6.1800 Spring 2024

Lecture #9: Routing

distance-vector, link-state, and how they scale

Katrina LaCurts | lacurts@mit.edu | 6.1800 2024

6.1800 in the news

Red Sea cables have been damaged, disrupting internet traffic

By Hanna Ziady, CNN
3 minute read · Updated 9:02 AM EST, Mon March 4, 2024

London (CNN) — Damage to submarine cables in the Red Sea is disrupting telecommunications networks and forcing providers to reroute as much as a quarter of traffic between Asia, Europe and the Middle East, including internet traffic.

HGC estimates that 25% of traffic between Asia and Europe as well the Middle East has been impacted, it said in a statement Monday.

Most large telecoms companies rely on multiple undersea cable systems, allowing them to reroute traffic in the event of an outage to ensure uninterrupted service.

https://www.cnn.com/2024/03/04/business/red-sea-cables-cut-internet/index.html

6.1800 in the news

when cables are damaged, the Internet has to **reroute** traffic

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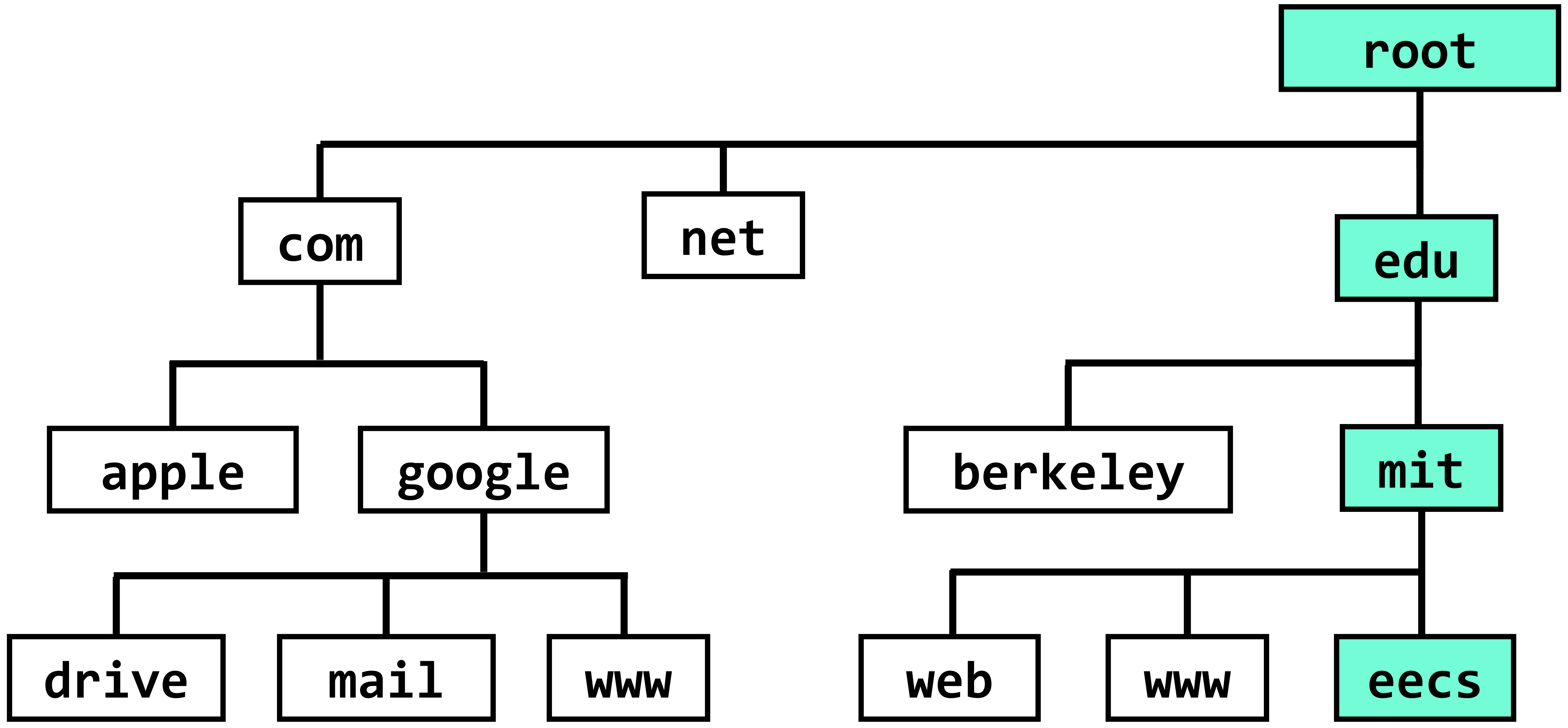
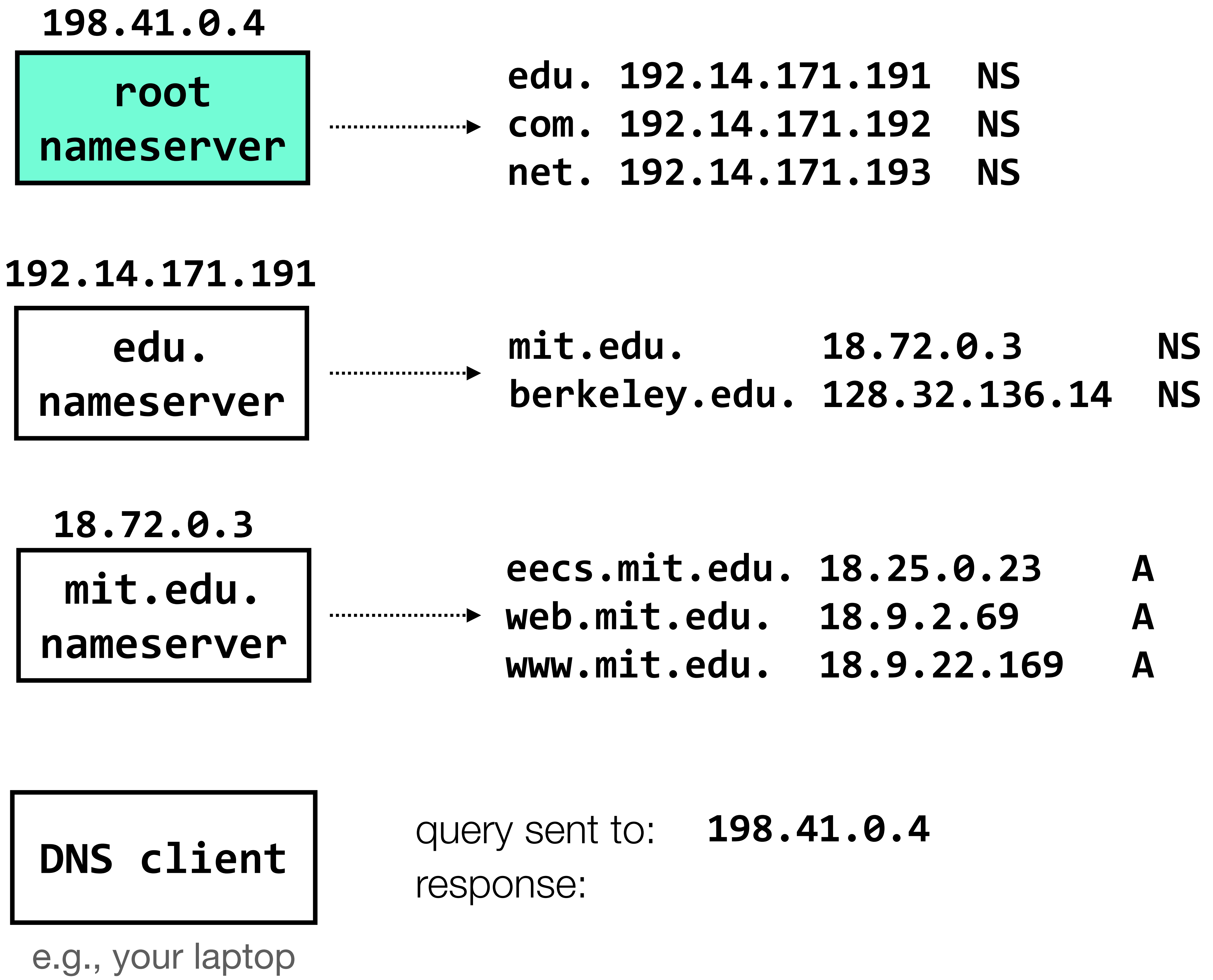
6.1800 in the past

the **domain name system (DNS)**, which maps **hostnames** (eecs.mit.edu) to **IP addresses** (18.25.0.23)



a partial view of the DNS hierarchy. each box represents a **zone**. name servers within a zone keep track of that zone's mappings



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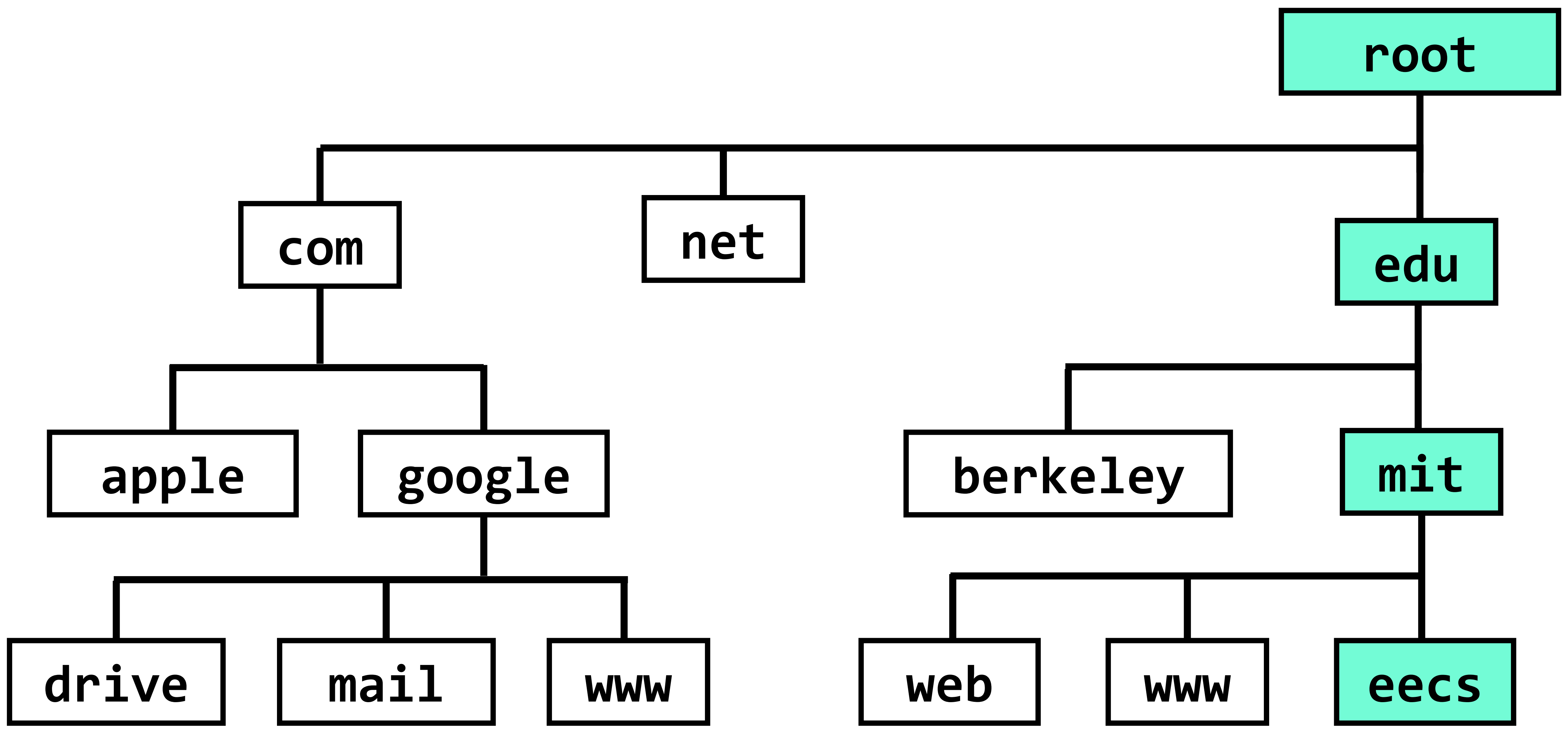

