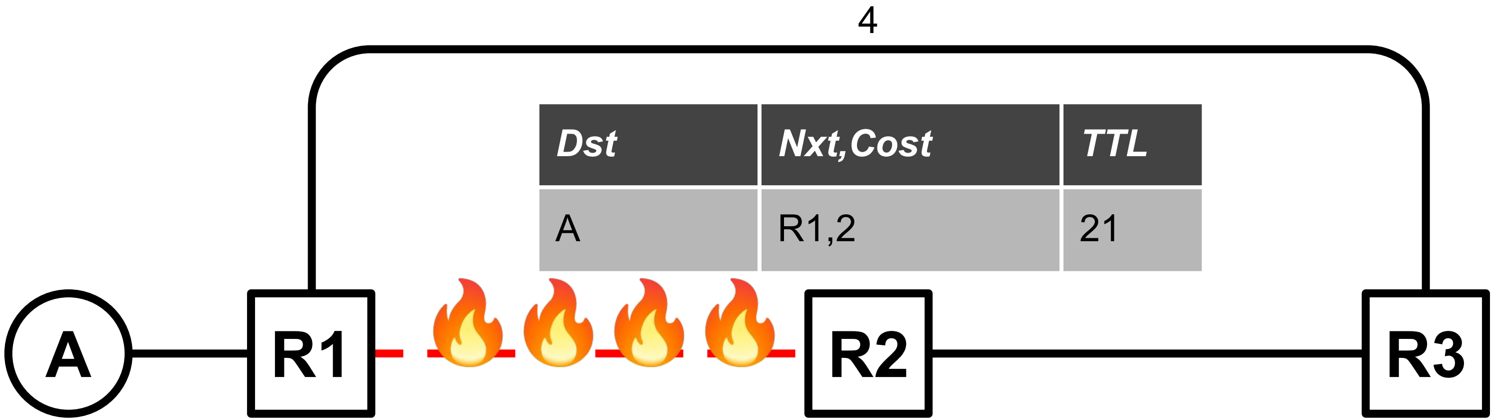
Dst	Nxt,Cost	TTL
A	R1,2	

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	

Each route only has a finite *Time To Live* (e.g., 21 seconds).
Gets "recharged" by the periodic advertisements.
If you don't get a periodic update (e.g., 10 seconds)… expire & remove route.

D-V: Failures



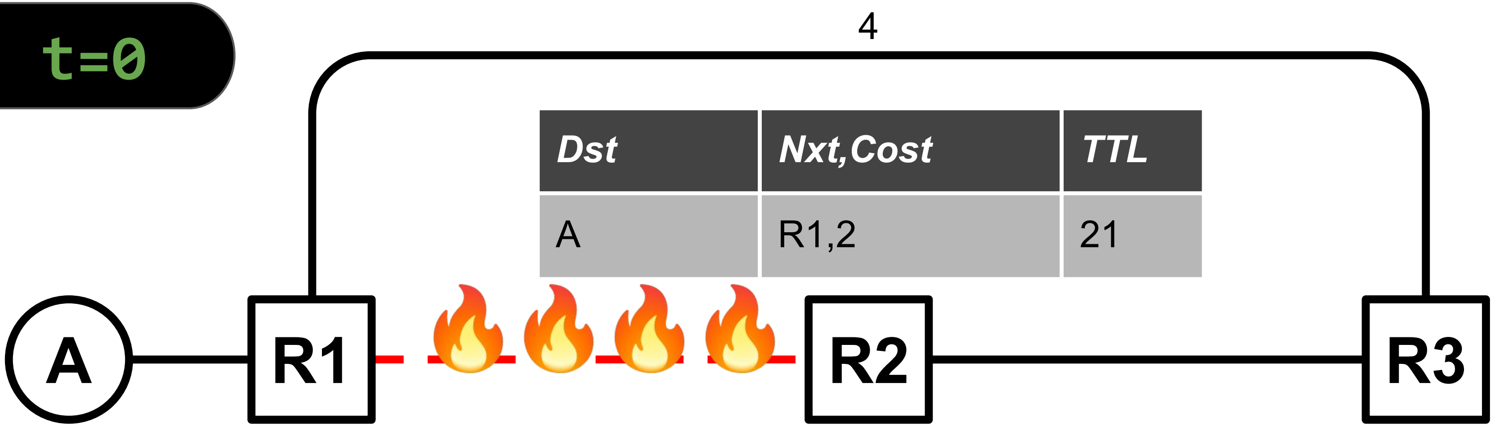
Dst	Nxt,Cost	TTL
A	R1,2	21

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

D-V: Failures

t=0



Dst	Nxt,Cost	TTL
A	R1,2	21

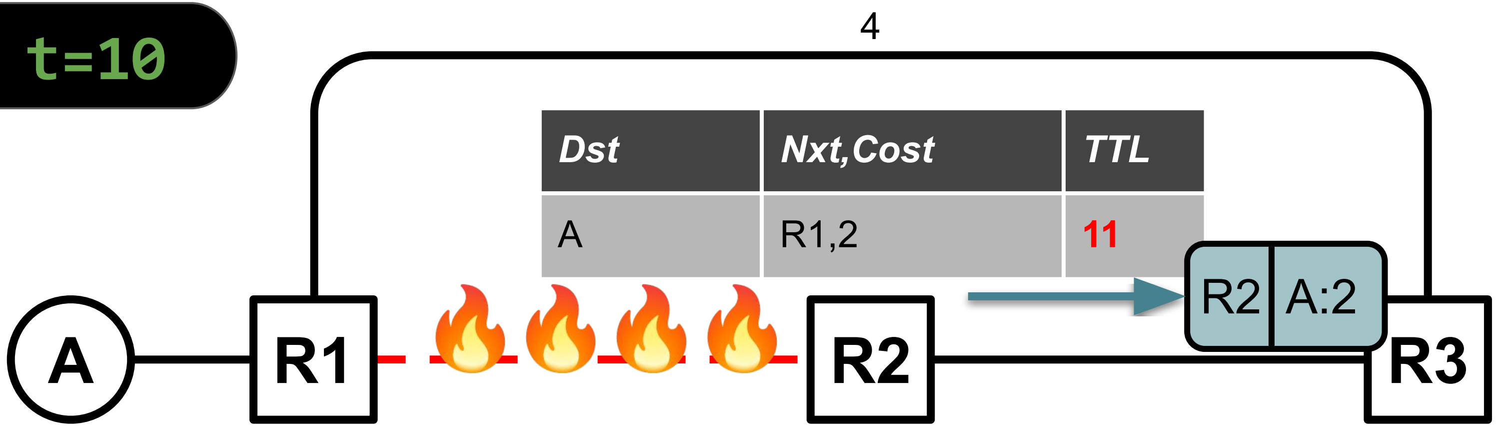
Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