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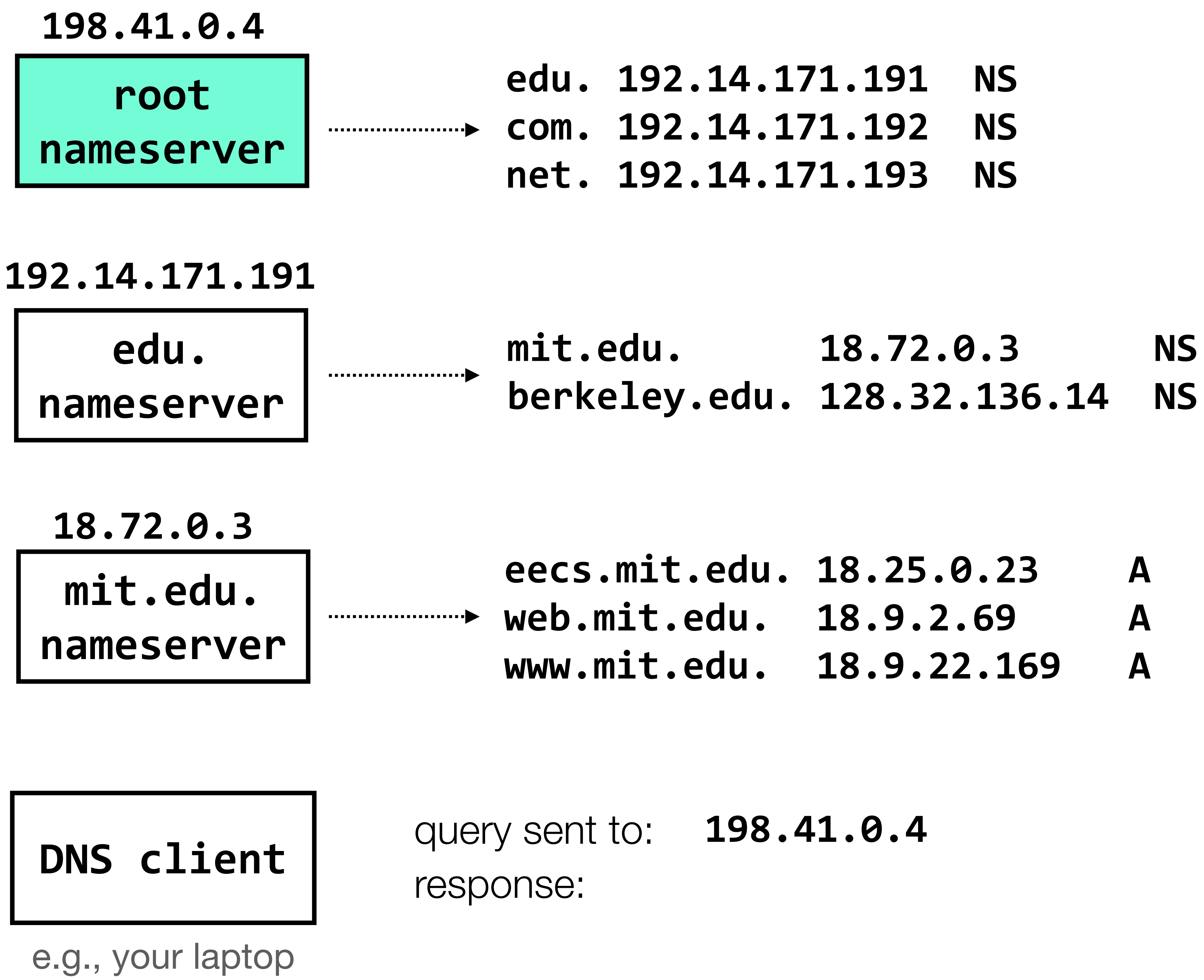
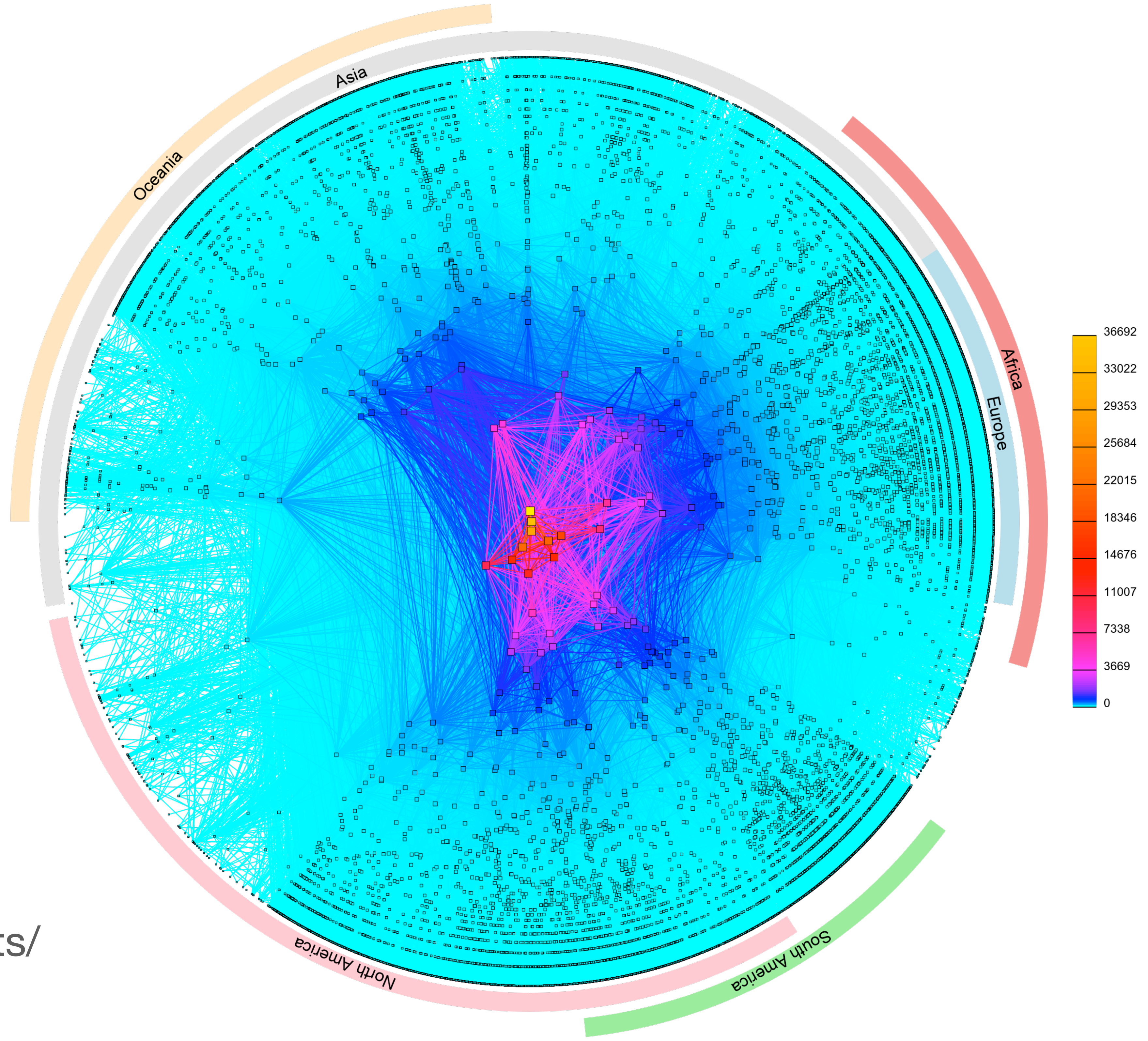


how does the DNS client's query *get* to 198.41.0.4?

1970s: ARPAnet — 1978: flexibility and layering — early 80s: growth → change — late 80s: growth → problems — 1993: commercialization

hosts.txt — distance-vector routing — TCP, UDP — OSPF, EGP, DNS — congestion collapse — policy routing — CIDR



CAIDA's IPv4 AS Core, January 2020 (https://www.caida.org/projects/cartography/as-core/2020/)

on the Internet, we have to solve all of the "normal" networking problems (addressing, routing, transport) **at massive scale, while supporting a diverse group of applications and competing economic interests**

`application` — `the things that actually generate traffic`

`transport` — `sharing the network, reliability (or not)`

examples: TCP, UDP

`network` — `naming, addressing, routing`

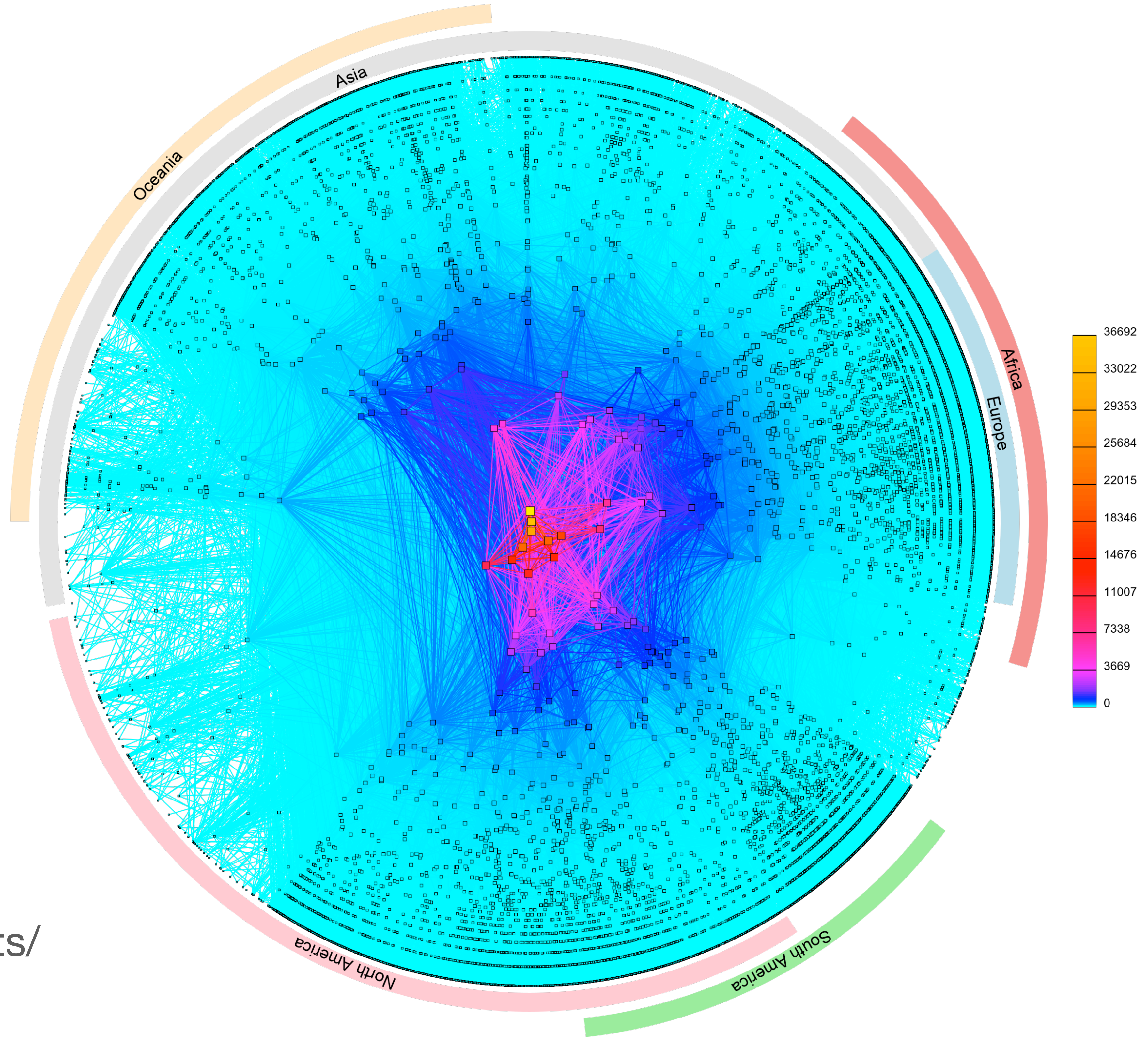
examples: IP

`link` — `communication between two directly-connected nodes`

examples: ethernet, bluetooth, 802.11 (wifi)

1970s: ARPAnet — 1978: flexibility and layering — early 80s: growth → change — late 80s: growth → problems — 1993: commercialization

hosts.txt | **distance-vector routing** | TCP, UDP | **OSPF**, EGP, DNS (a link-state routing protocol) | congestion collapse | policy routing | CIDR



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today: routing in general (not specifically on the Internet)

`application`	the things that actually generate traffic	
`transport`	sharing the network, reliability (or not)	*examples: TCP, UDP*
`network`	naming, addressing, routing	*examples: IP*
`link`	communication between two directly-connected nodes	*examples: ethernet, bluetooth, 802.11 (wifi)*

goal of a routing protocol: allow each switch to know, for every node `dst` in the network, a **minimum-cost** route to `dst`

distributed routing: nodes build up their own routing tables, rather than having tables given to them by a centralized authority

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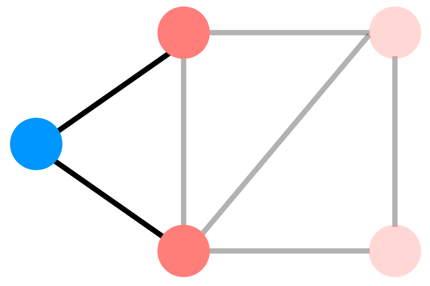
1. nodes learn about their neighbors via the `HELLO` protocol



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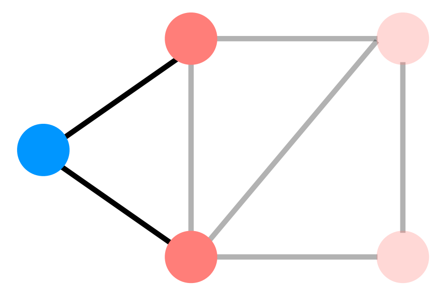
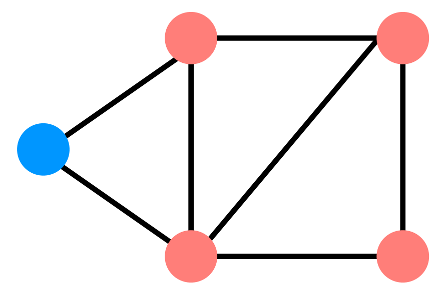


2. nodes learn about other reachable nodes via advertisements



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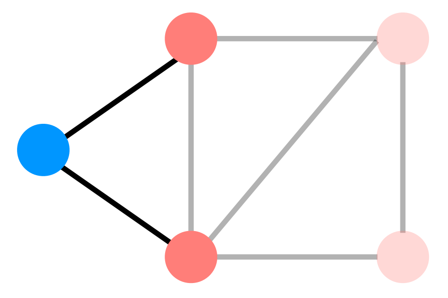

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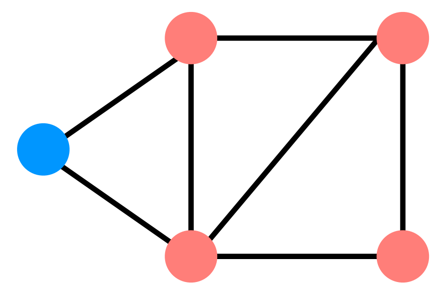
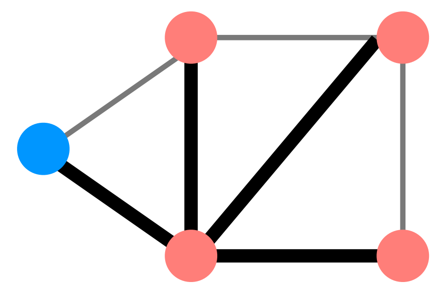


3. nodes determine the minimum-cost routes (of the routes they know about)



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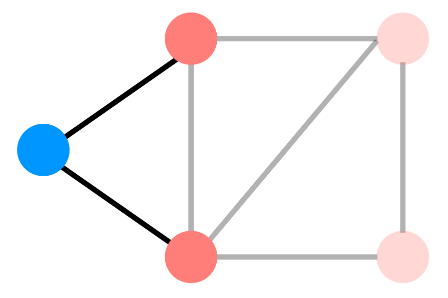

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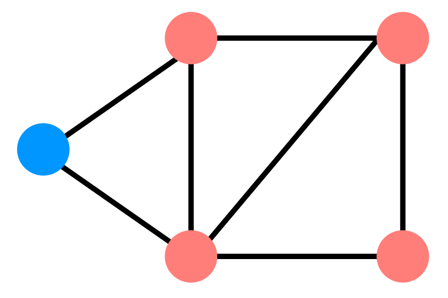

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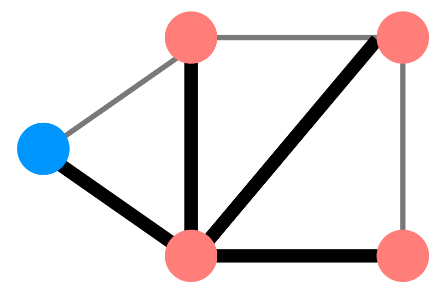

what the advertisements contain, and how the nodes use those advertisements to determine the min-cost routes, will change depending on the specific protocol

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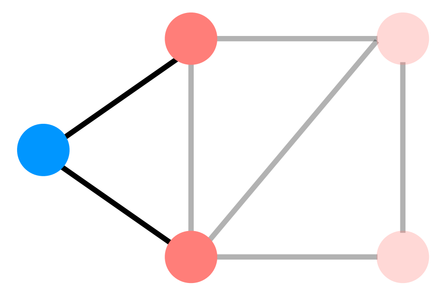