D-V: Failures

t=10

Dst	Nxt,Cost	TTL
A	R1,2	11

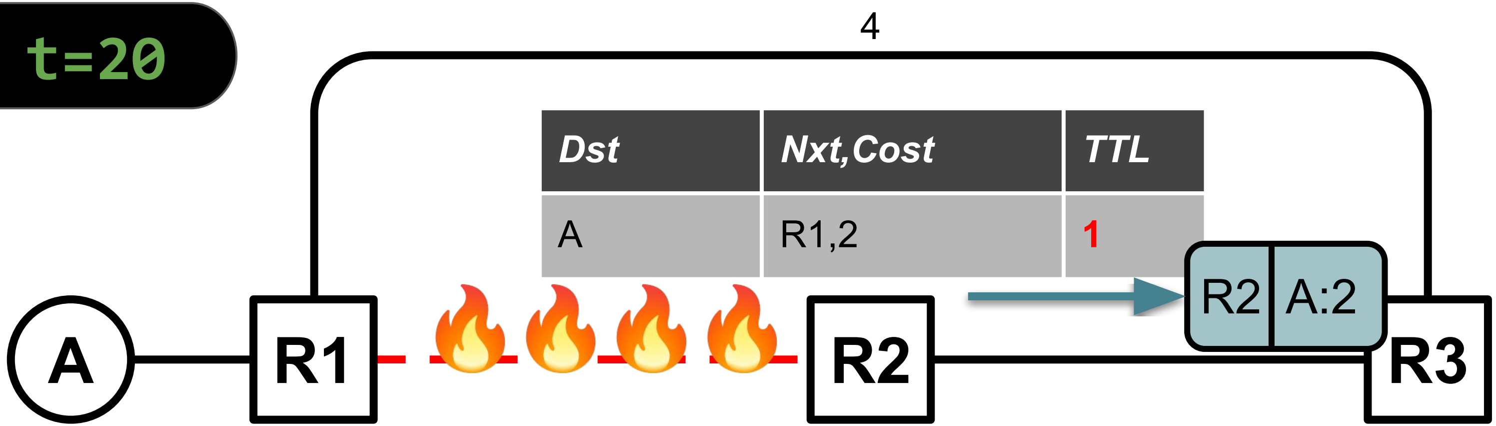


Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

D-V: Failures

t=20



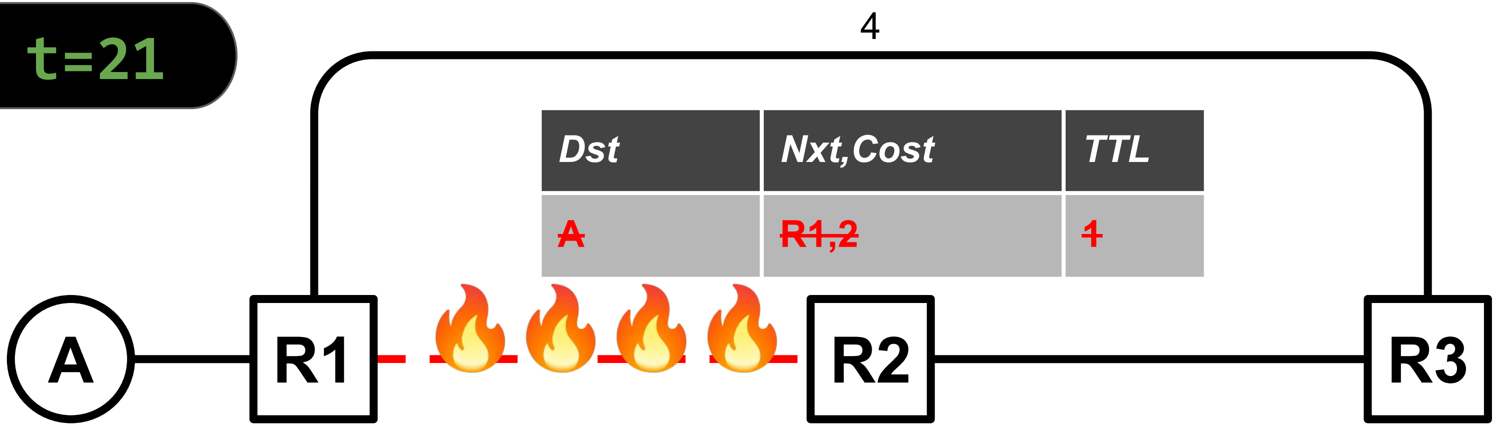
Dst	Nxt,Cost	TTL
A	R1,2	1

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

D-V: Failures

t=21



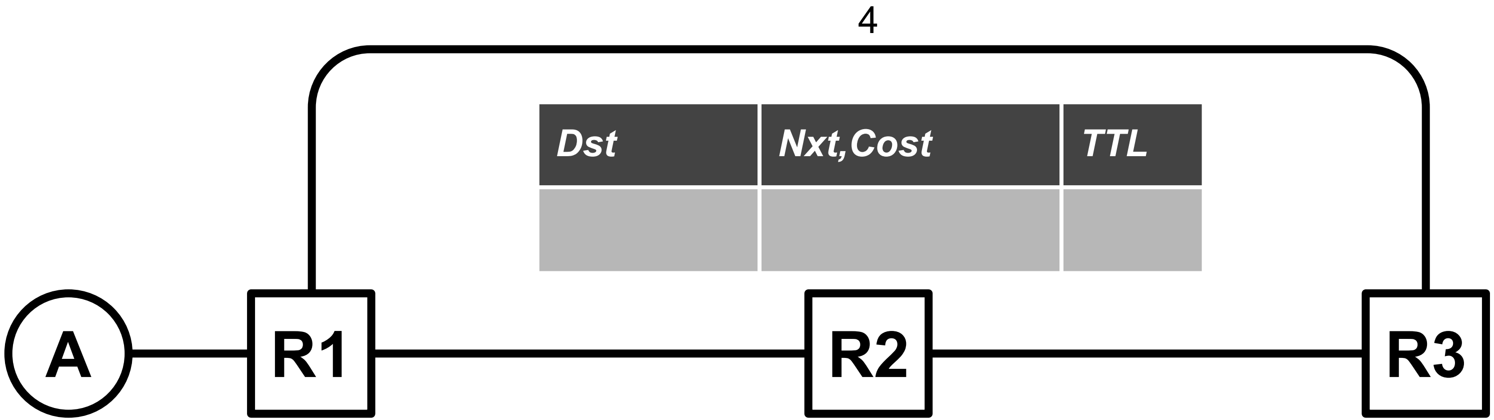
Dst	Nxt,Cost	TTL
~~A~~	~~R1,2~~	~~1~~

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

How do we deal with changing topology?
Link failures.

D-V: Failures



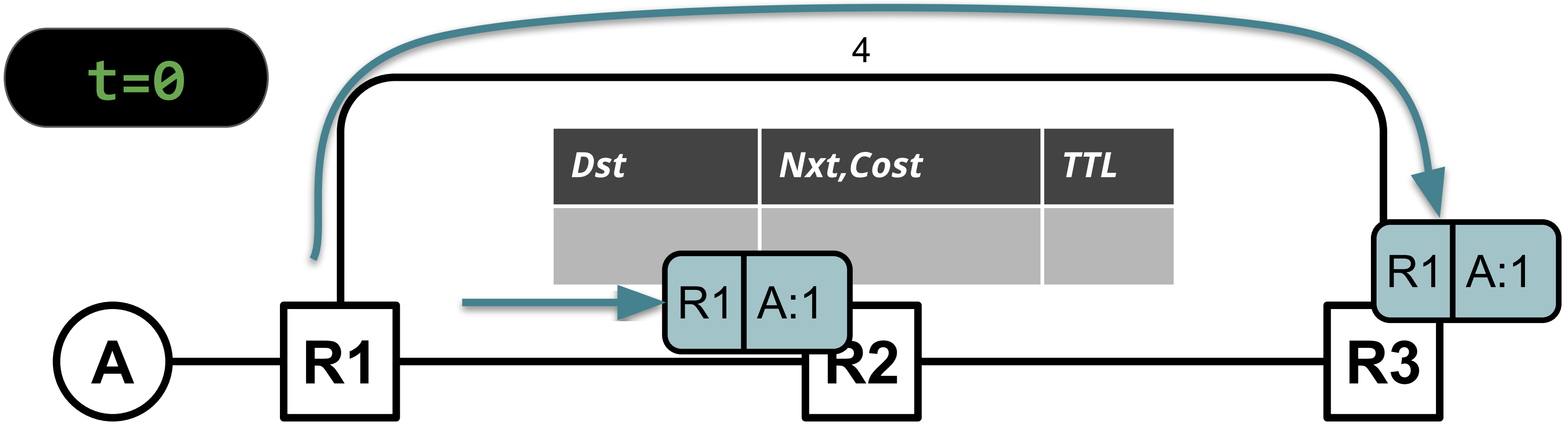
Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL

Static and connected routes don't expire

D-V: Failures



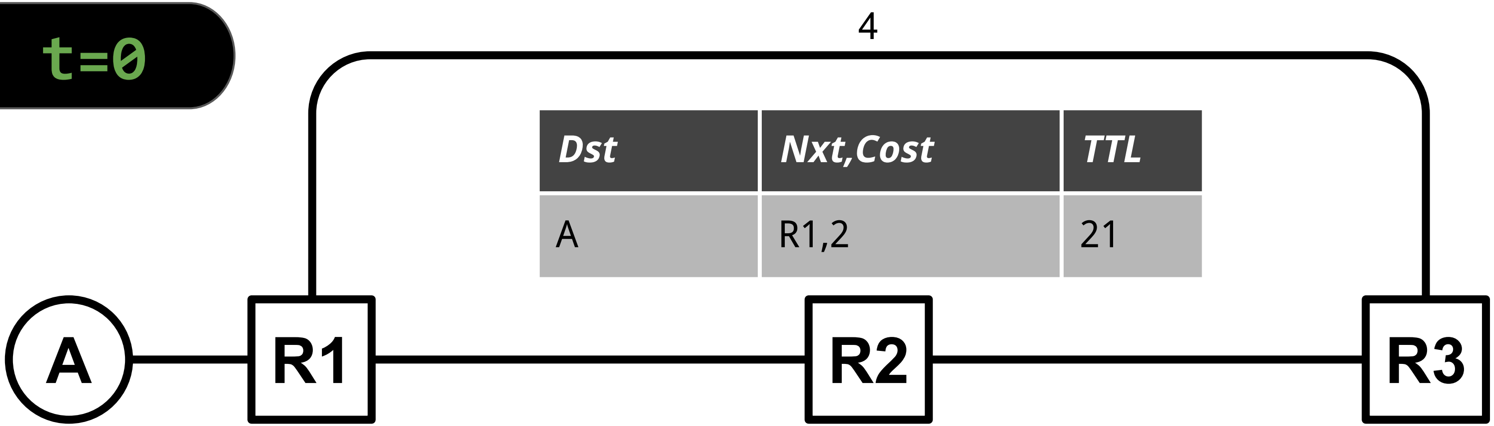
Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL

D-V: Failures

t=0



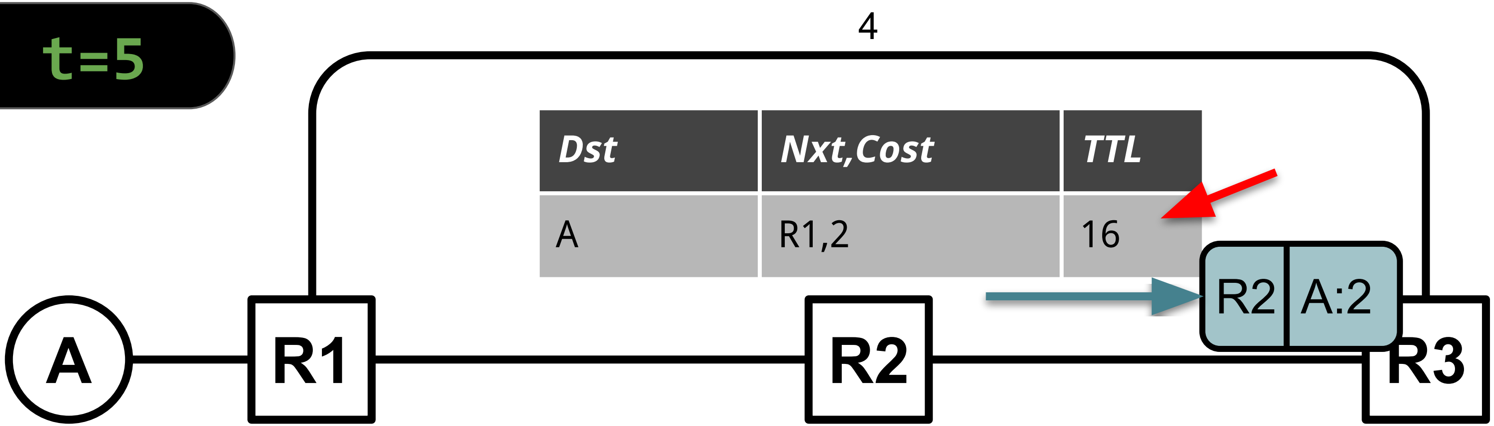
Dst	*Nxt,Cost*	*TTL*
A	R1,2	21

Dst	*Nxt,Cost*	*TTL*
A	Direct,1	---

Dst	*Nxt,Cost*	*TTL*
A	R1,5	21

D-V: Failures

t=5



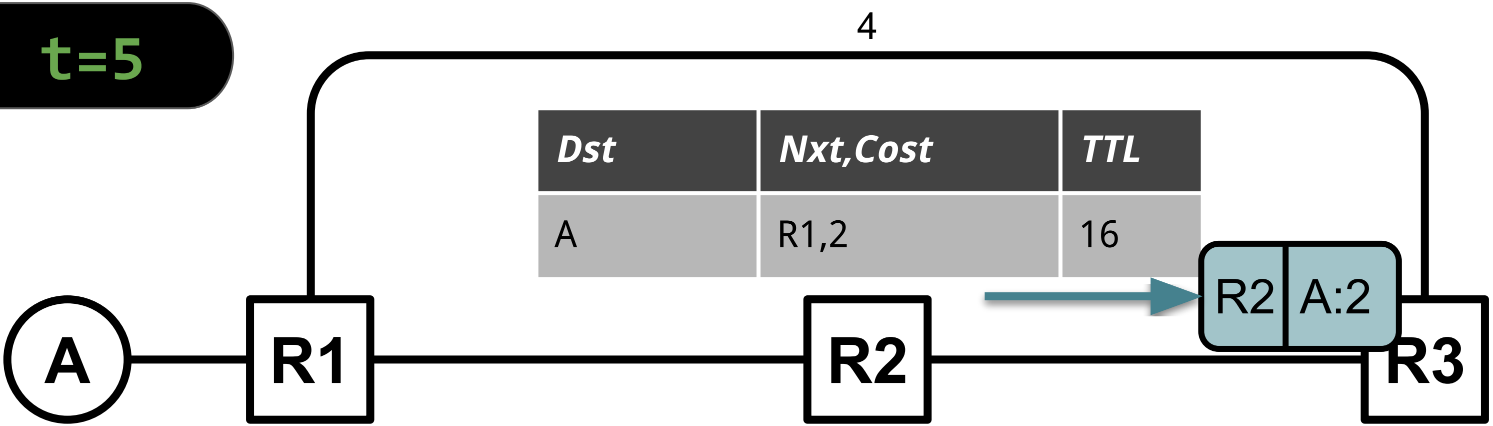
Dst	Nxt,Cost	TTL
A	R1,2	16

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R1,5	16

D-V: Failures

t=5

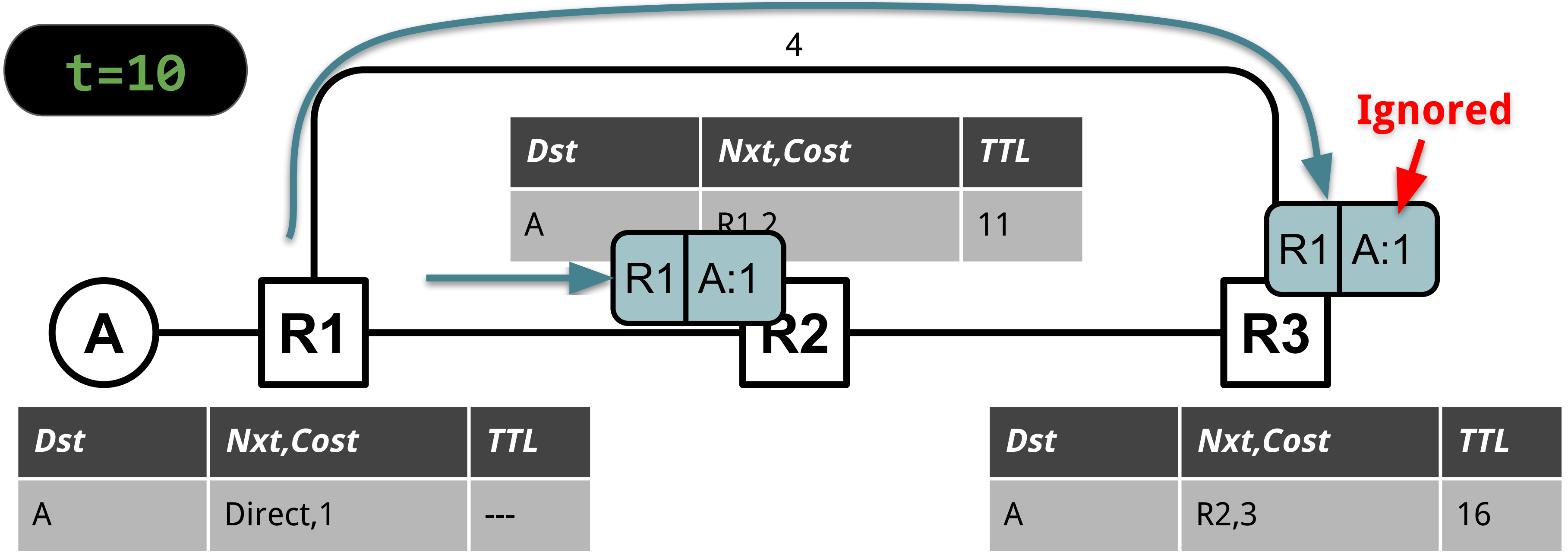


Dst	Nxt,Cost	TTL
A	R1,2	16

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	~~R1,5~~ R2,3	~~16~~ 21

D-V: Failures

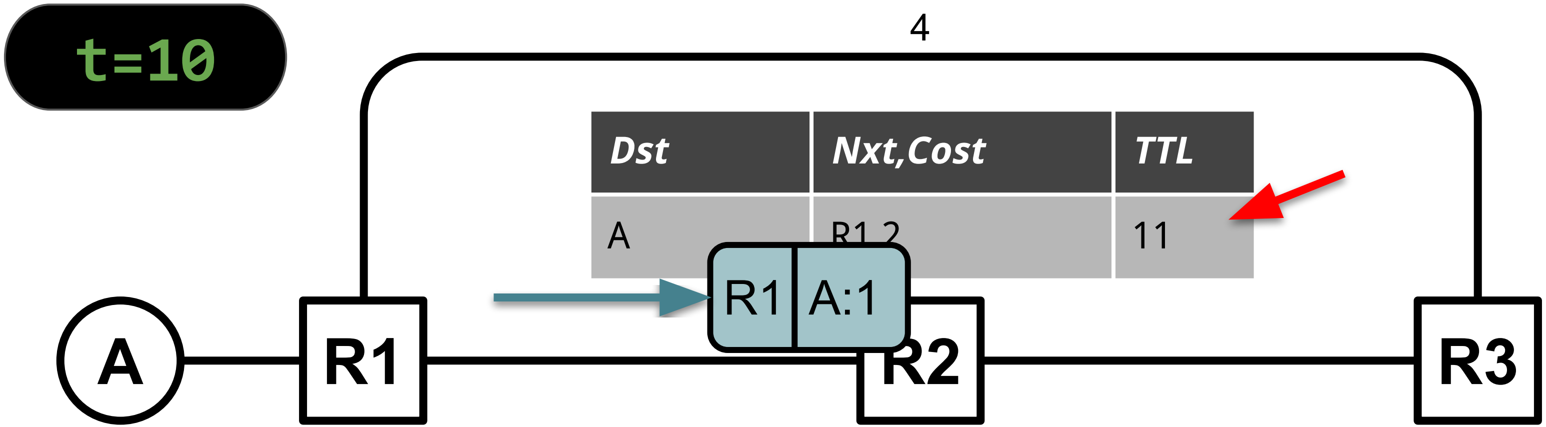


Dst	Nxt,Cost	TTL
A	R1,2	11

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures



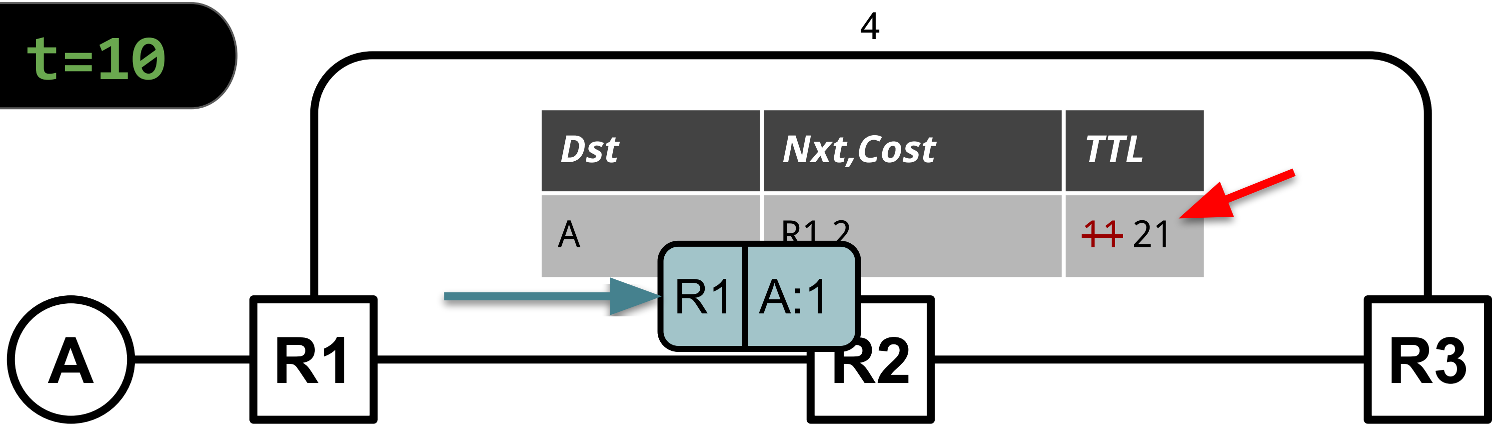
Dst	Nxt,Cost	TTL
A	R1,2	11

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures

t=10



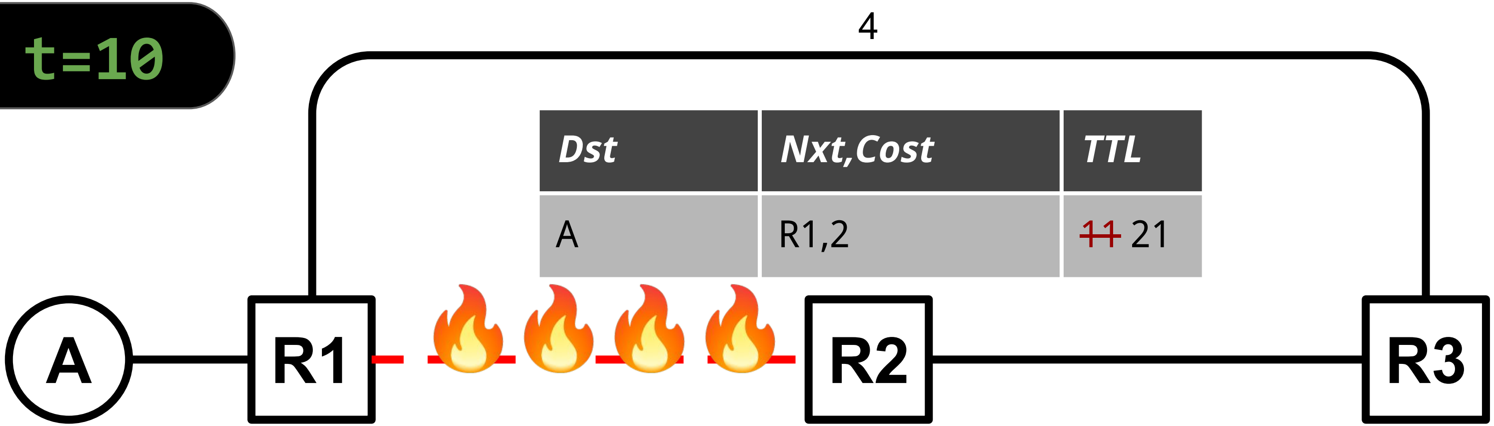
Dst	Nxt,Cost	TTL