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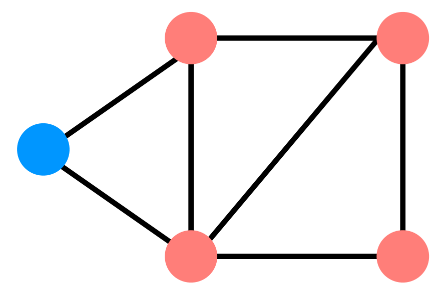
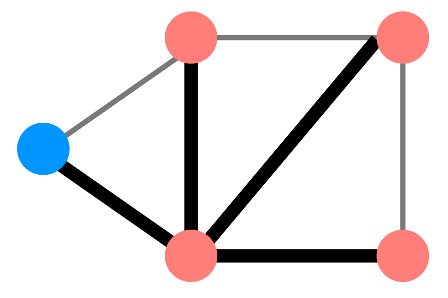
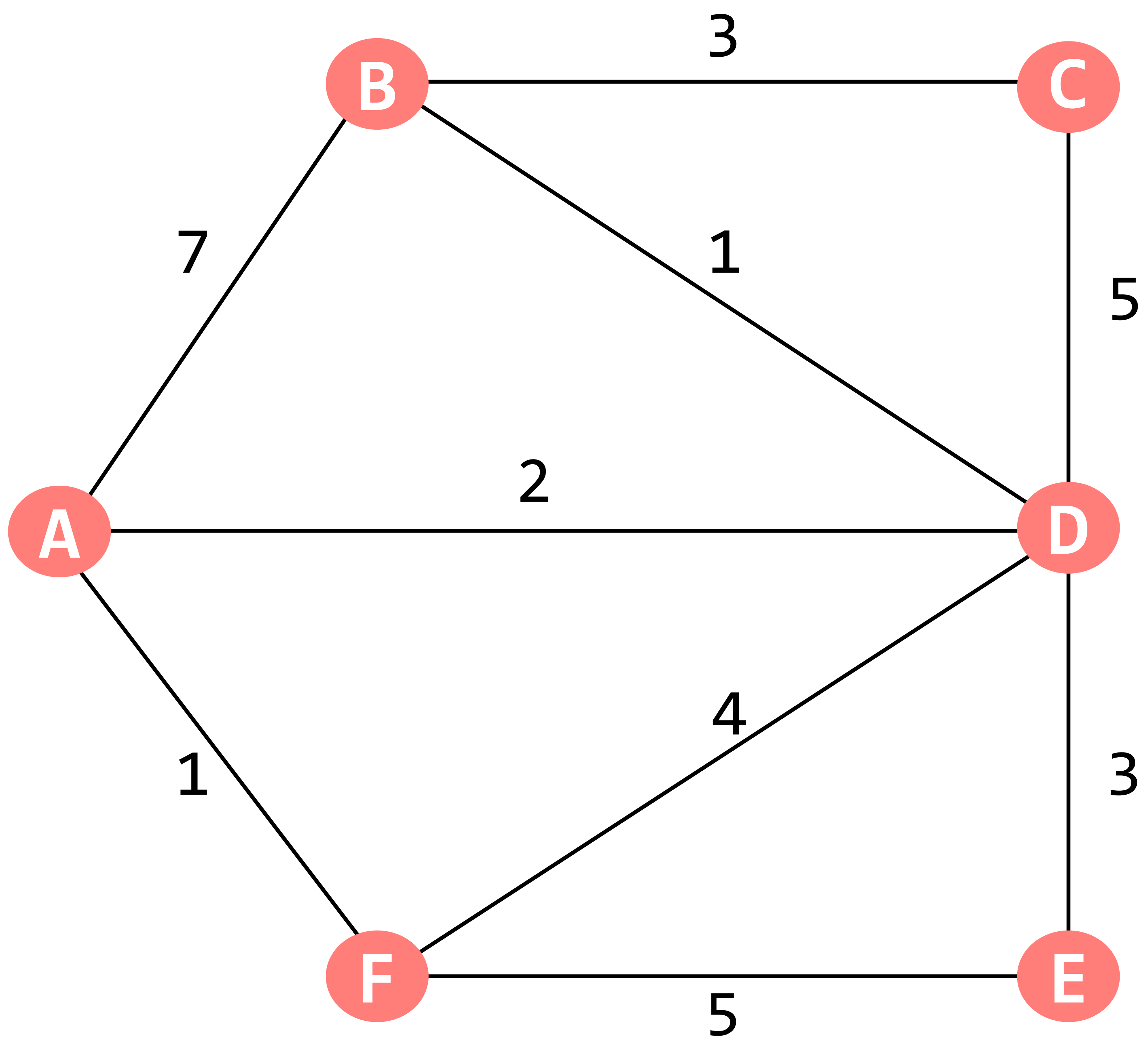


what the advertisements contain, and how the nodes use those advertisements to determine the min-cost routes, will change depending on the specific protocol

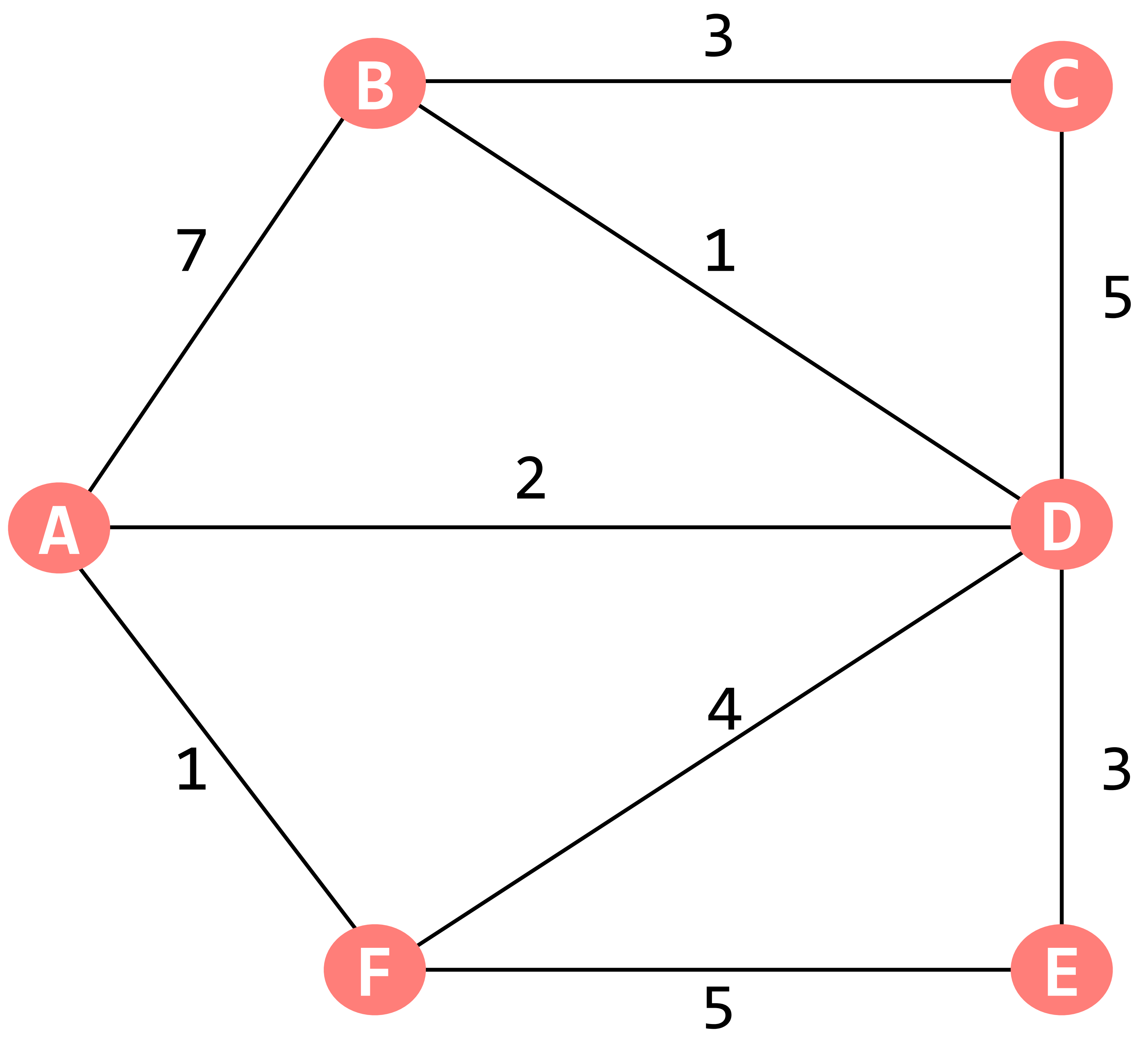
3. nodes determine the minimum-cost routes (of the routes they know about)



all of these steps happen periodically, which allows the routing protocol to detect and respond to failures, and adapt to other changes in the network

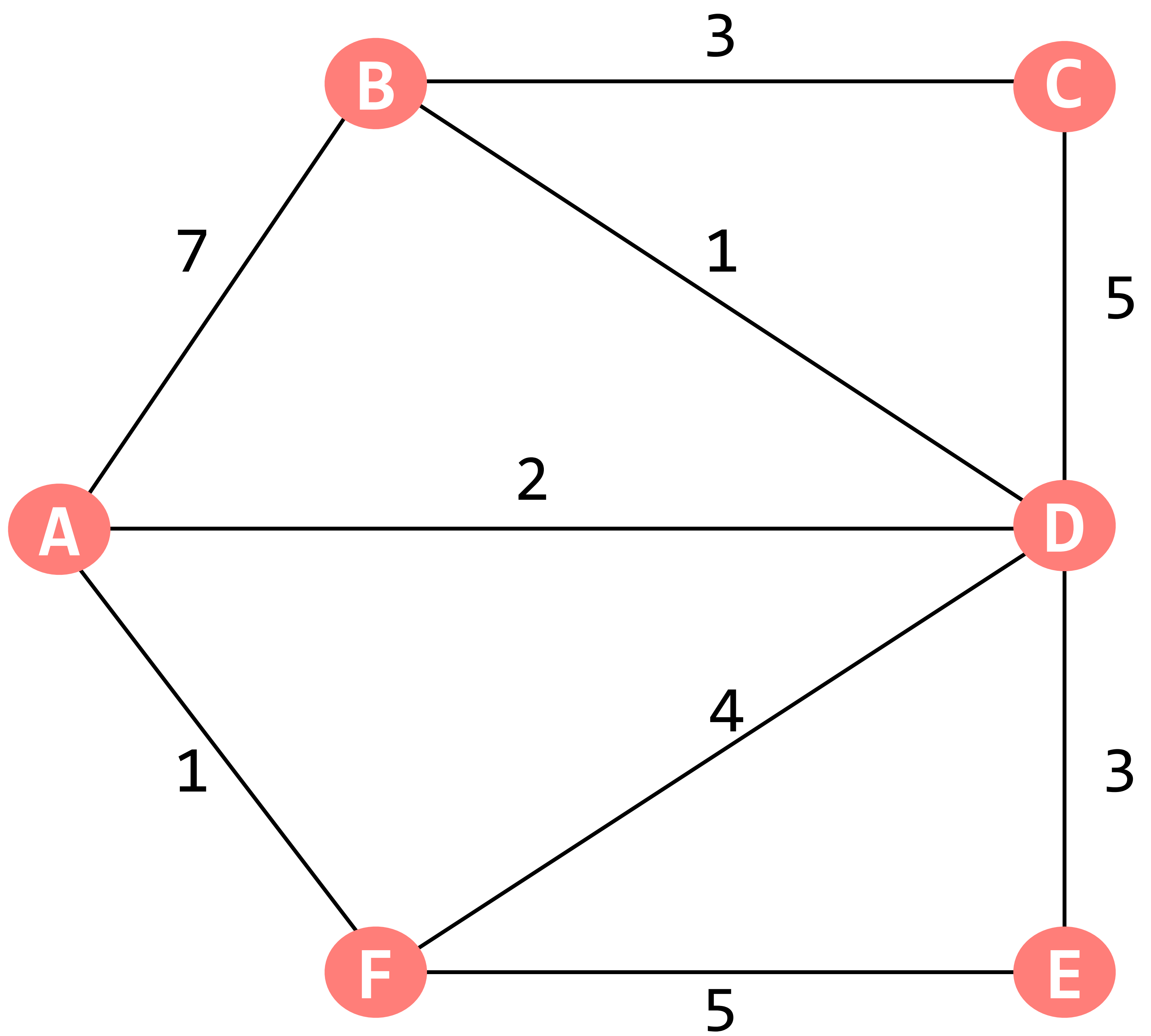


A
B
C
D
E
F
7
3
1
5
2
1
4
3
5



link state

link-state routing: disseminate full topology information so that nodes can run a shortest-path algorithm



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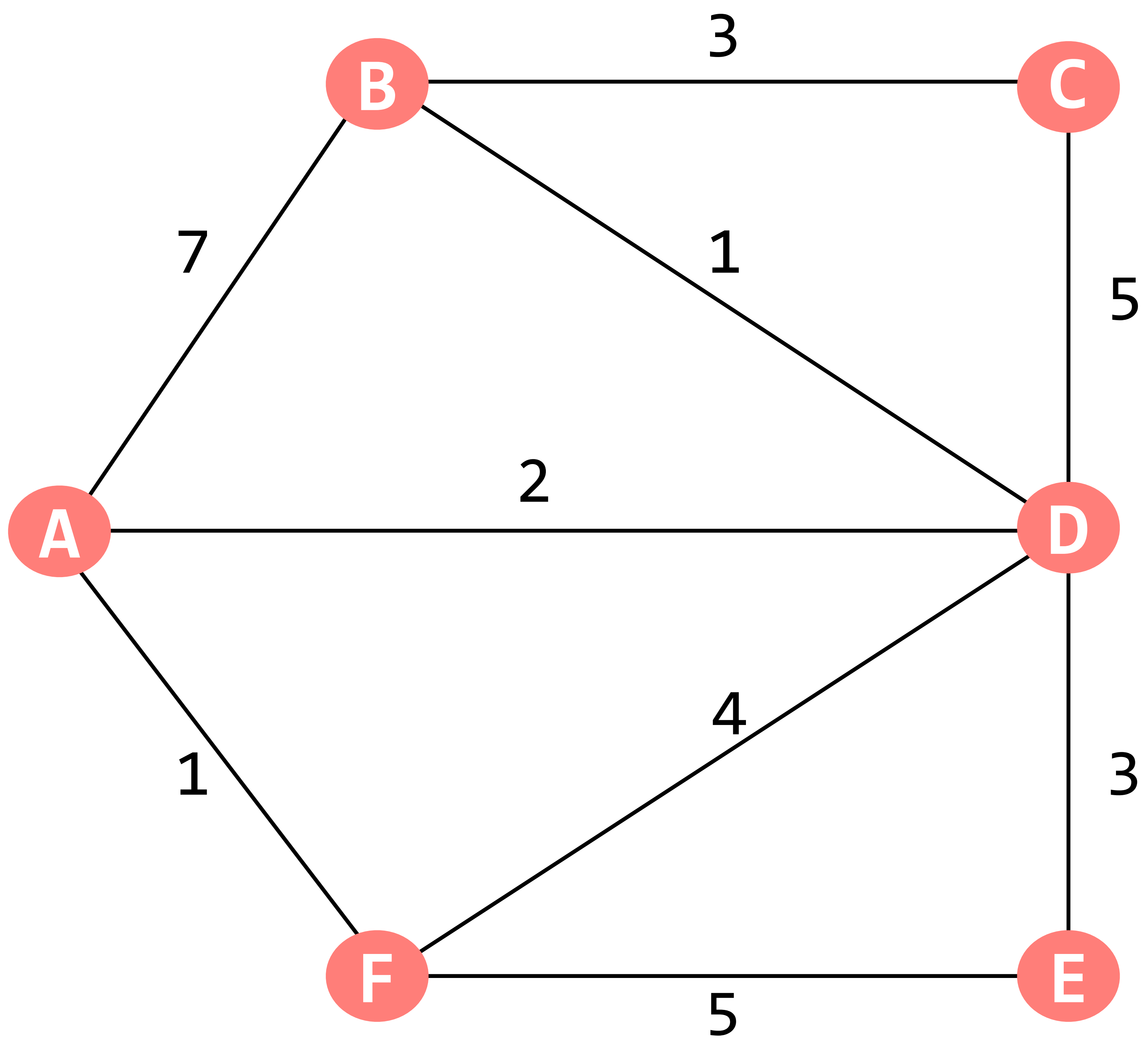