A	R1,2	~~11~~ 21

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures

t=10



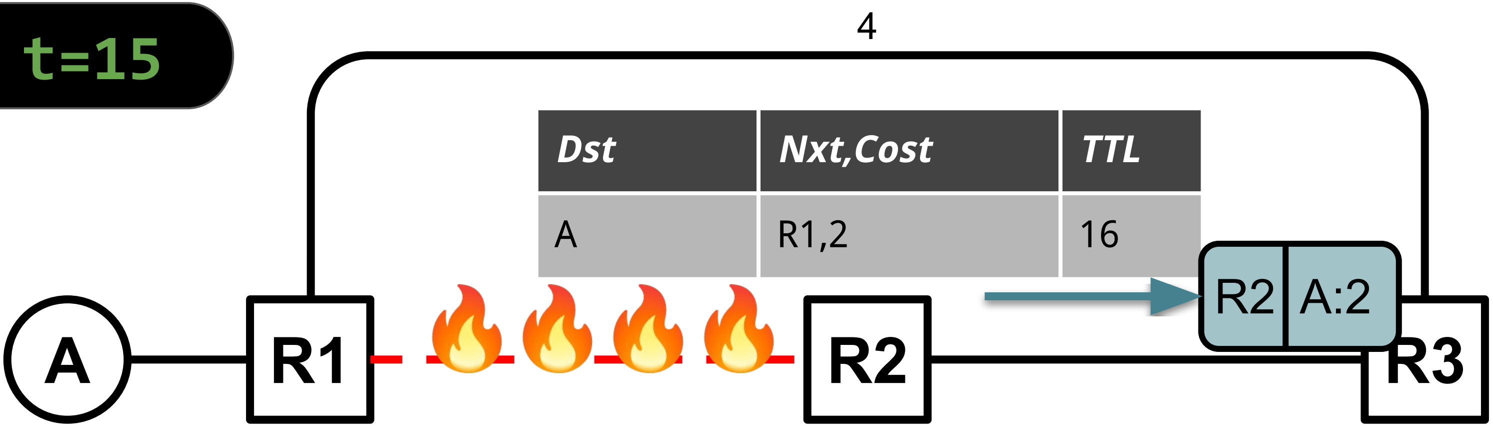
Dst	Nxt,Cost	TTL
A	R1,2	~~11~~ 21

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures

t=15

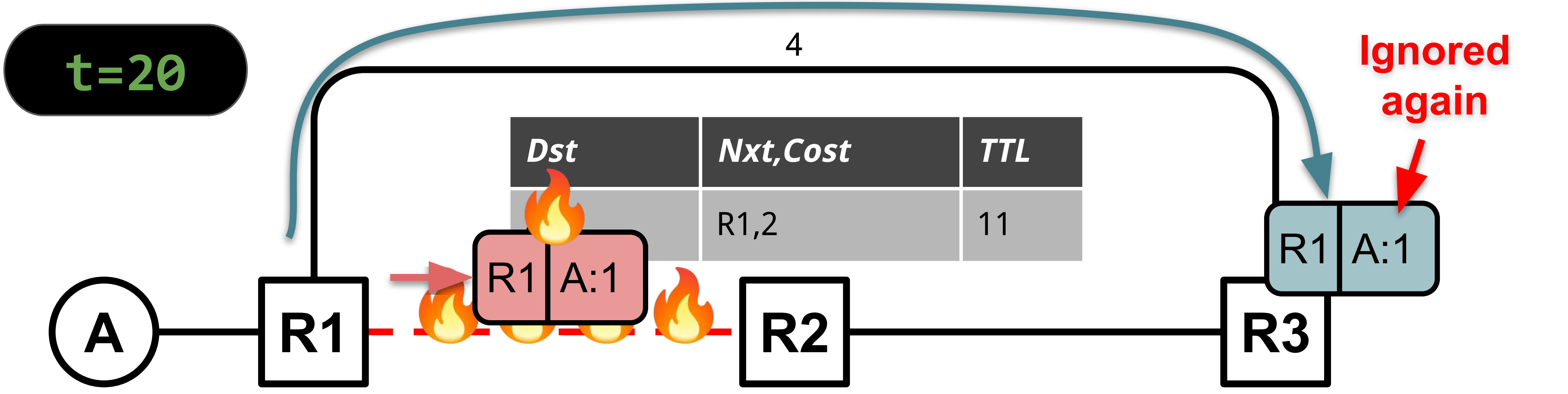


Dst	Nxt,Cost	TTL
A	R1,2	16

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	~~11~~ 21

D-V: Failures



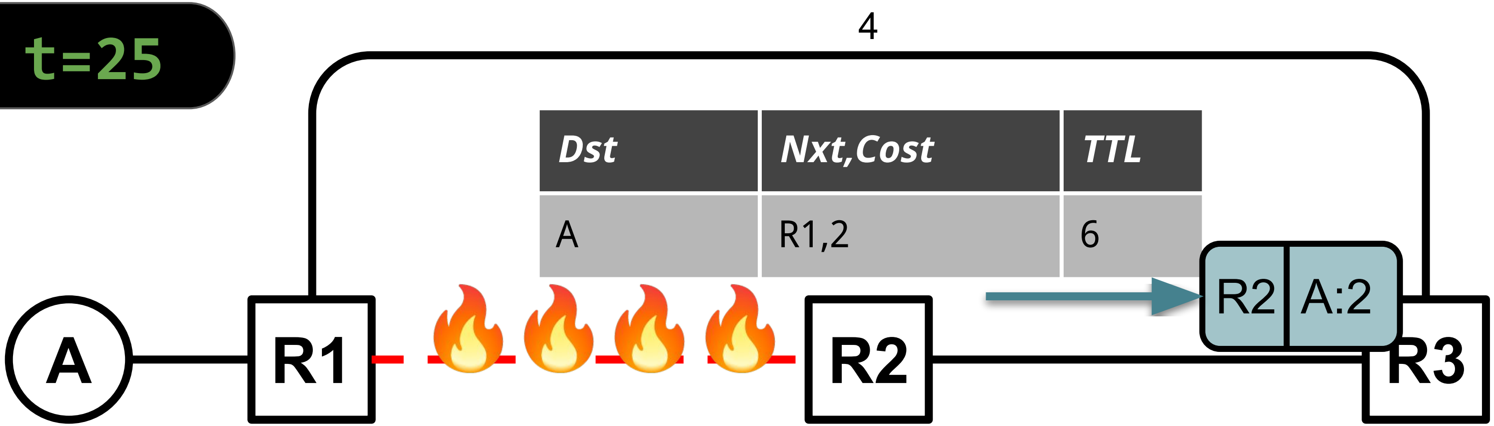
Dst	Nxt,Cost	TTL
	R1,2	11

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures

t=25

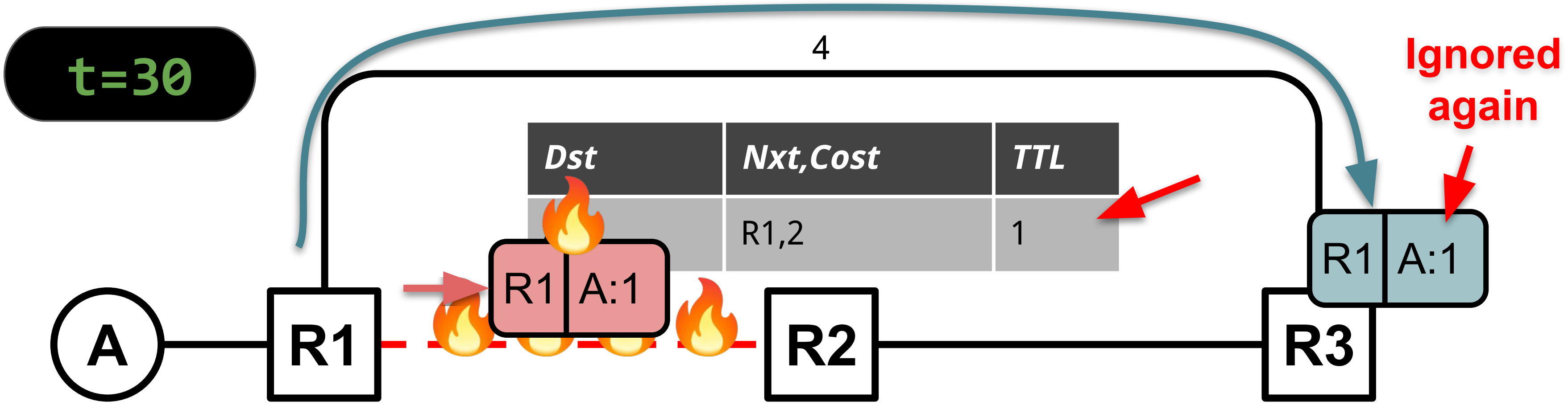


Dst	Nxt,Cost	TTL
A	R1,2	6

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	~~16~~ 21

D-V: Failures



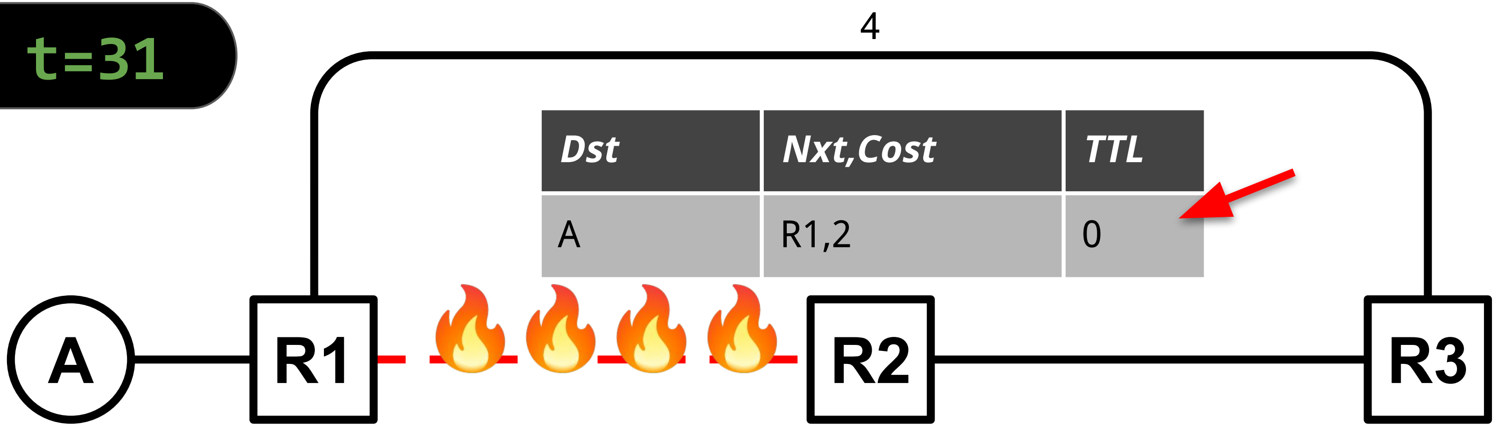
Dst	Nxt,Cost	TTL
	R1,2	1

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	16

D-V: Failures

t=31



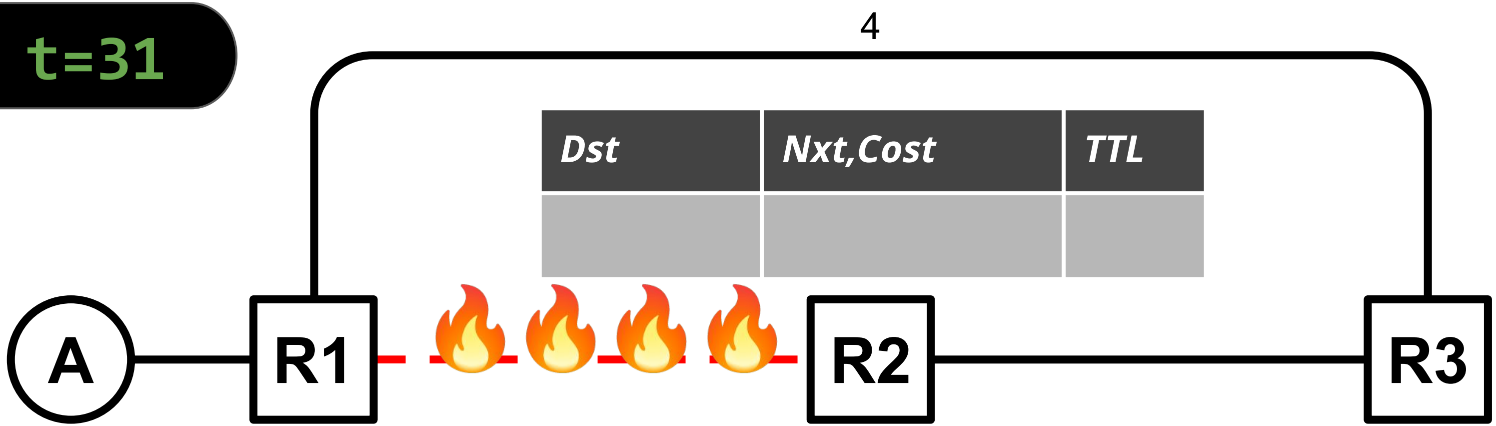
Dst	Nxt,Cost	TTL
A	R1,2	0

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Failures

t=31



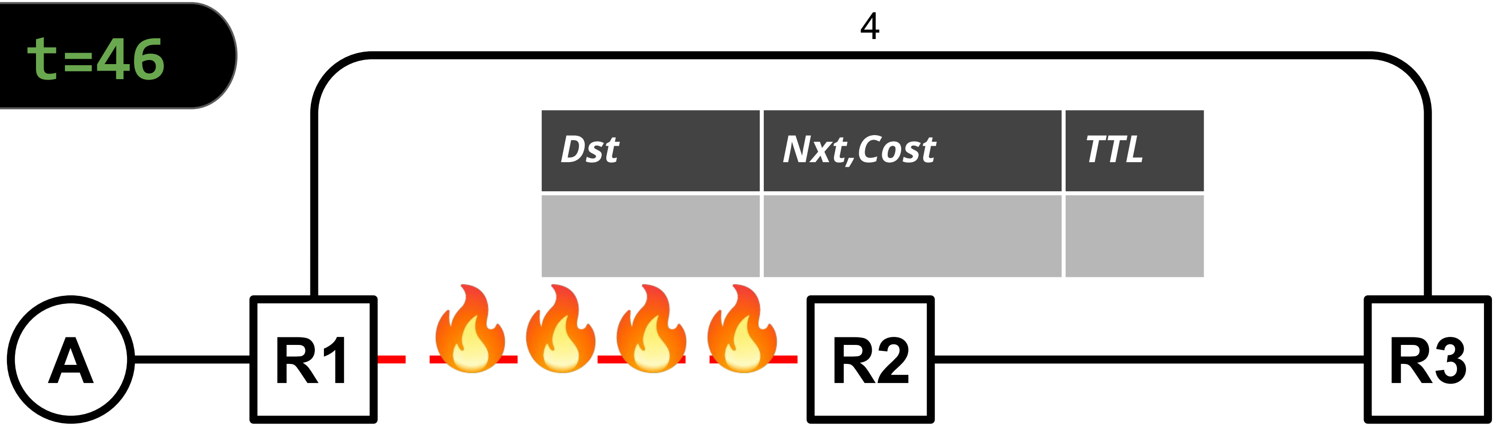
Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Failures

t=46

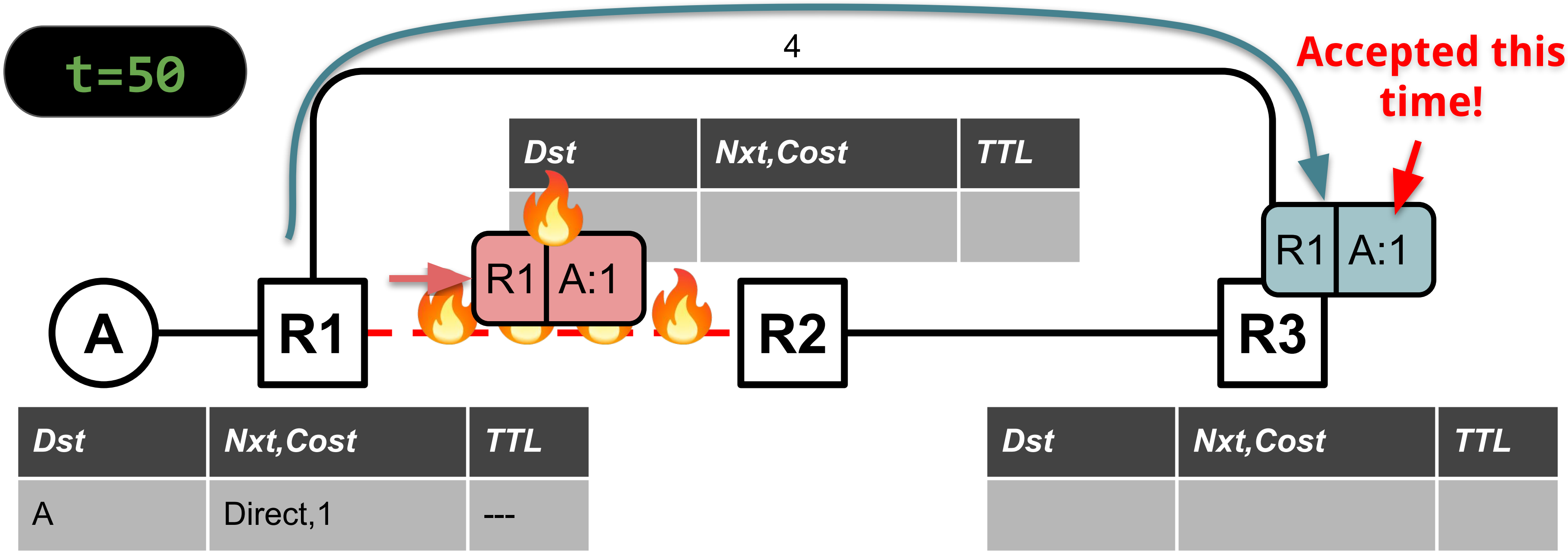


Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL

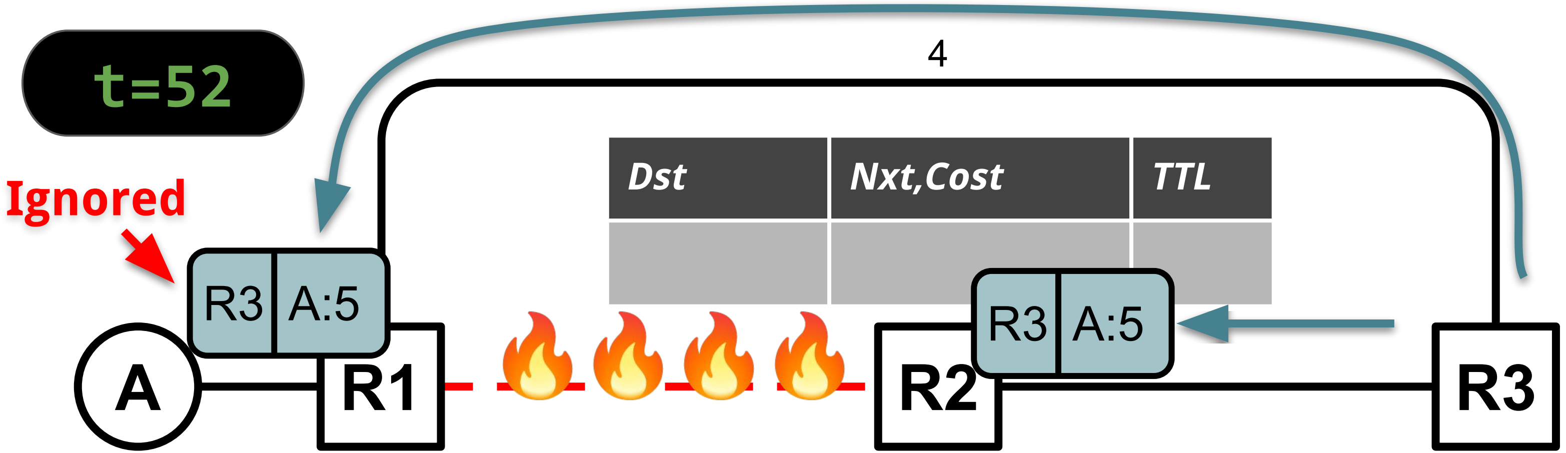
D-V: Failures


t=50
4
Accepted this time!
Dst
Nxt,Cost
TTL
R1
A:1
R1
A:1
A
R1
R2
R3
Dst
Nxt,Cost
TTL
A
Direct,1

Dst
Nxt,Cost
TTL

D-V: Failures

t=52



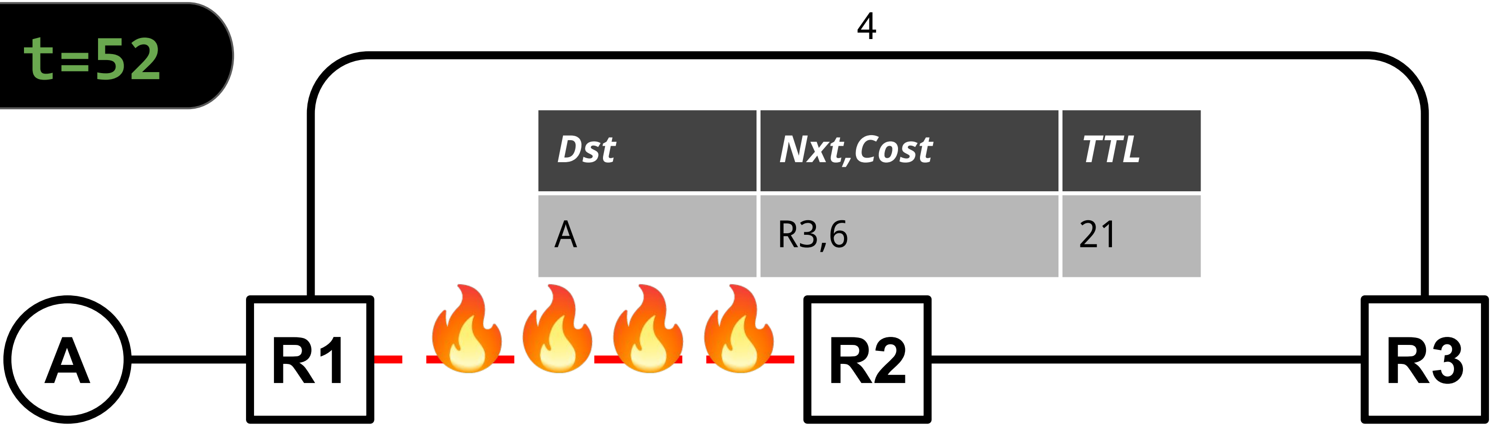
Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R1,5	19

D-V: Failures

t=52



Dst	Nxt,Cost	TTL
A	R3,6	21

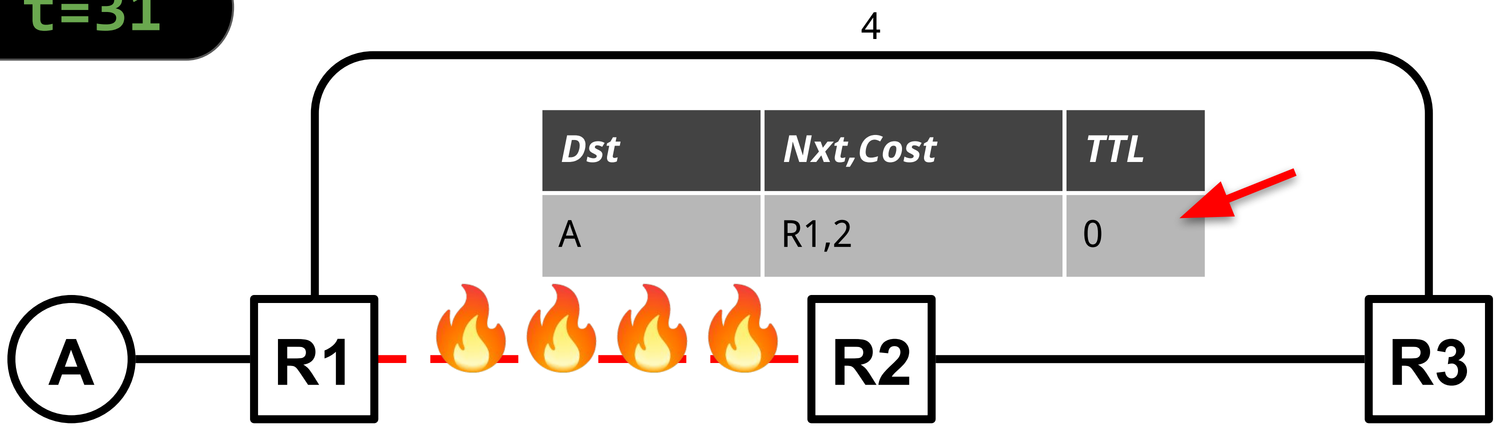
Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R1,5	19

Showing the absence of a route - poisoning.