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what's in an advertisement

its **link costs** to each of its **neighbors**

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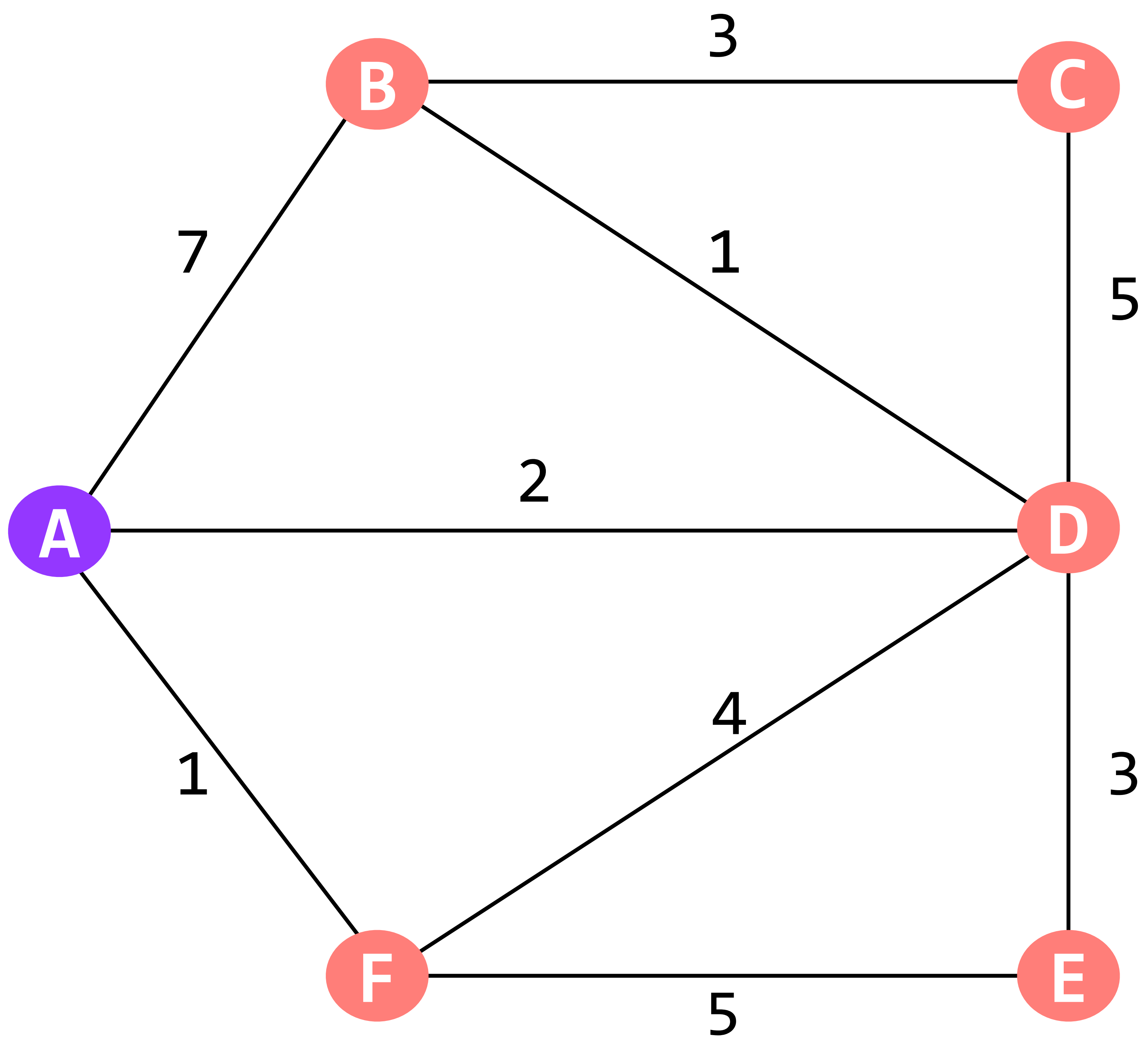

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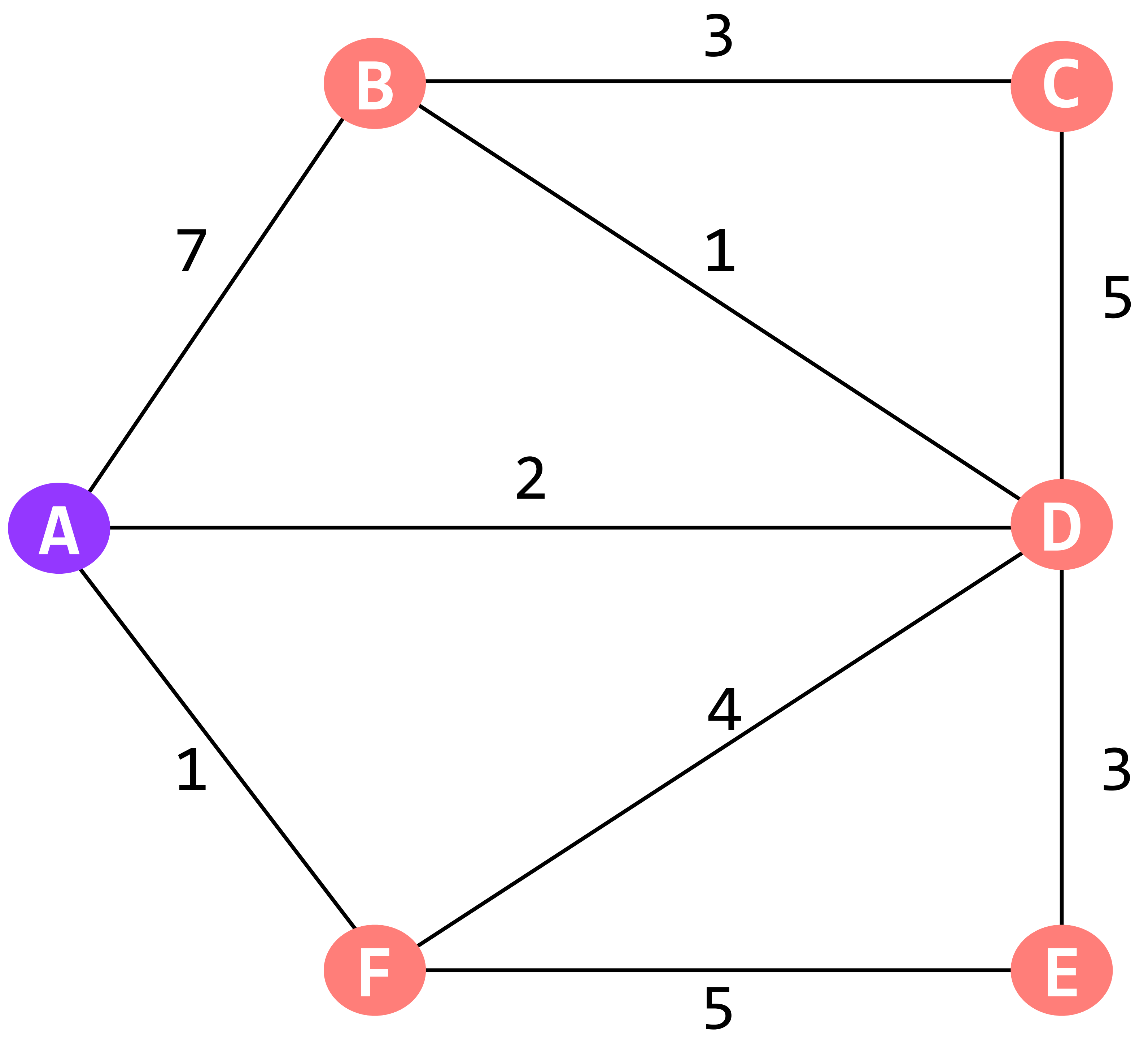

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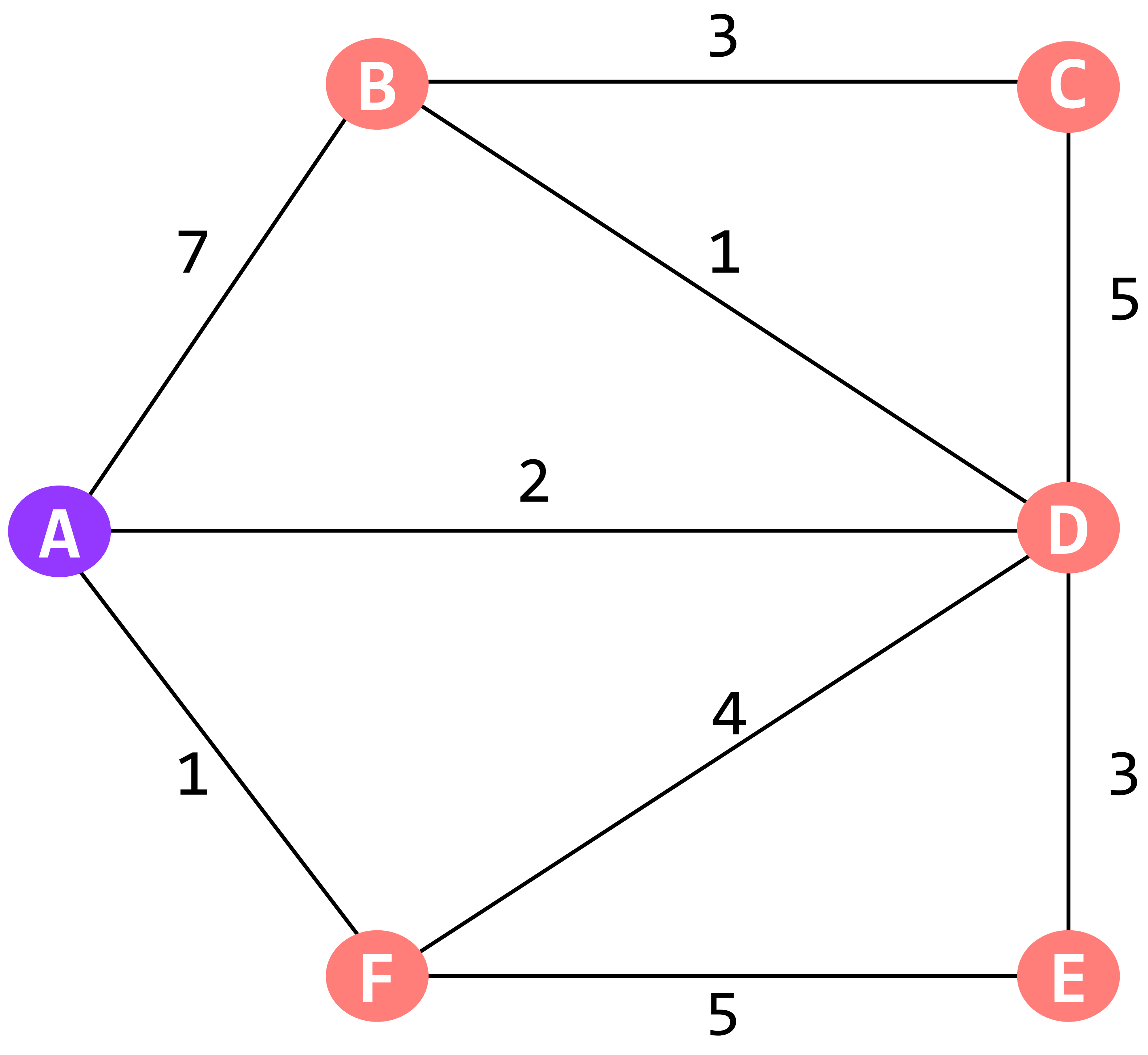

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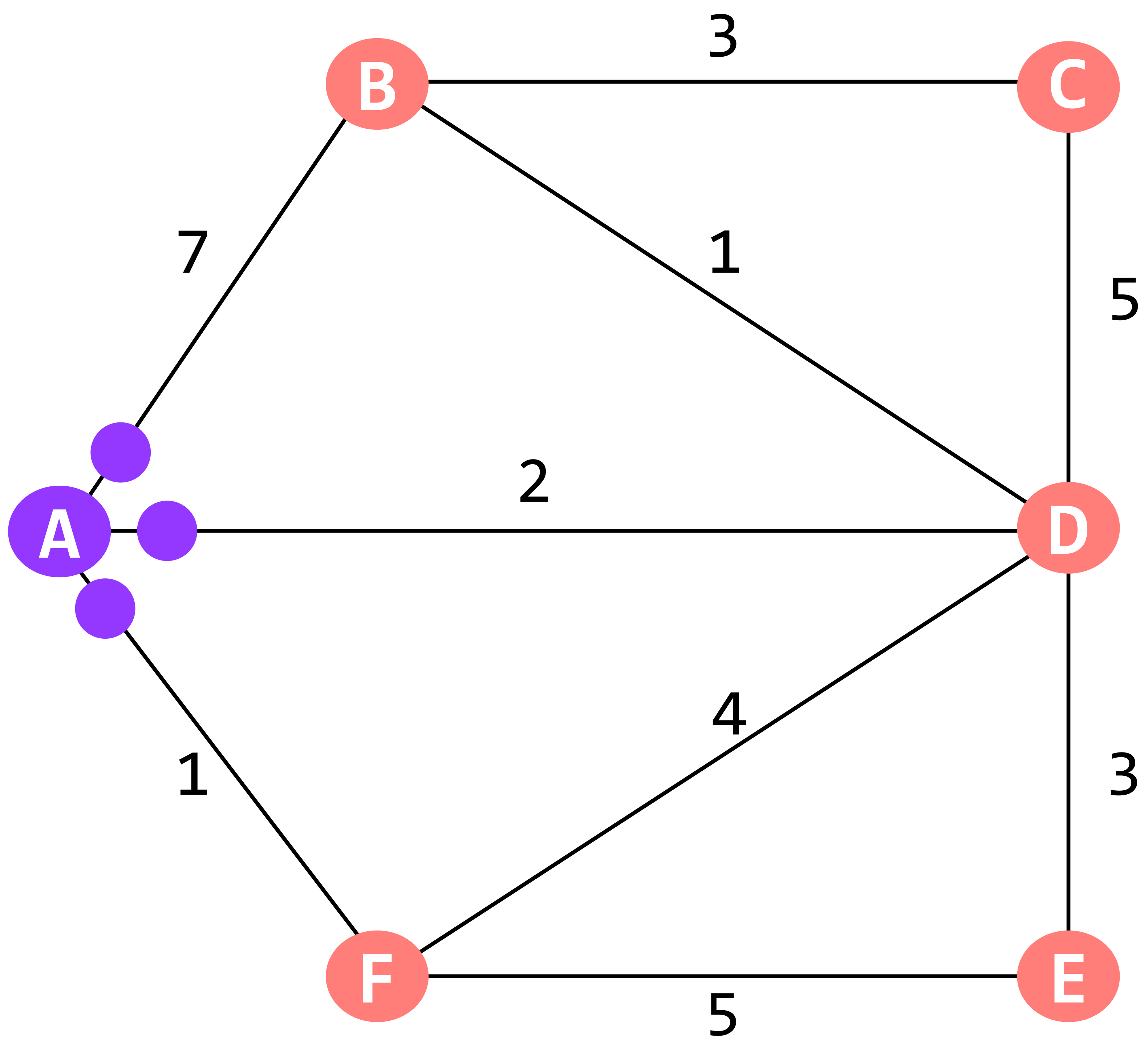

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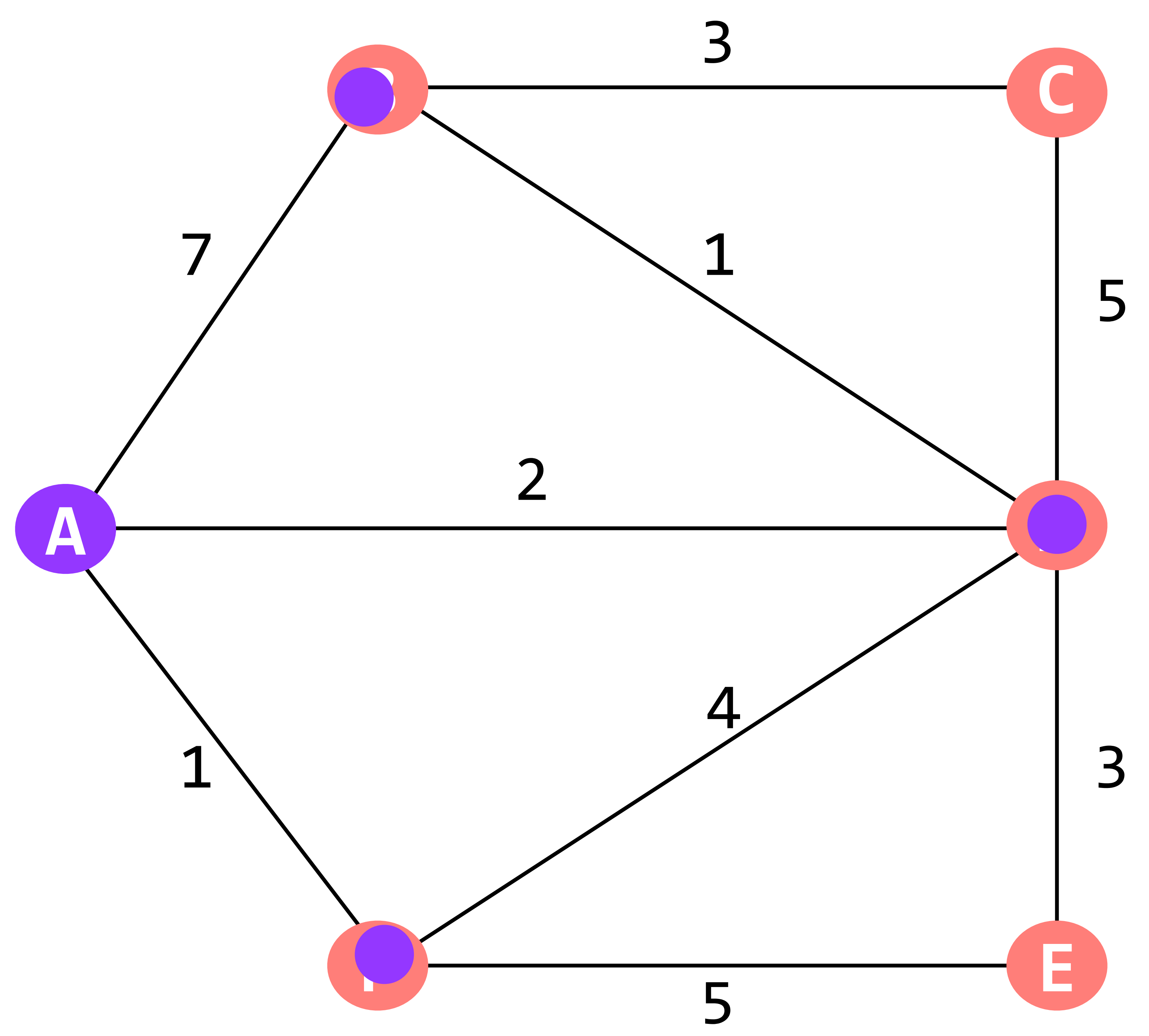