D-V: Poisoning

t=31



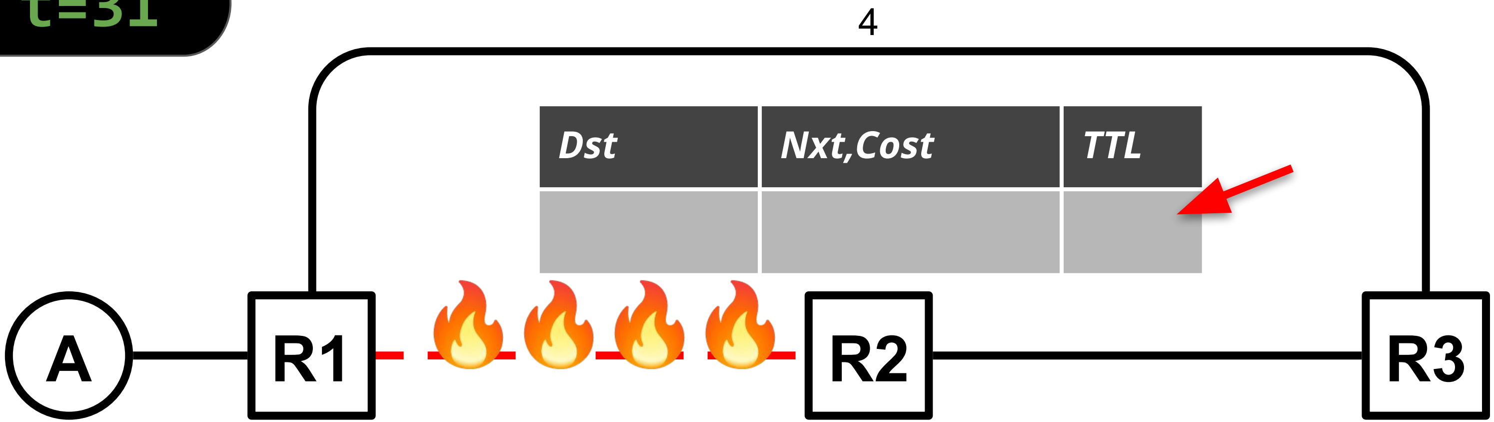
Dst	Nxt,Cost	TTL
A	R1,2	0

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Poisoning

t=31

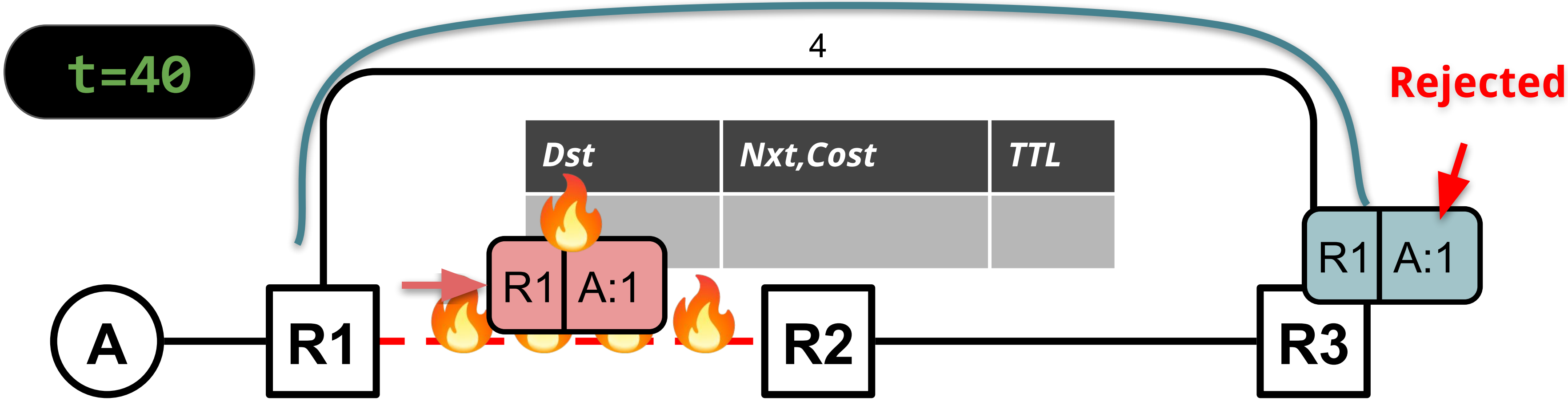


Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Poisoning

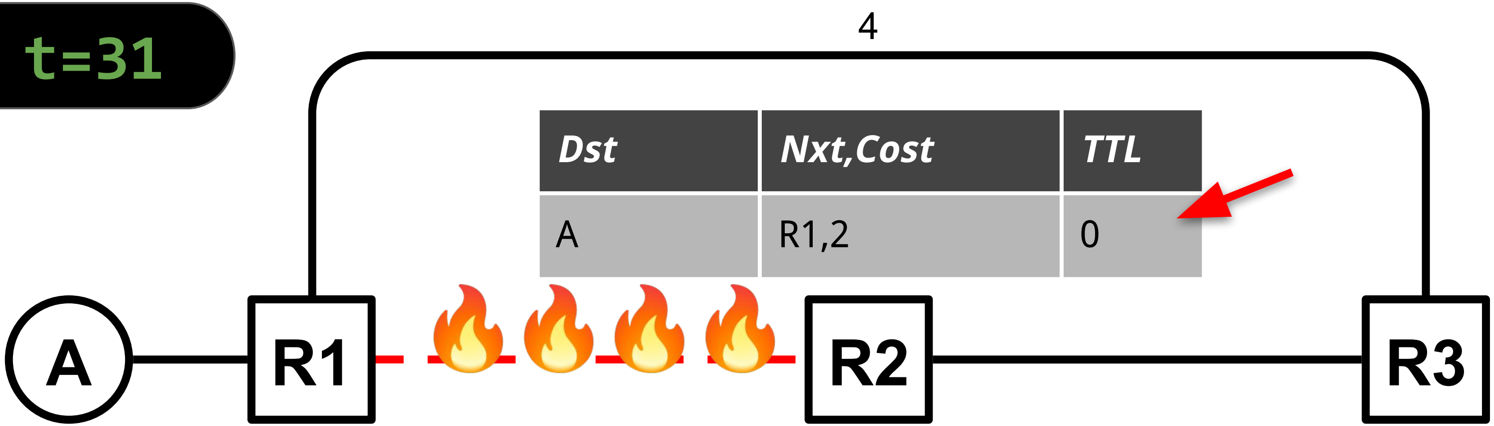


Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	6

D-V: Poisoning

t=31



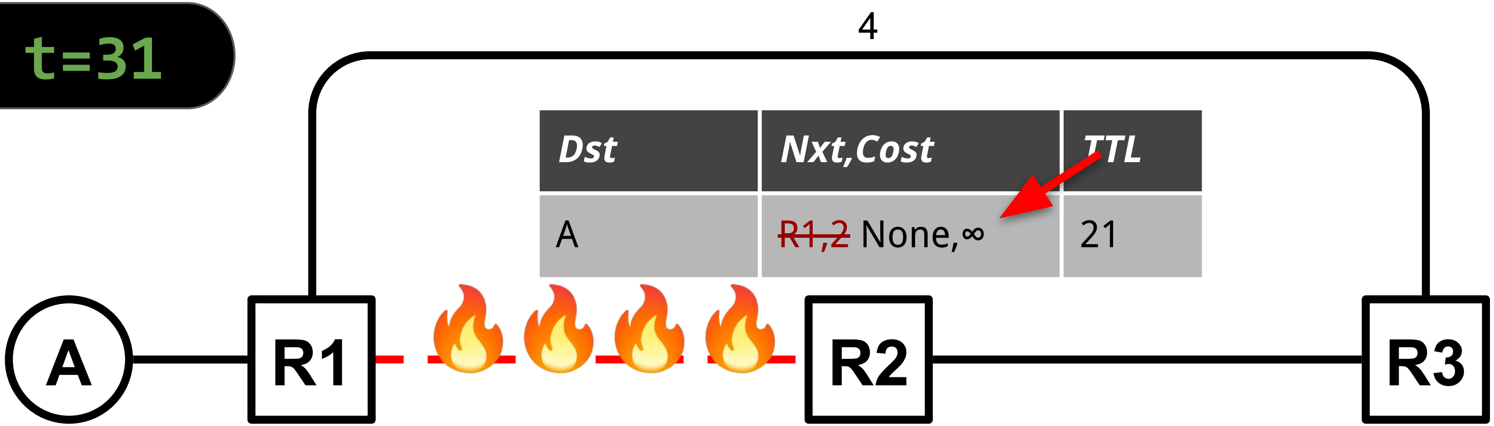
Dst	Nxt,Cost	TTL
A	R1,2	0

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Poisoning

t=31



R2:

Dst	Nxt,Cost	TTL
A	~~R1,2~~ None,∞	21

R1:

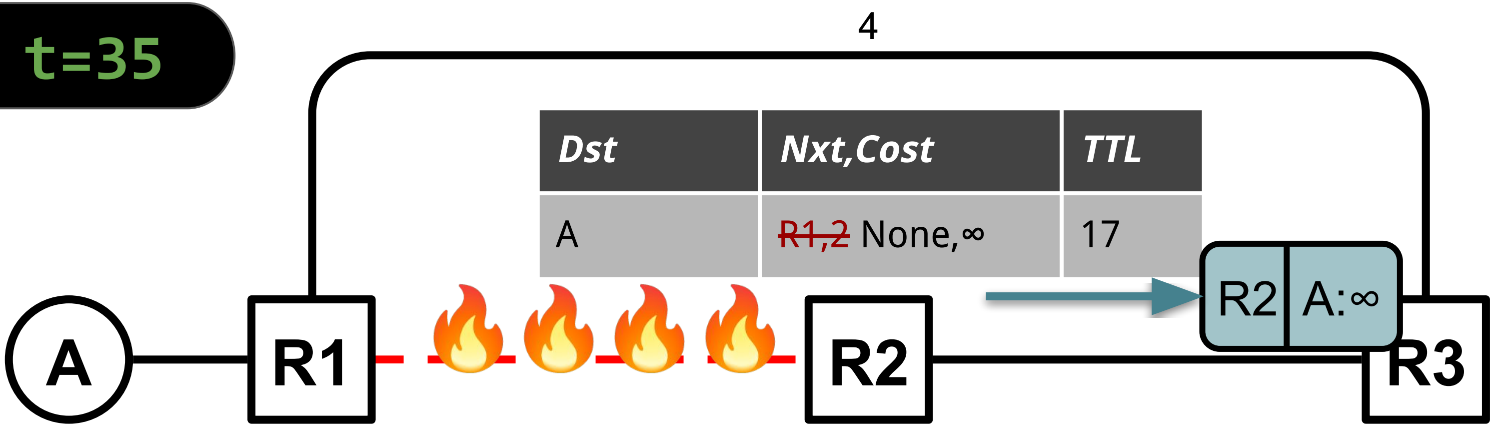
Dst	Nxt,Cost	TTL
A	Direct,1	---

R3:

Dst	Nxt,Cost	TTL
A	R2,3	15

D-V: Poisoning

t=35



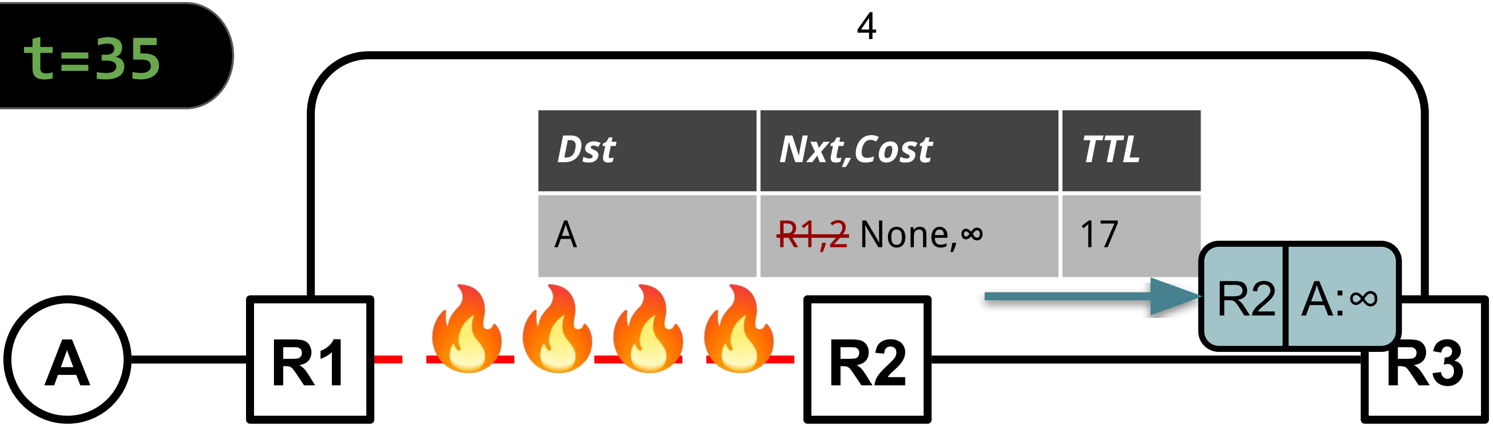
Dst	*Nxt,Cost*	*TTL*
A	~~R1,2~~ None,∞	17

Dst	*Nxt,Cost*	*TTL*
A	Direct,1	---

Dst	*Nxt,Cost*	*TTL*
A	R2,3	11

D-V: Poisoning

t=35

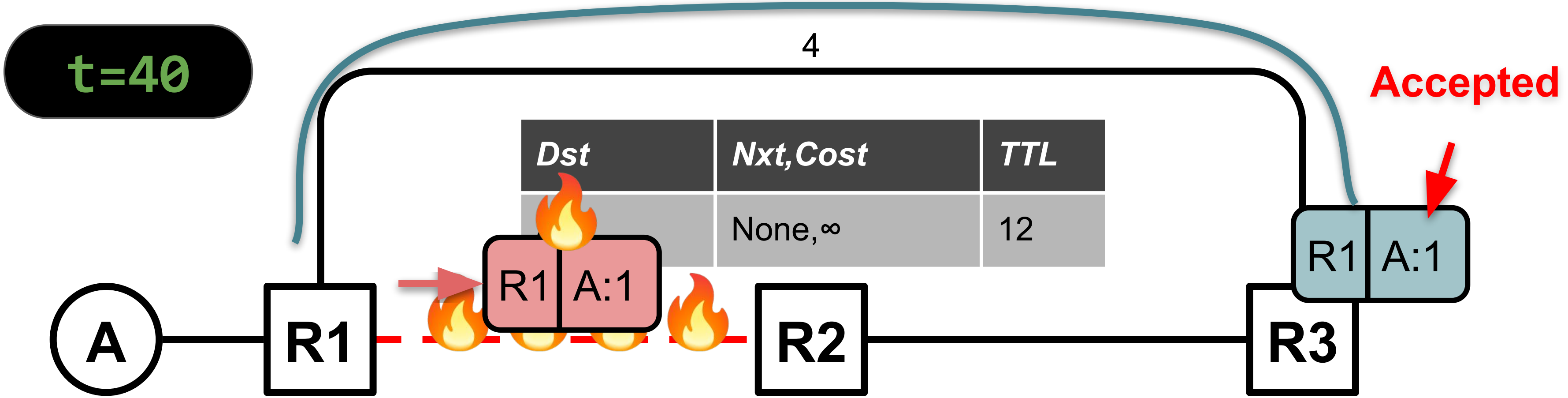


Dst	Nxt,Cost	TTL
A	~~R1,2~~ None,∞	17

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,~~3~~ ∞	21

D-V: Poisoning



Dst	Nxt,Cost	TTL
	None,∞	12

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	~~R2,∞~~ R1,5	~~16~~ 21

D-V: Poison

- Key idea:
  - Instead of just *not* advertising a route
  - .. actively advertise that you *don't* have a route

- Do this by advertising an impossibly high cost
  - A "poison" route

- This route should propagate like other routes, poisoning the entry on any other router that was using it

- Can be much faster than waiting for timeouts!

D-V: Poison

- And this doesn't just work for timed advertisements…

- If you get a poison advertisement and it changes your table…
    - Will trigger you to send poison
    - Propagates dead routes as fast as they can reach and be processed by neighbor!

- .. can be much, *much* faster than waiting for timeouts!

D-V: Poison

- Besides expired routes, where else did we *not* advertise something?

D-V: Poison

- Besides expired routes, where else did we *not* advertise something?
  - Split horizon!

- In split horizon, we had a route but chose not to advertise
  - Don’t want to advertise a route back to router that advertised it to us!
  - Can lead to sending things backwards (or even looping)

D-V: Poison

- Besides expired routes, where else did we *not* advertise something?
  - Split horizon!

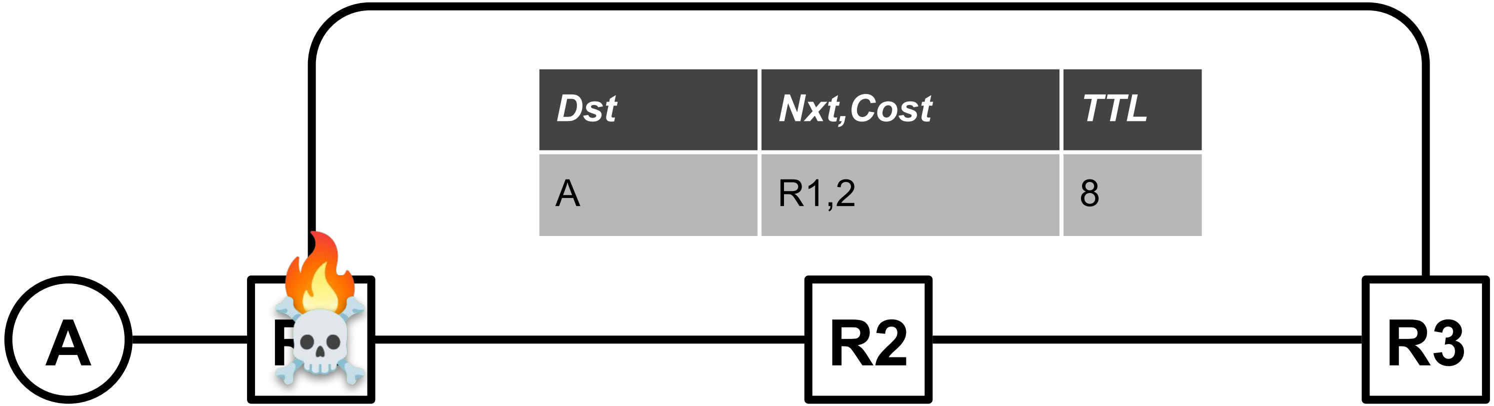
- In split horizon, we had a route but chose not to advertise
  - Don't want to advertise a route back to router that advertised it to us!
  - Can lead to sending things backwards (or even looping)

- Instead of *not* advertising in this case… *advertise infinite cost*
  - We call this *poison reverse*