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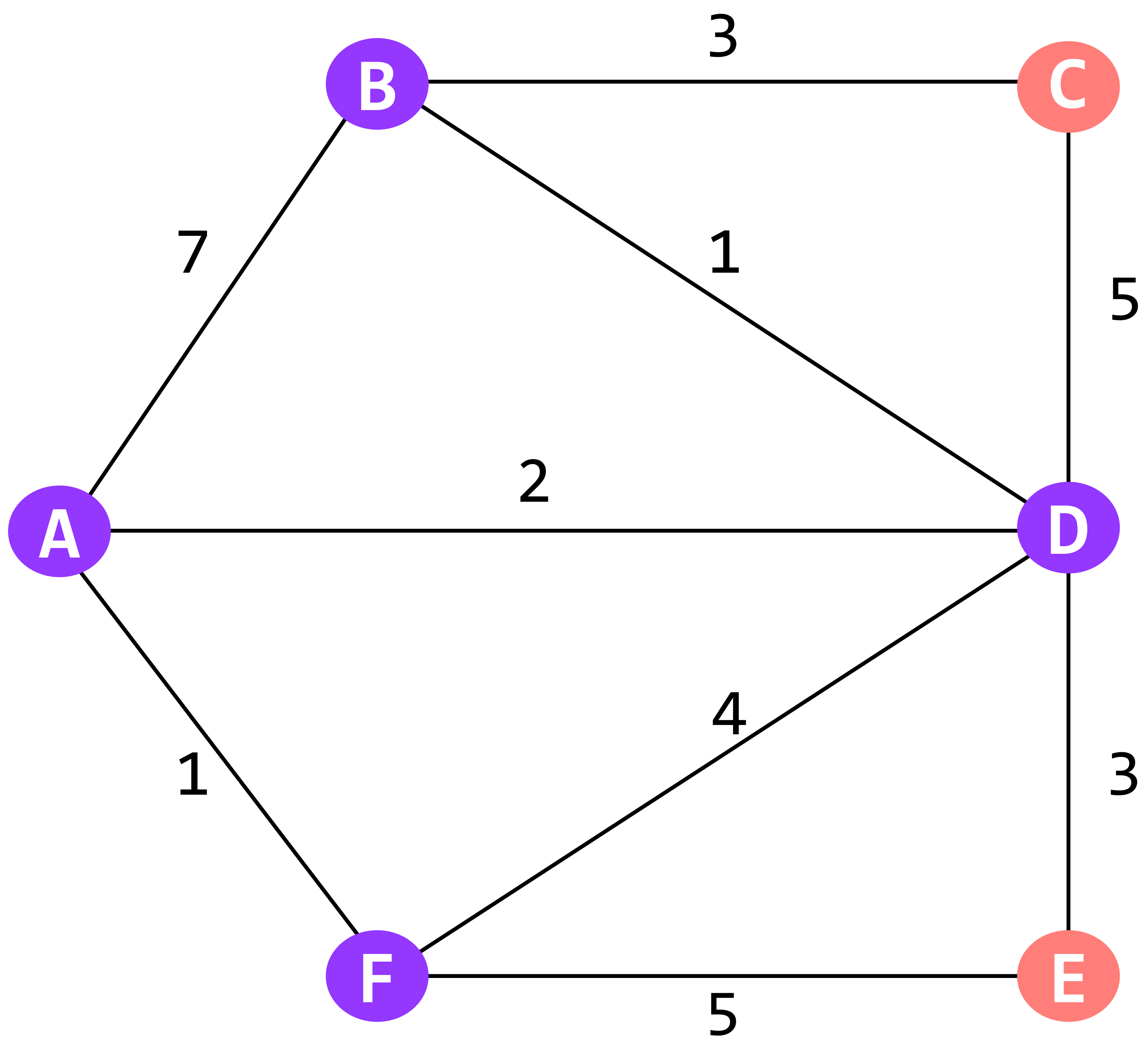

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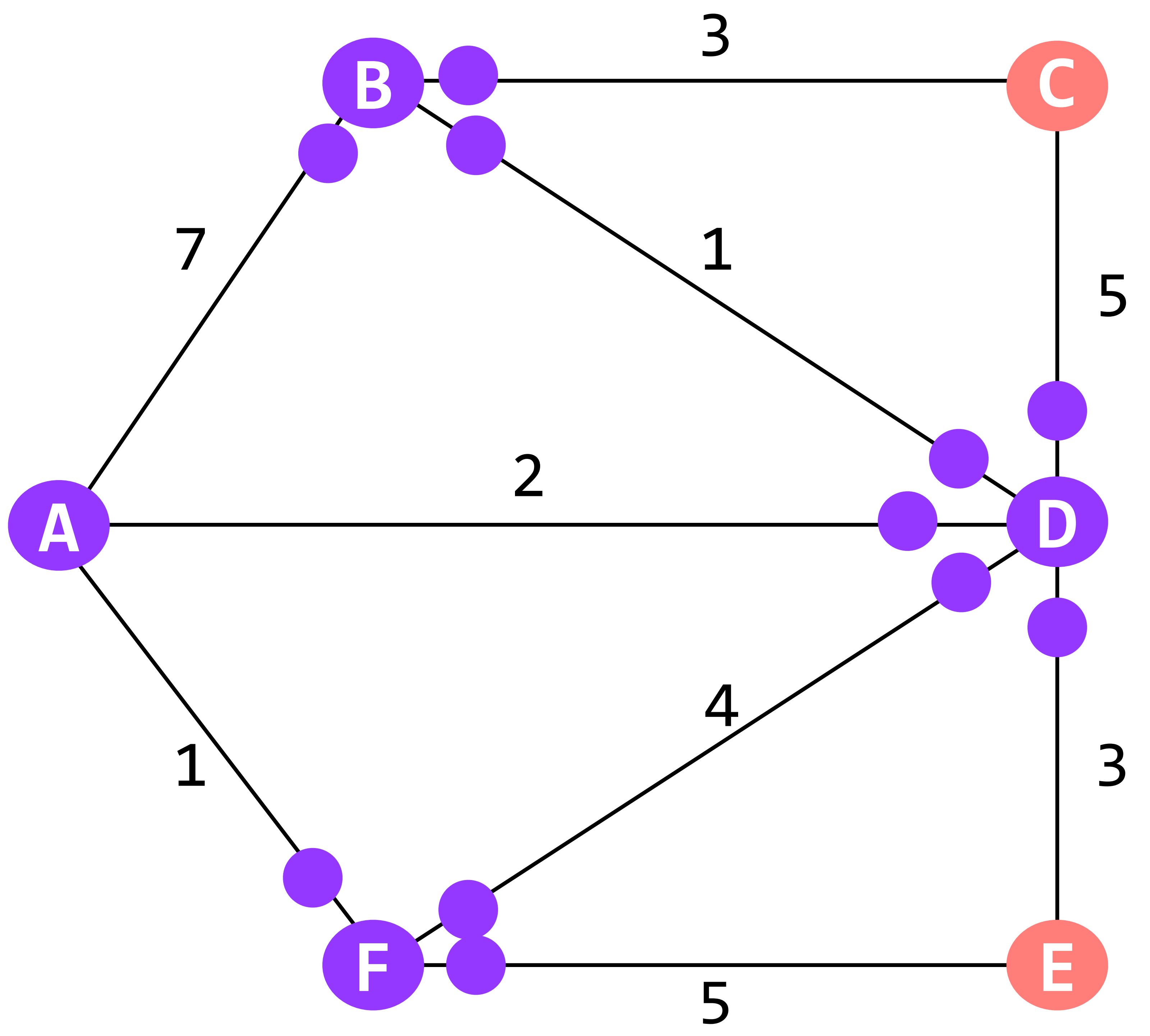

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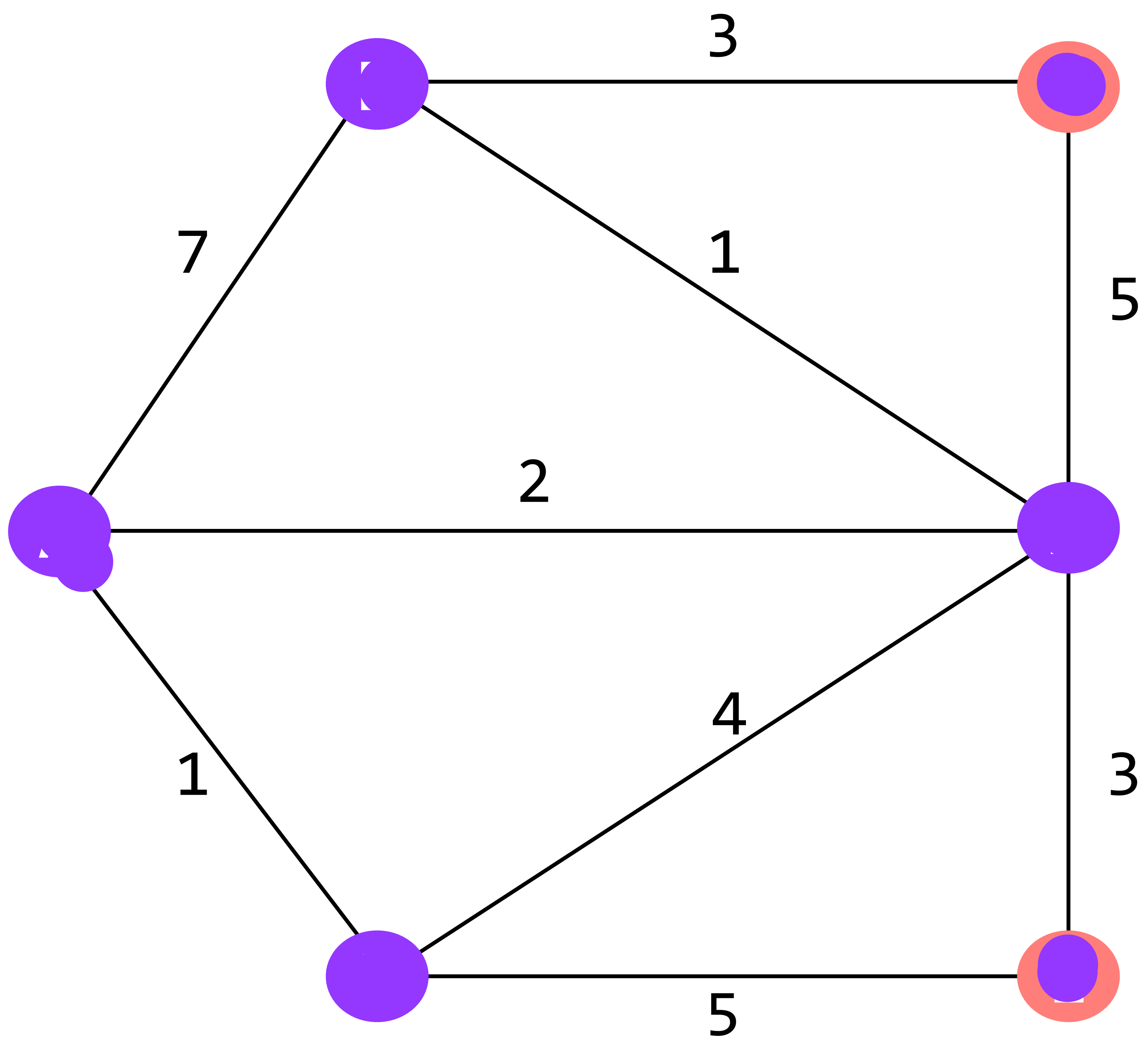

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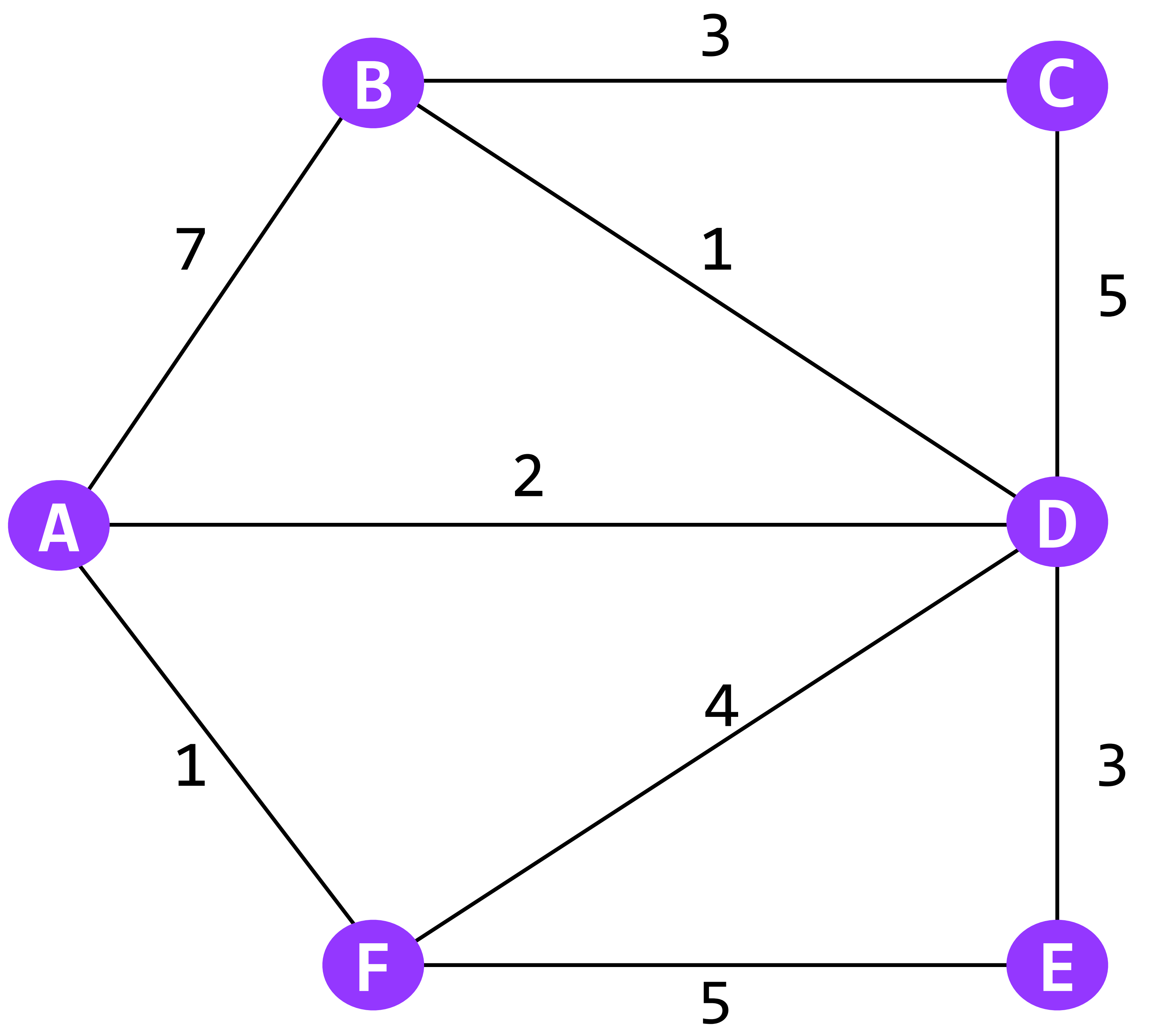


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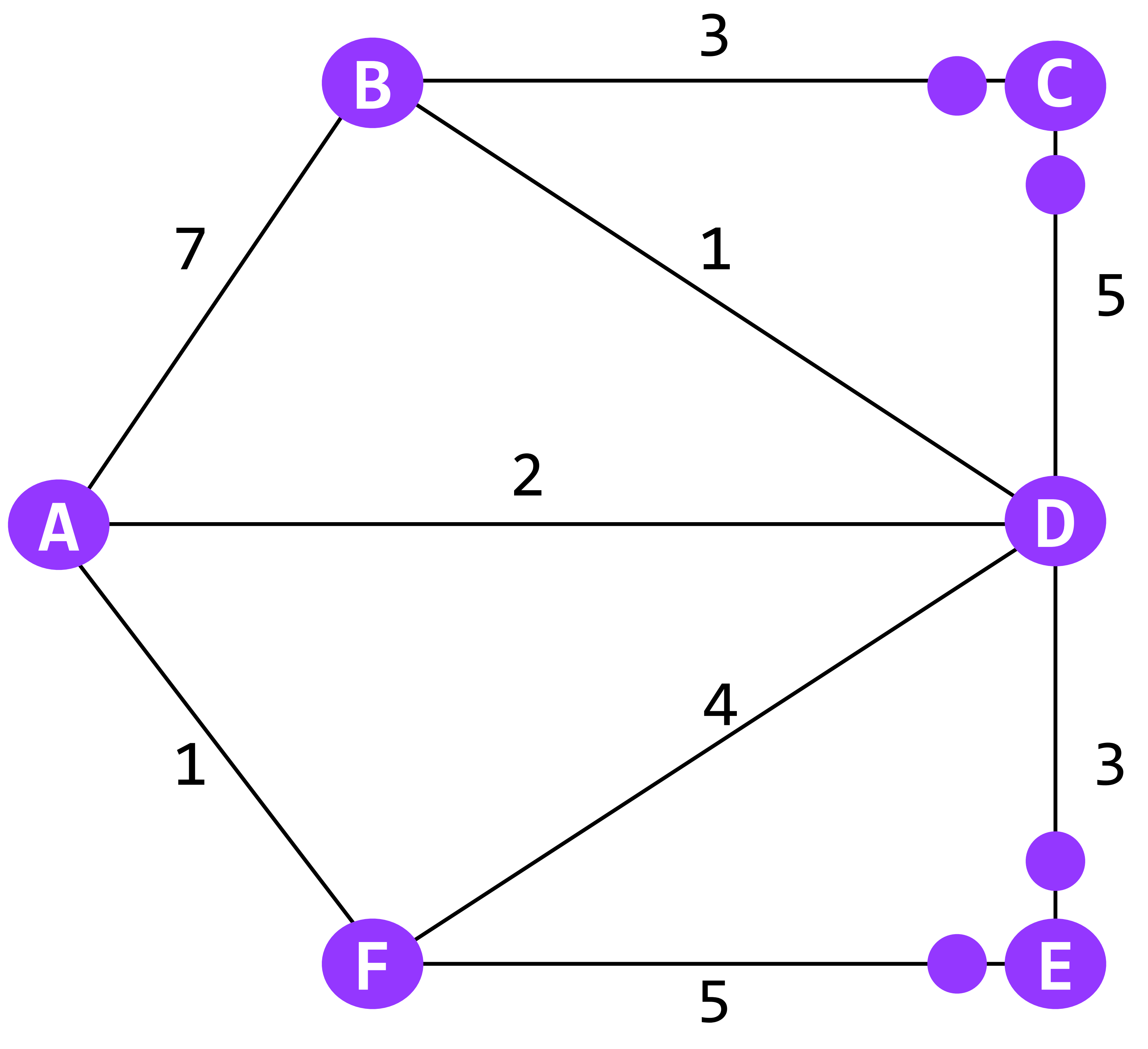

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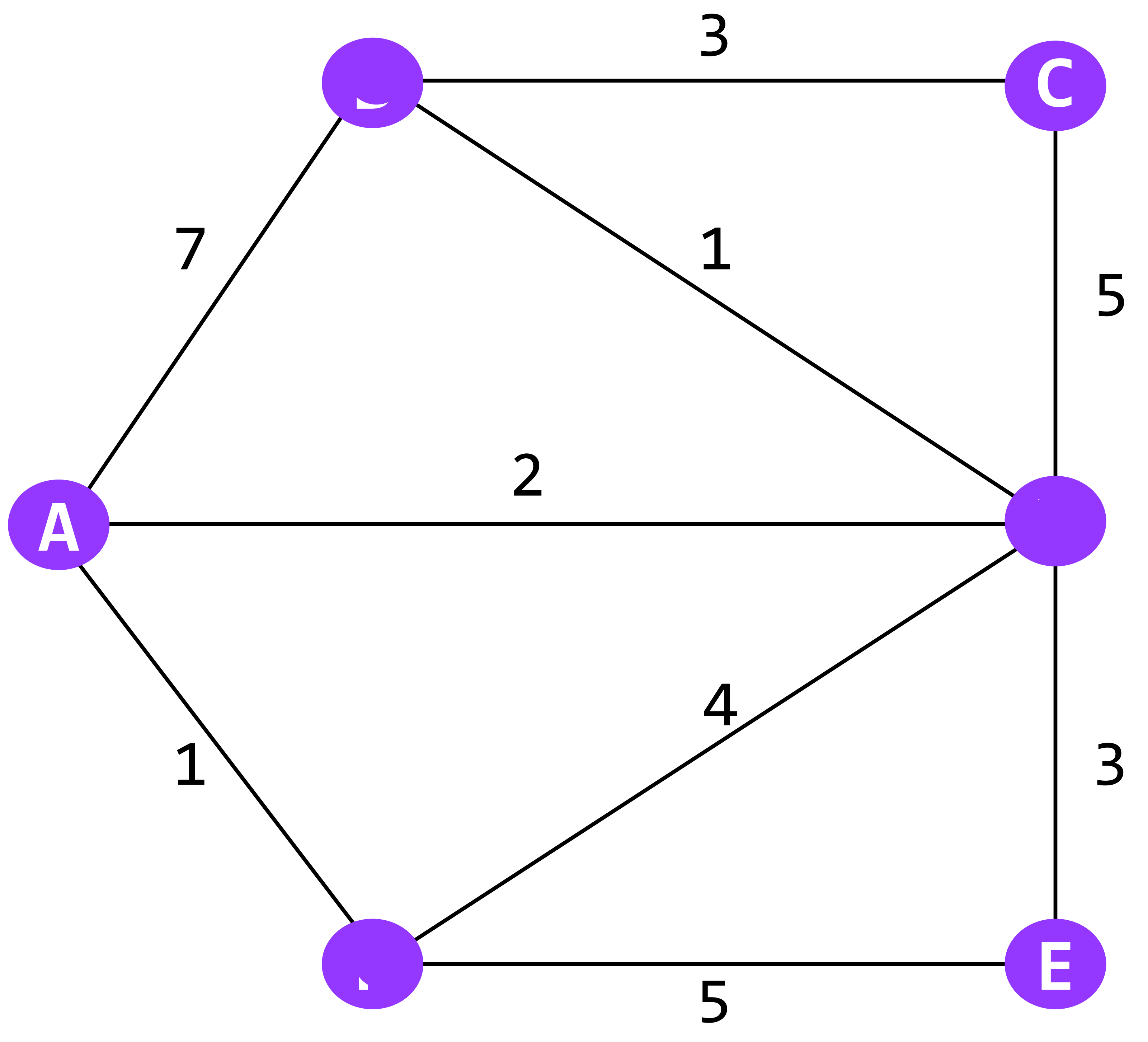


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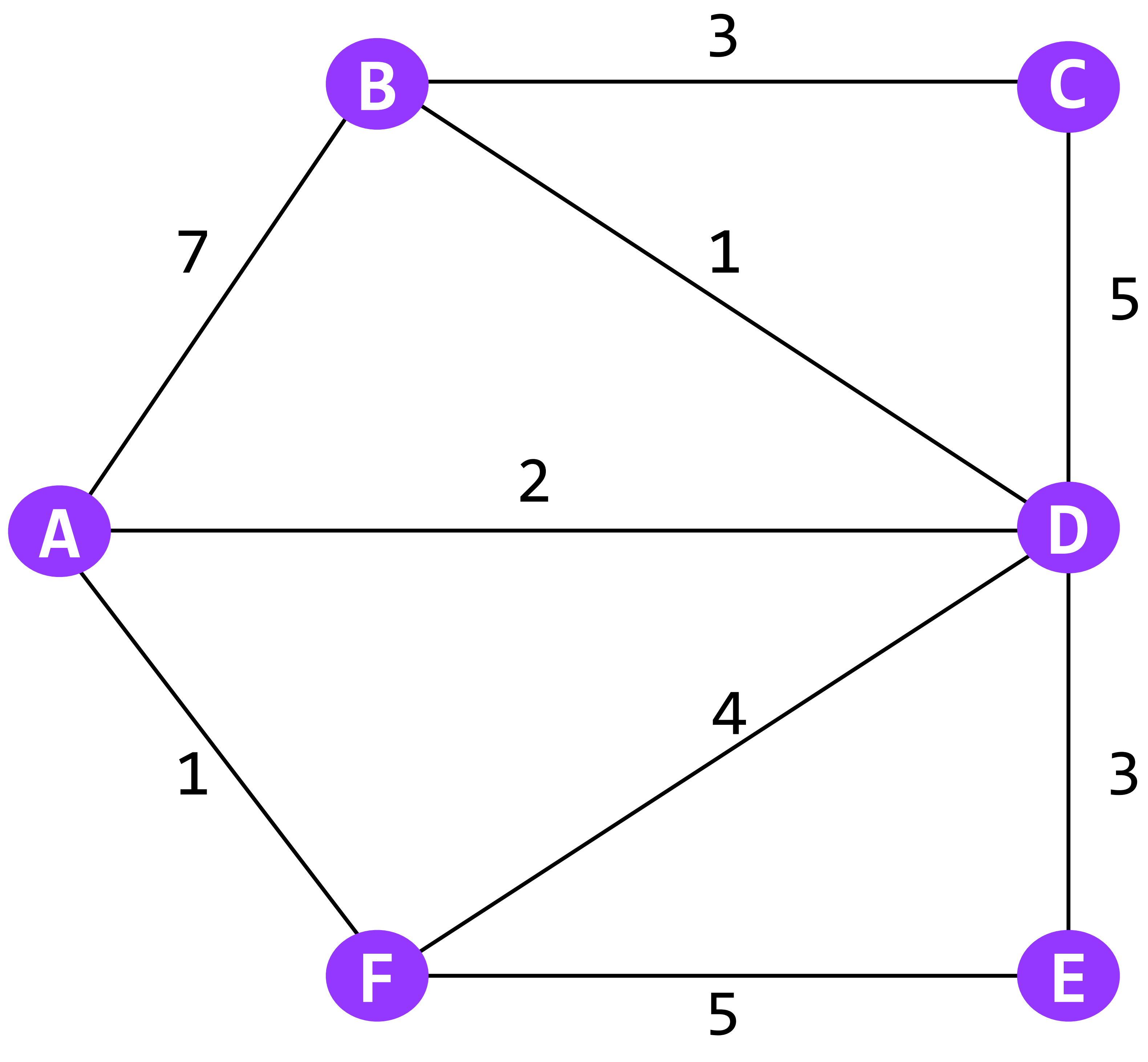


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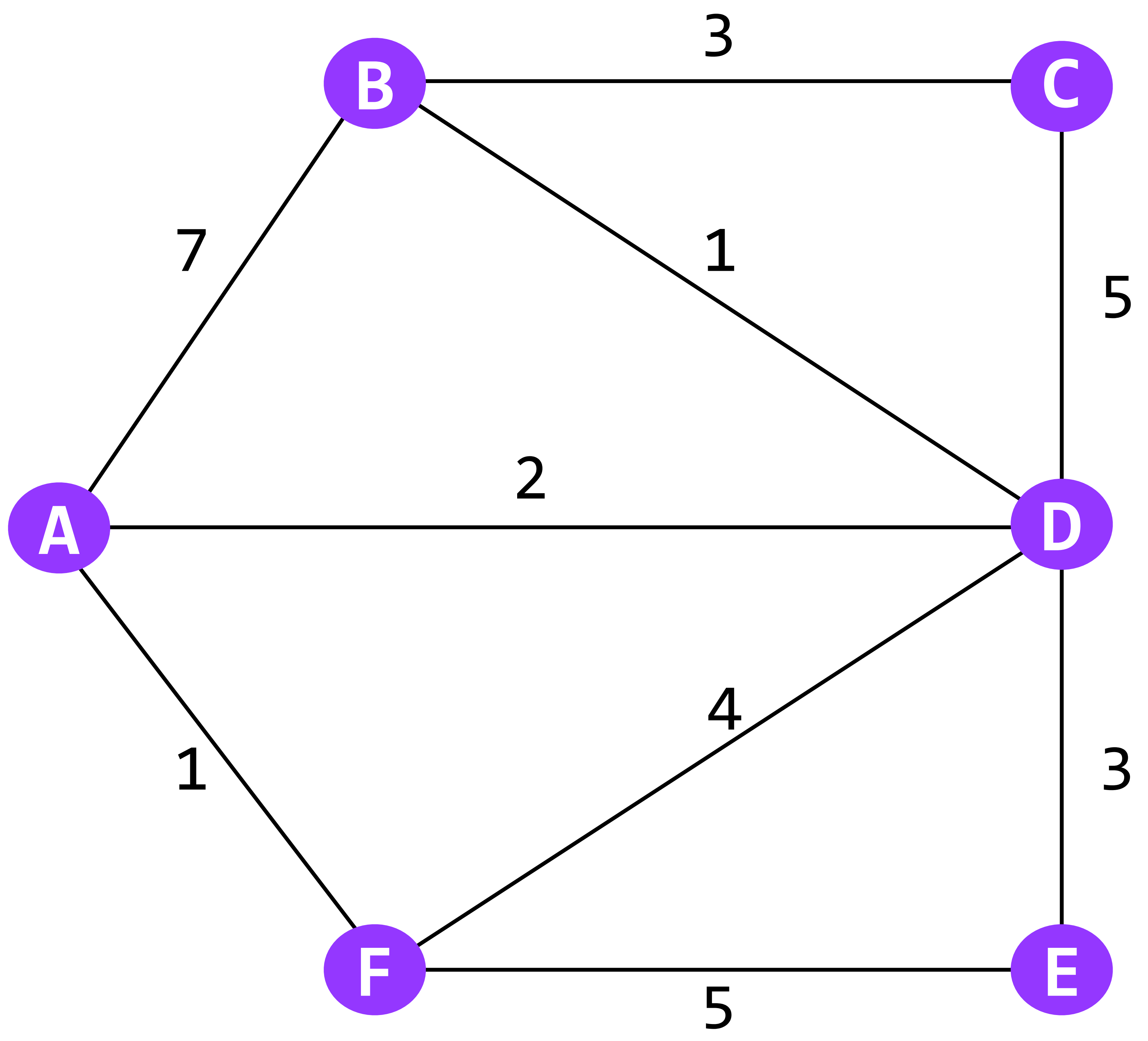