  - Same exact idea as split horizon, but more aggressive

D-V: Poison Reverse

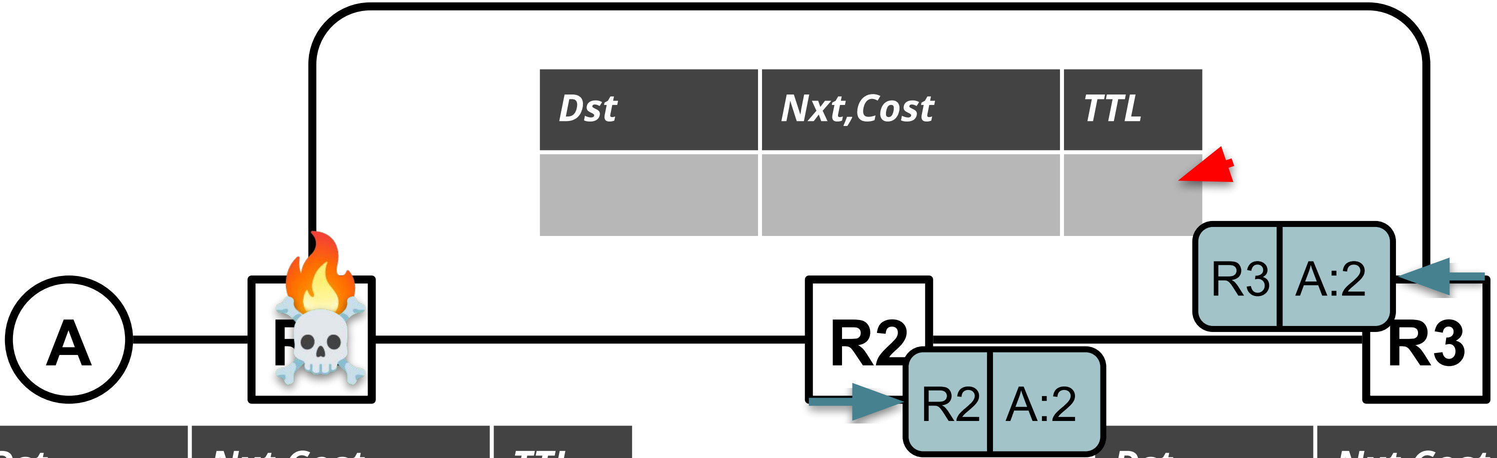
Dst	Nxt,Cost	TTL
A	R1,2	8



Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R1,2	8

D-V: Poison Reverse

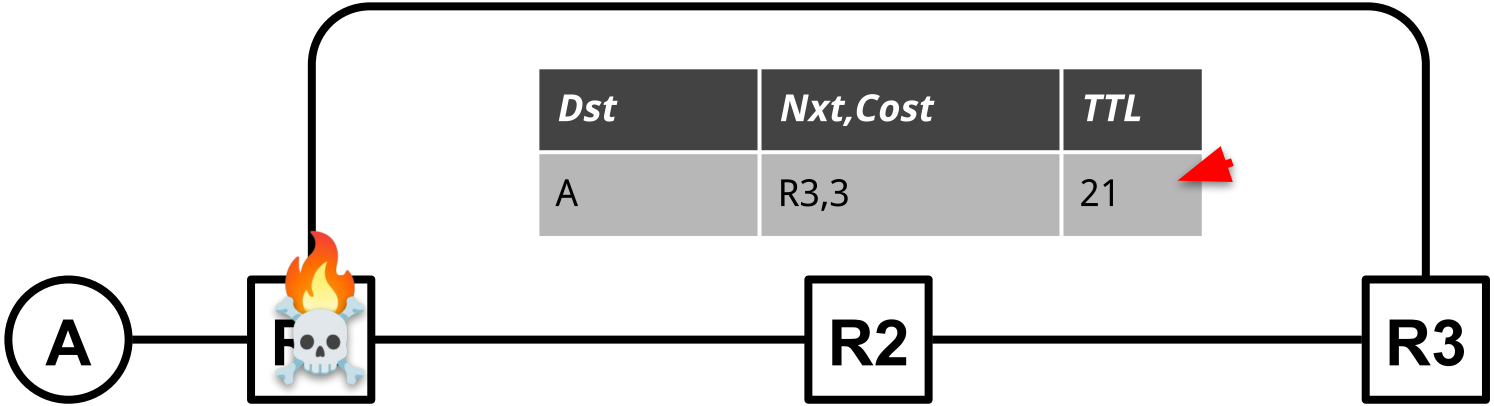


Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL

Dst	Nxt,Cost	TTL

D-V: Poison Reverse



Dst	Nxt,Cost	TTL
A	R3,3	21

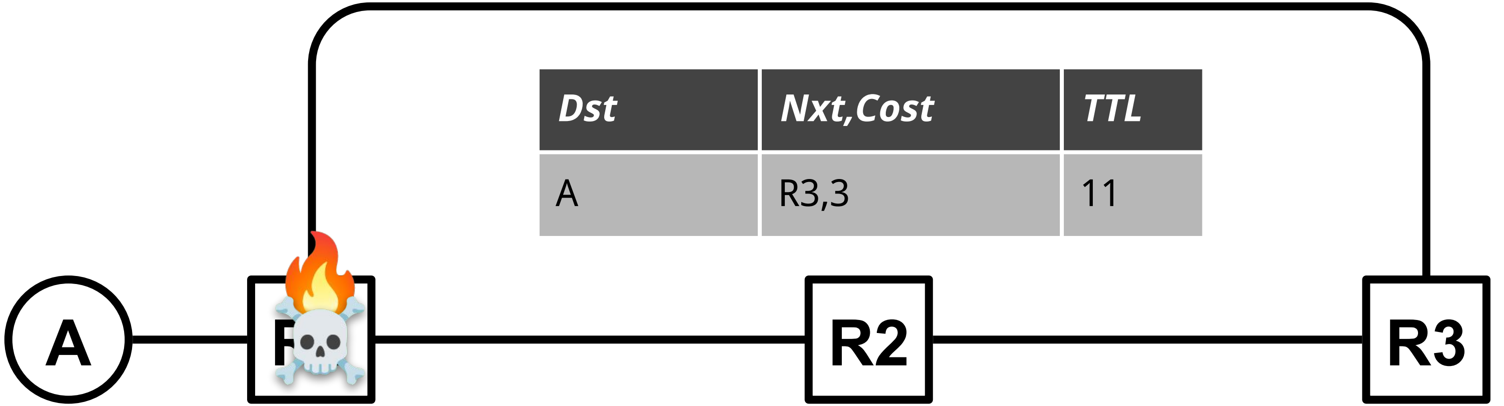
Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	21

With split horizon, loopy state exists until expiration

D-V: Poison Reverse

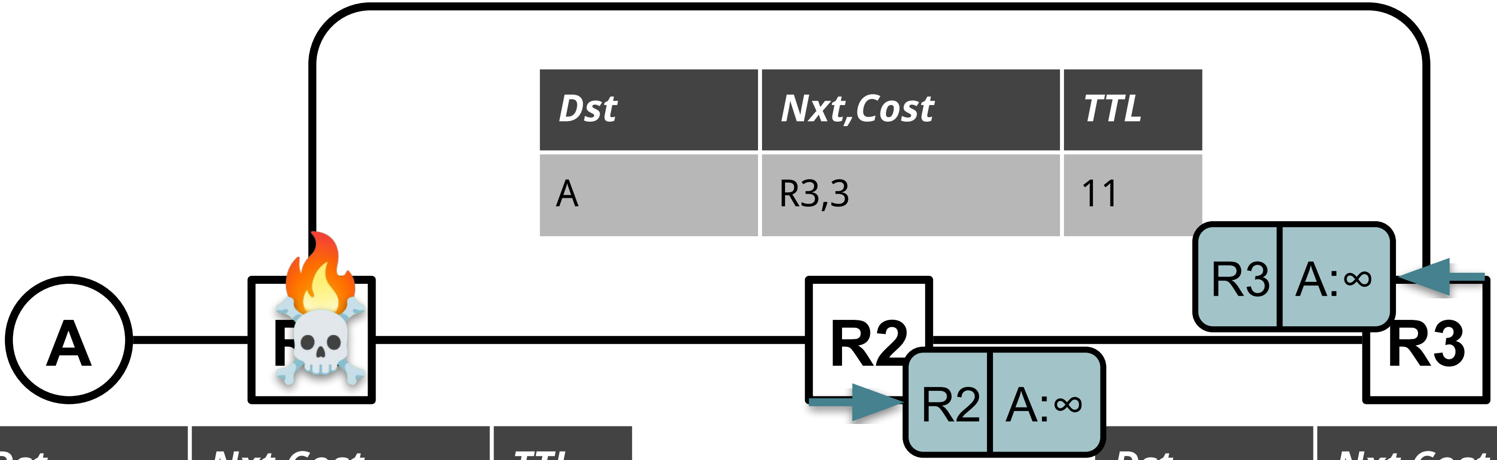
Dst	Nxt,Cost	TTL
A	R3,3	11



Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	11

D-V: Poison Reverse

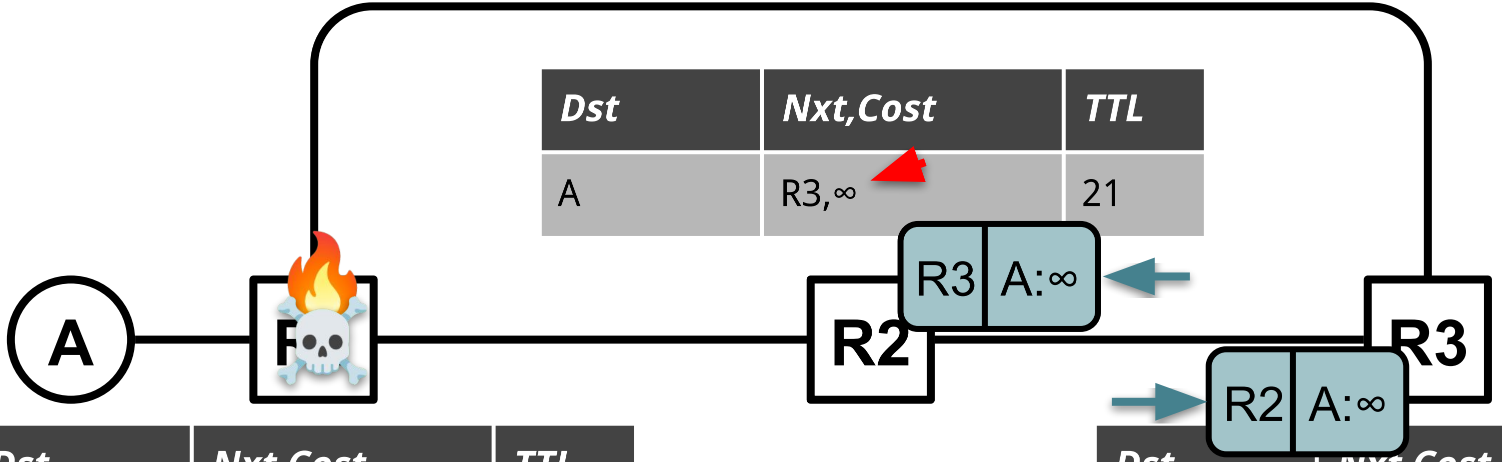


Dst	Nxt,Cost	TTL
A	R3,3	11

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,3	11

D-V: Poison Reverse



Dst	Nxt,Cost	TTL
A	R3,∞	21

Dst	Nxt,Cost	TTL
A	Direct,1	---

Dst	Nxt,Cost	TTL
A	R2,∞	21

With poison reverse, loopy state exists until next advertisement

D-V: Poison

- Poisoning and poison reverse…

- In both cases, without poisoning, you would have *not* sent a route
- Instead, *send an explicitly terrible route* (any other route will be better)
  - (And never forward using these terrible infinite-length routes.)

D-V: More triggers

- We know that our table changing should trigger us to send an update
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D-V: More triggers

- We know that our table changing should trigger us to send an update
- Can be useful to handle other events too…
- Sometimes we can detect when a link becomes available
  - Immediately send new neighbor advertisements
  - No need to wait for timer
- Sometimes we can detect when a link fails
  - Immediately poison all table entries using that link
  - .. if there are any, advertise the newly poisoned ones!

From B-F to D-V

- We refined our update rule
- We resolved some loopy problems with split horizon
- We ensured that we eventually converge instead of counting to infinity
- We made it robust to packet drops by advertising periodically
- We saw that we can adapt to new links easily
- We can identify failed links and dead routes by missing advertisements
- We can converge faster by explicitly signaling the absence of a route
- We can adapt more quickly by advertising when “triggered” by events

- This is now a pretty good routing protocol!

Next Time

- Other types of routing protocols - *Link State.*
- Thus far - addressing has been an abstract concept.
- How do we address hosts on the Internet?
  - IPv4, IPv6.
- How do we avoid the need to advertise every single host in routing protocols?