`A’s advertisement: [(B,7),(D,2),(F,1)]`

nodes keep track of which advertisements they’ve forwarded so that they don’t re-forward them

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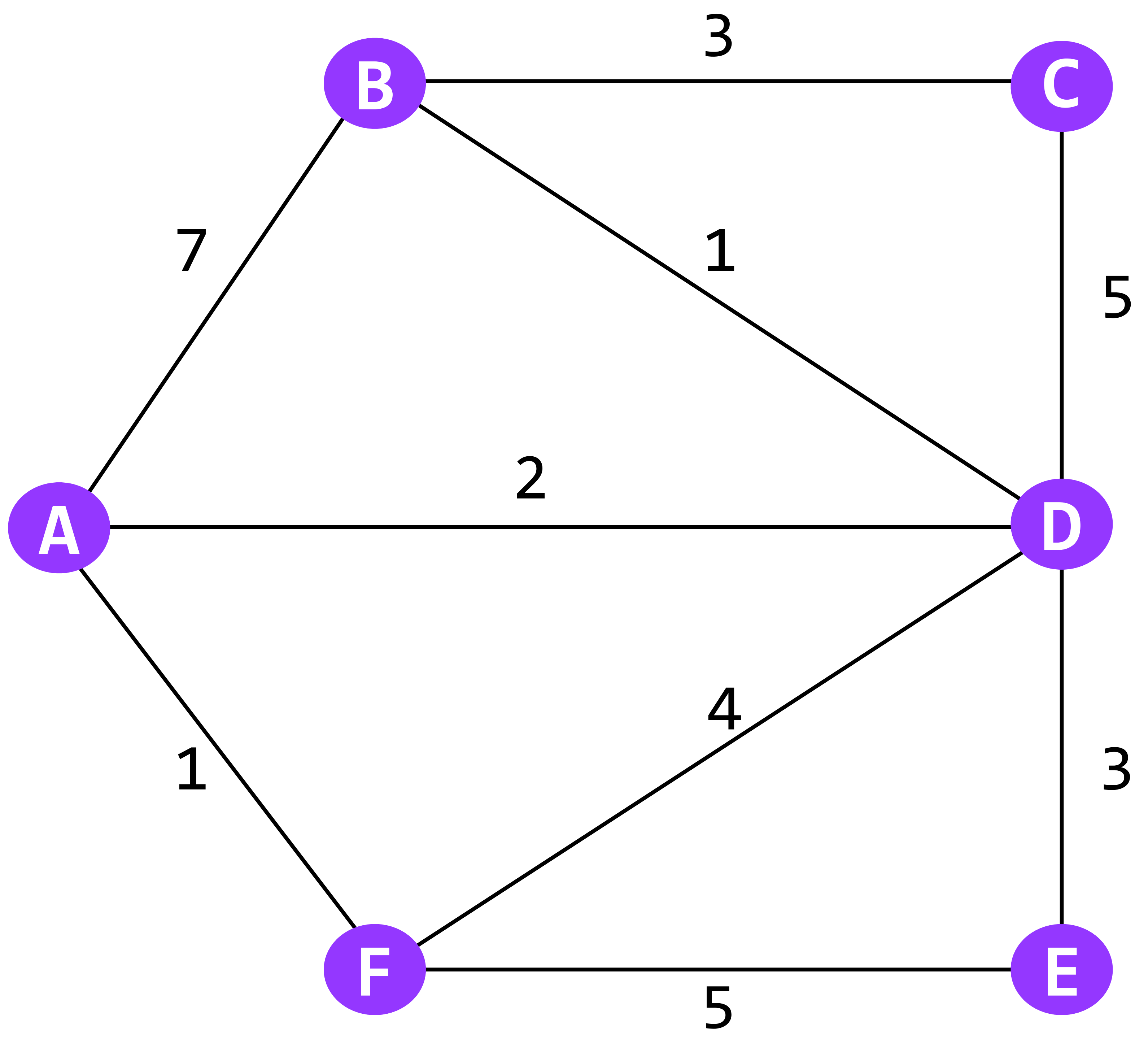


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nodes keep track of which advertisements they’ve forwarded so that they don’t re-forward them

they can also be a bit smarter about flooding, and not forward an advertisement back to the node that sent it

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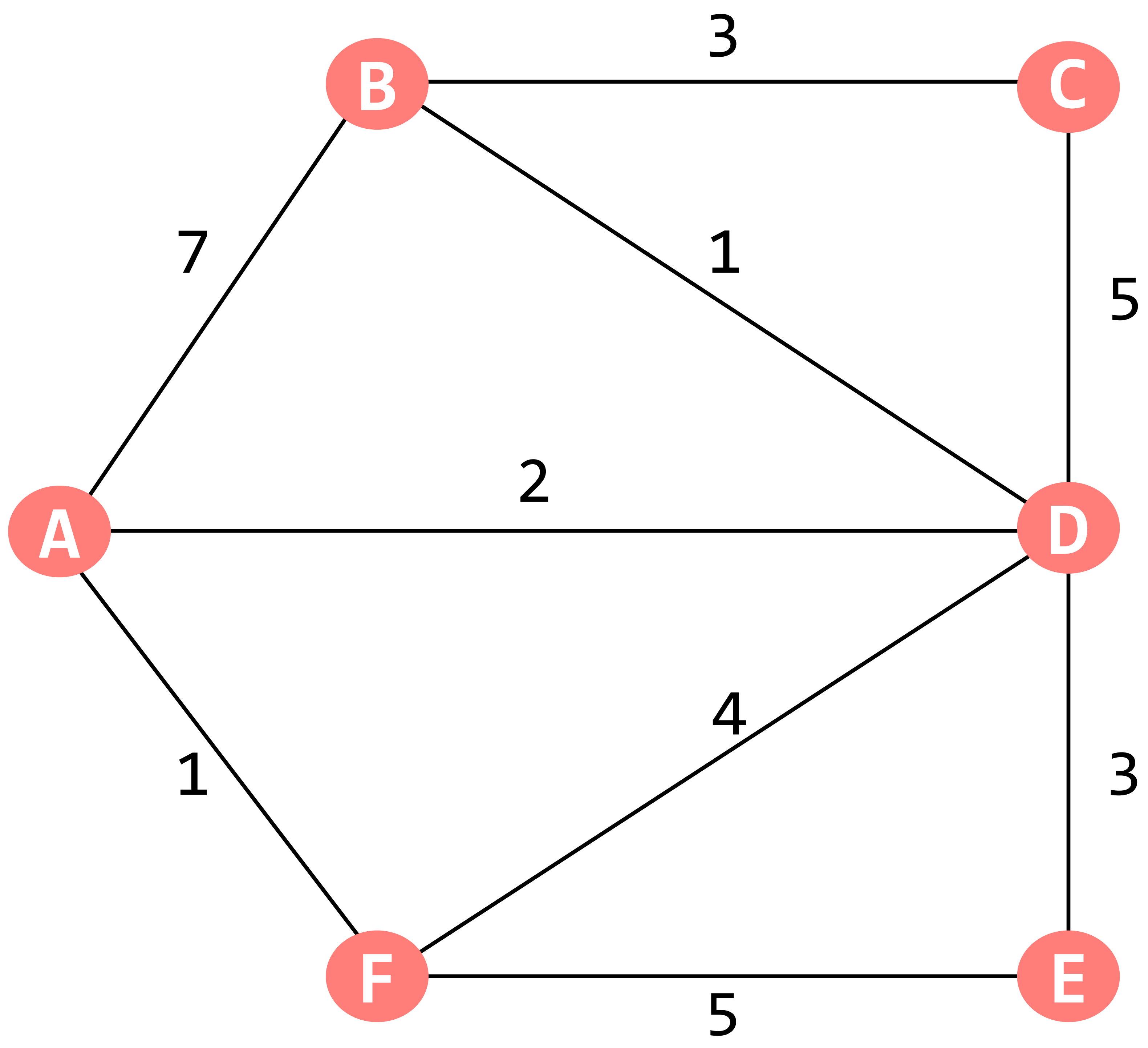

nodes *integrate* advertisements by running Dijkstra's Algorithm

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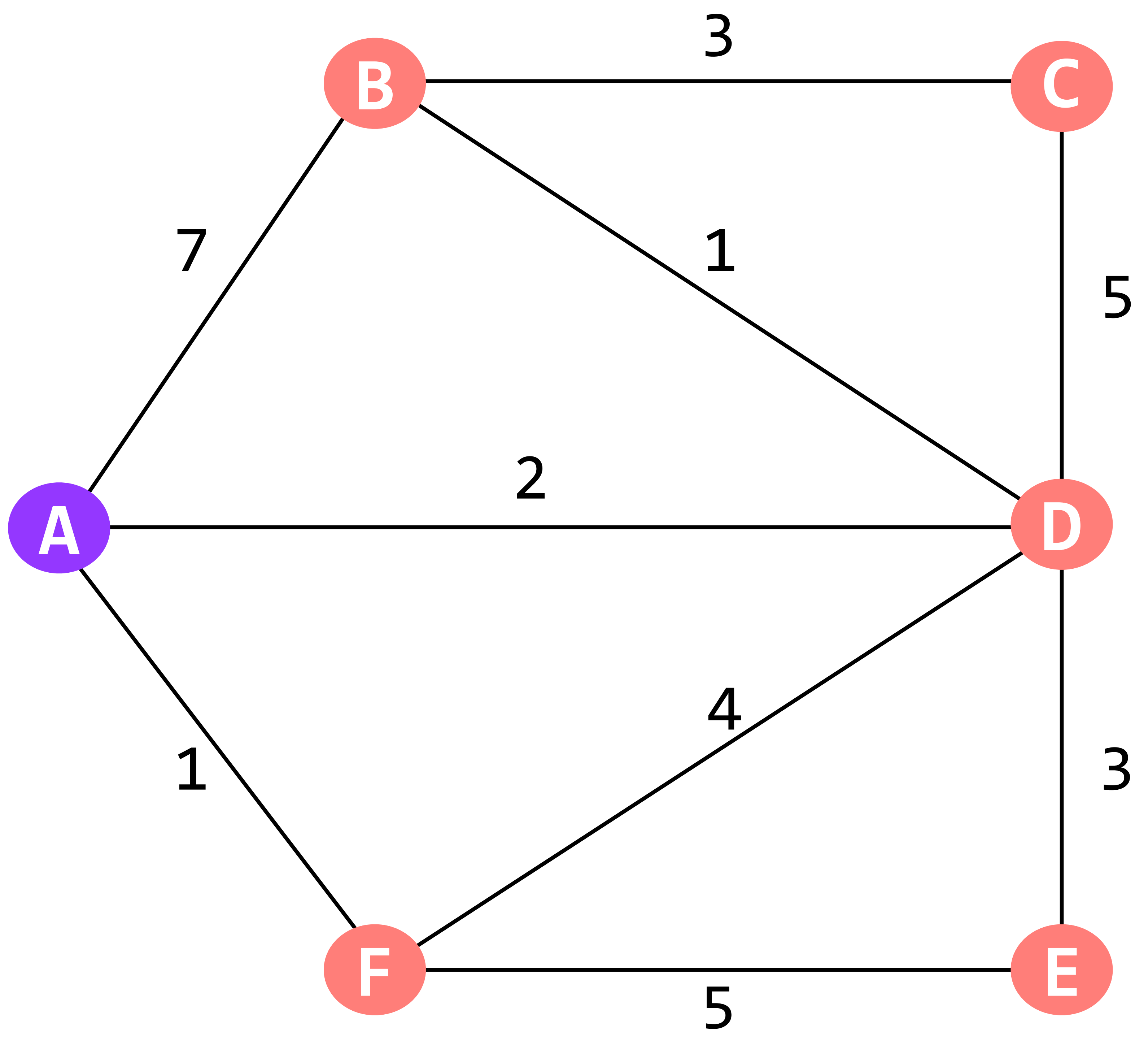

A's routing table

dst	route	cost
B	A-B	7
C	?	∞
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E	?	∞
F	A-F	1

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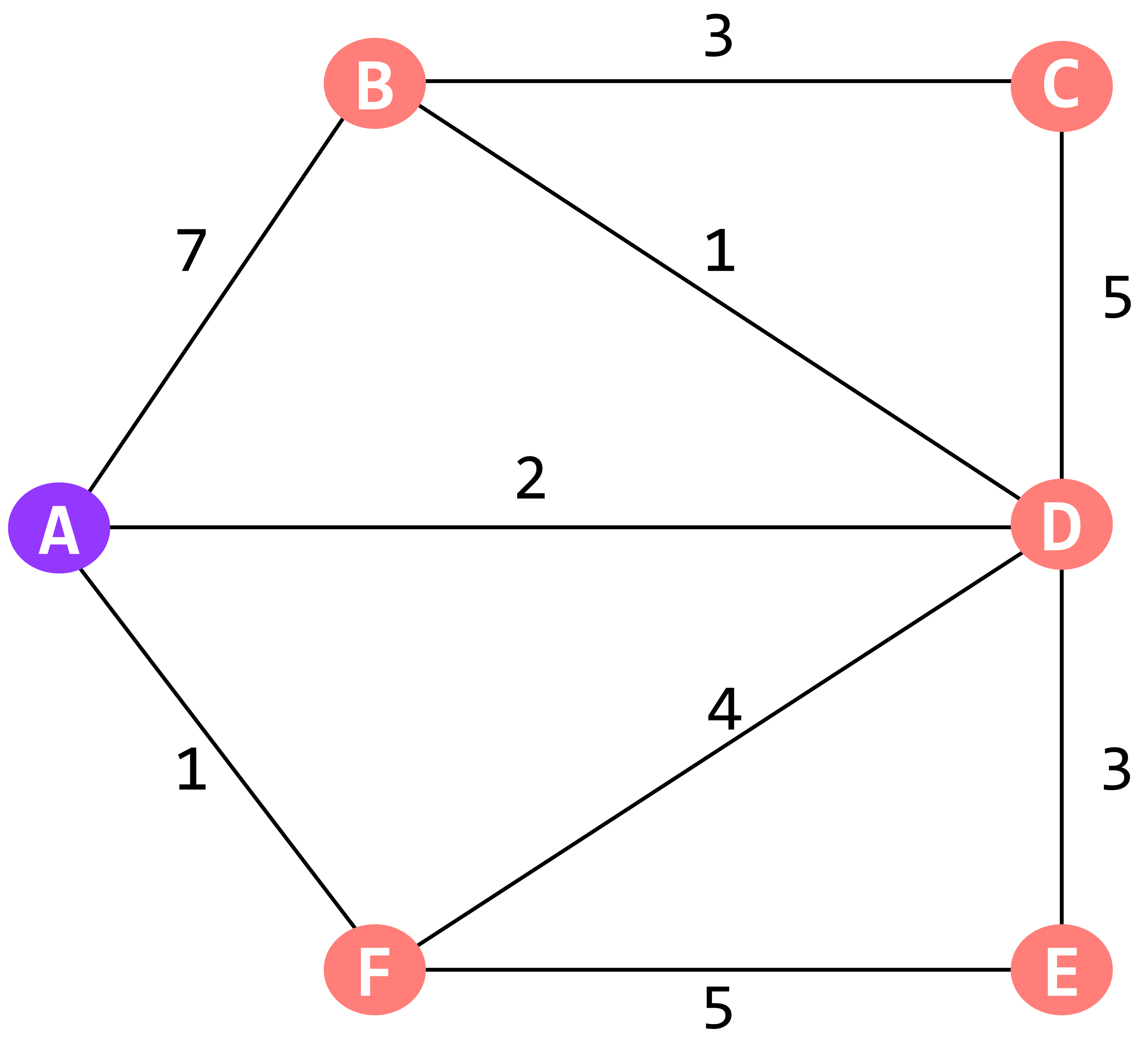

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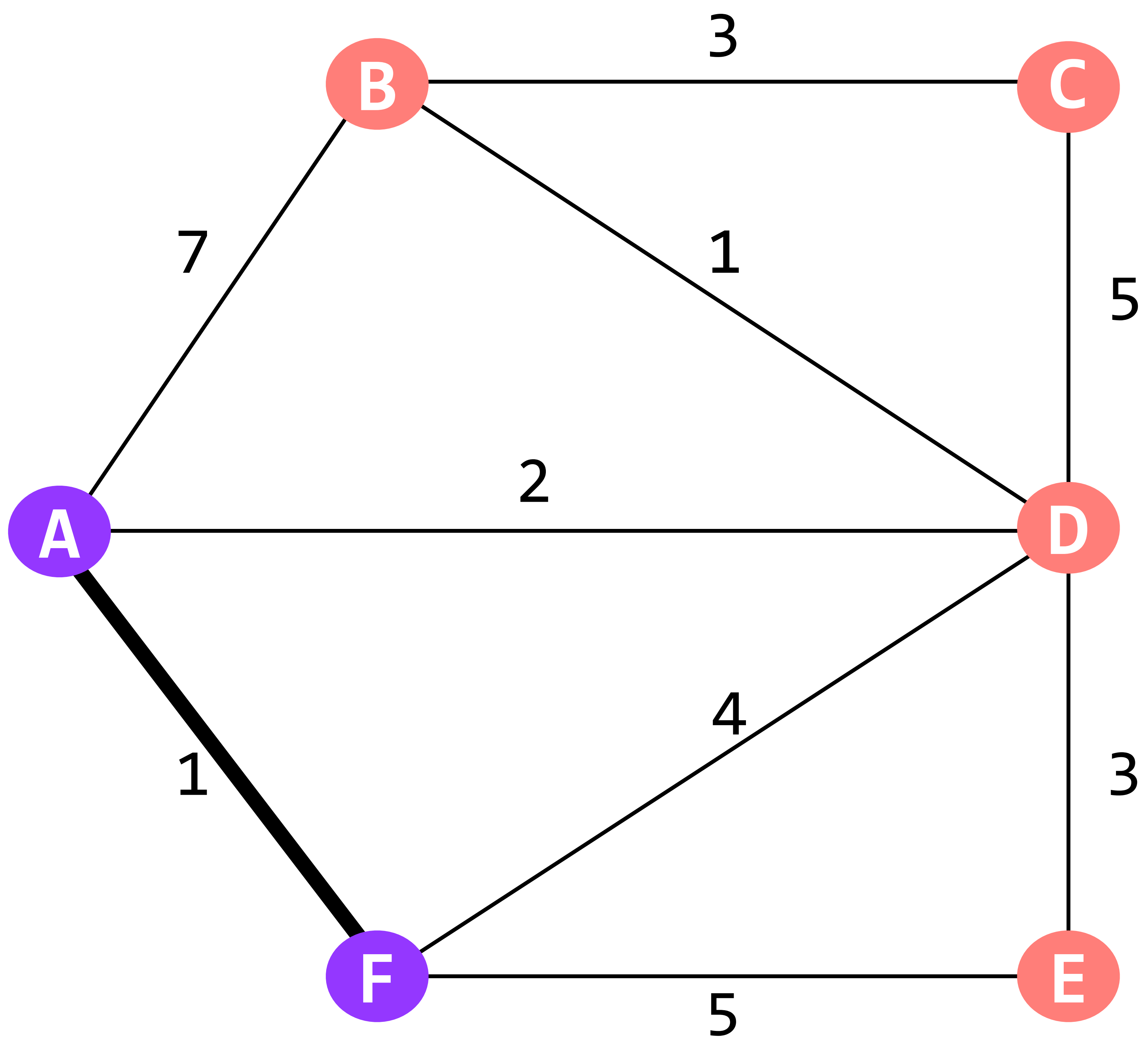

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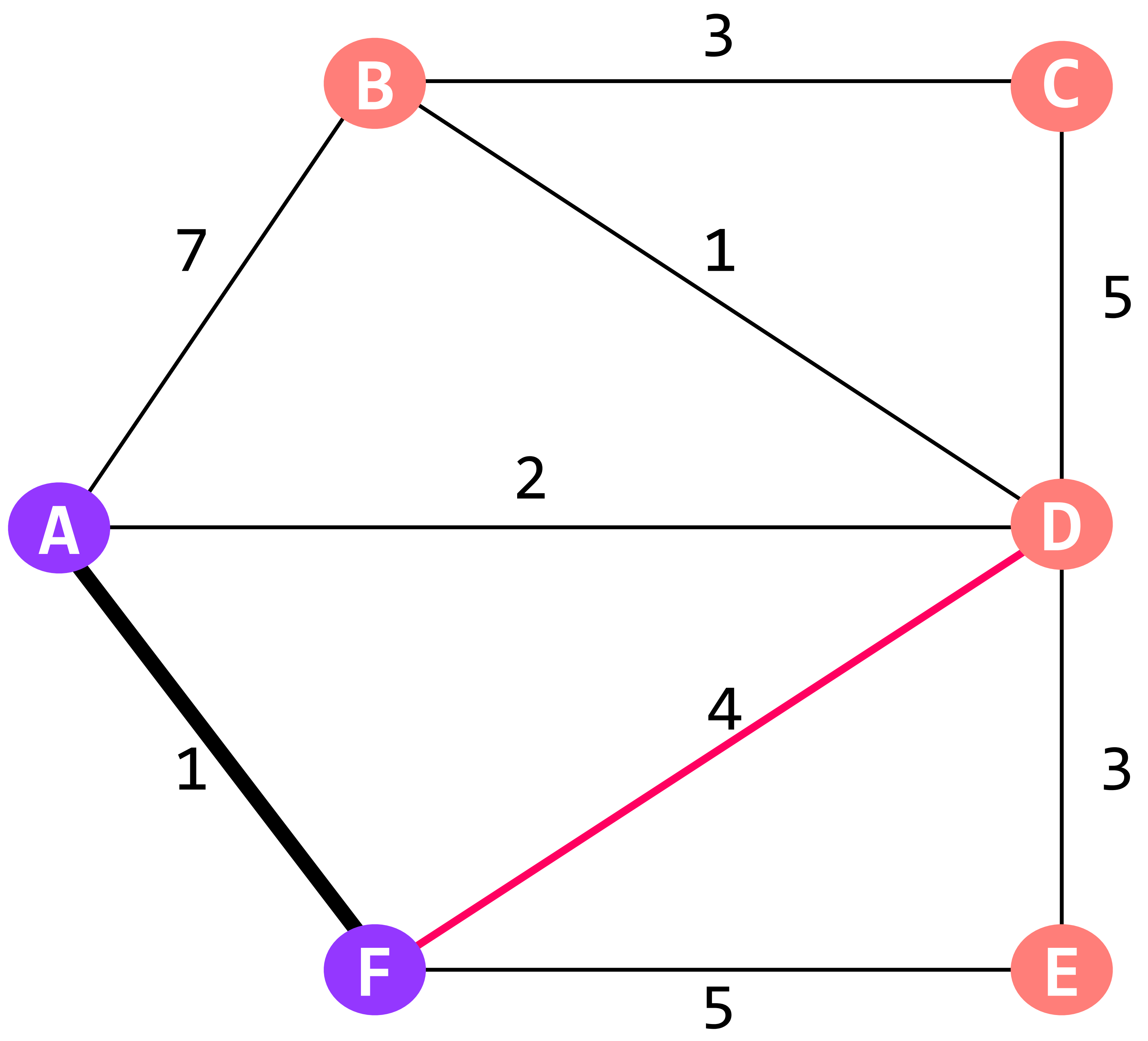

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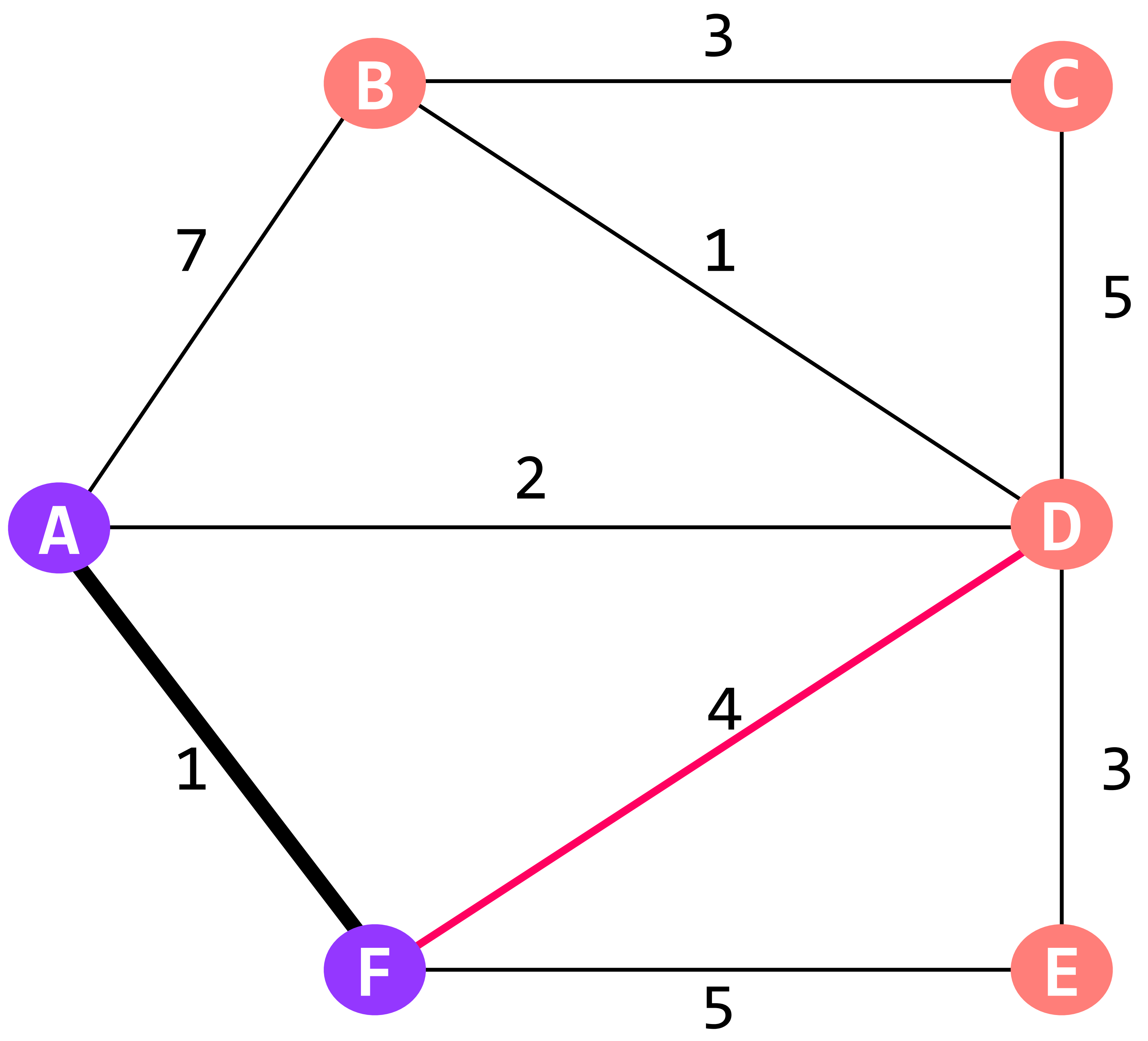

A's routing table

dst	route	cost
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C	?	∞
D	A-D	2
E	?	∞
F	**A-F**	**1**

F does not provide A with a better route to D

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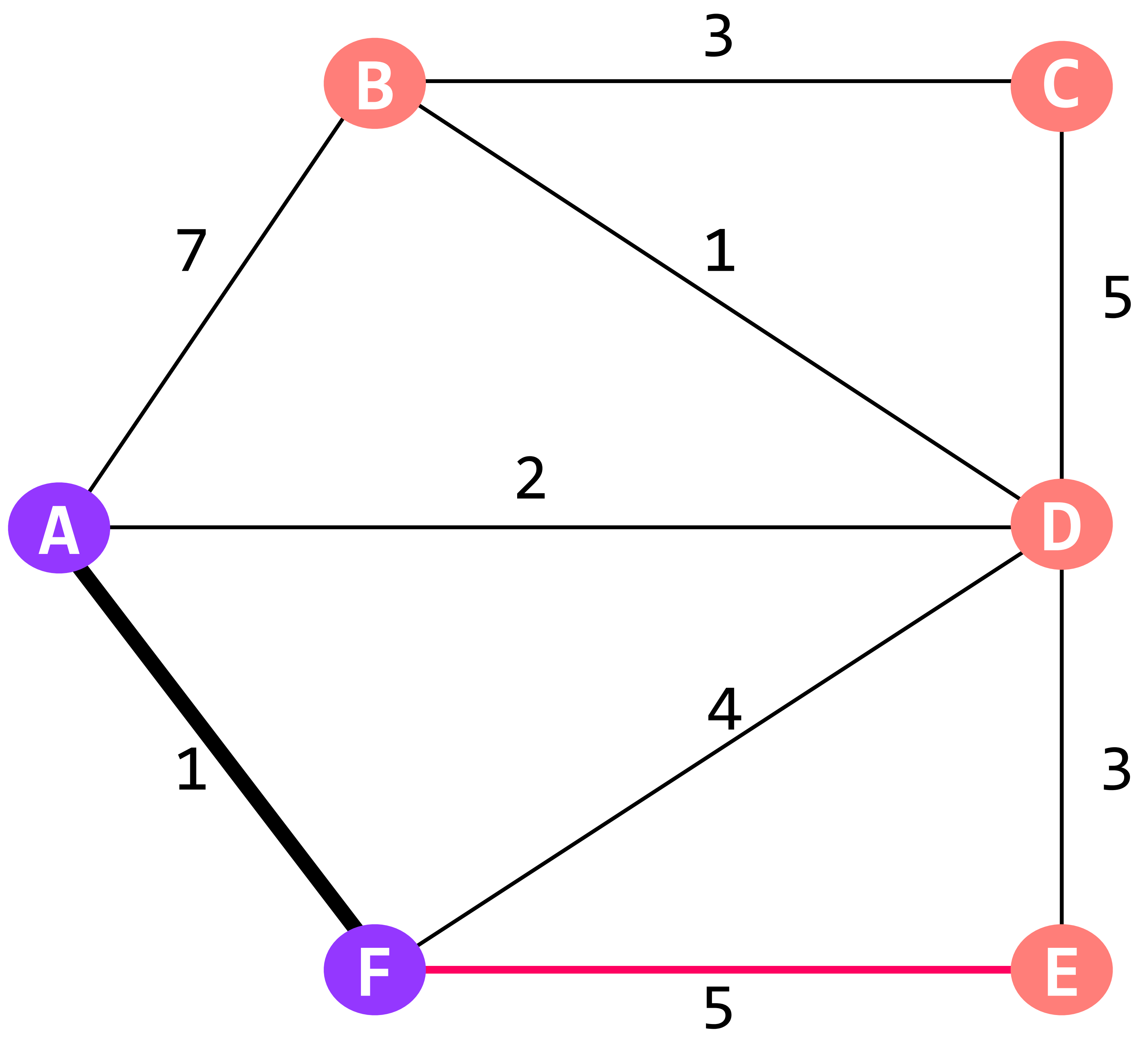
Katrina LaCurts | lacurts@mit.edu | 6.1800 2024

link-state routing: disseminate full topology information so that nodes can run a shortest-path algorithm



A's routing table

dst	route	cost
B	A-B	7
C	?	∞
D	A-D	2
E	?	∞
F	A-F	1

link state

what's in an advertisement

its **link costs** to each of its **neighbors**

who gets a node's advertisement

effectively, **every other node** (via flooding)

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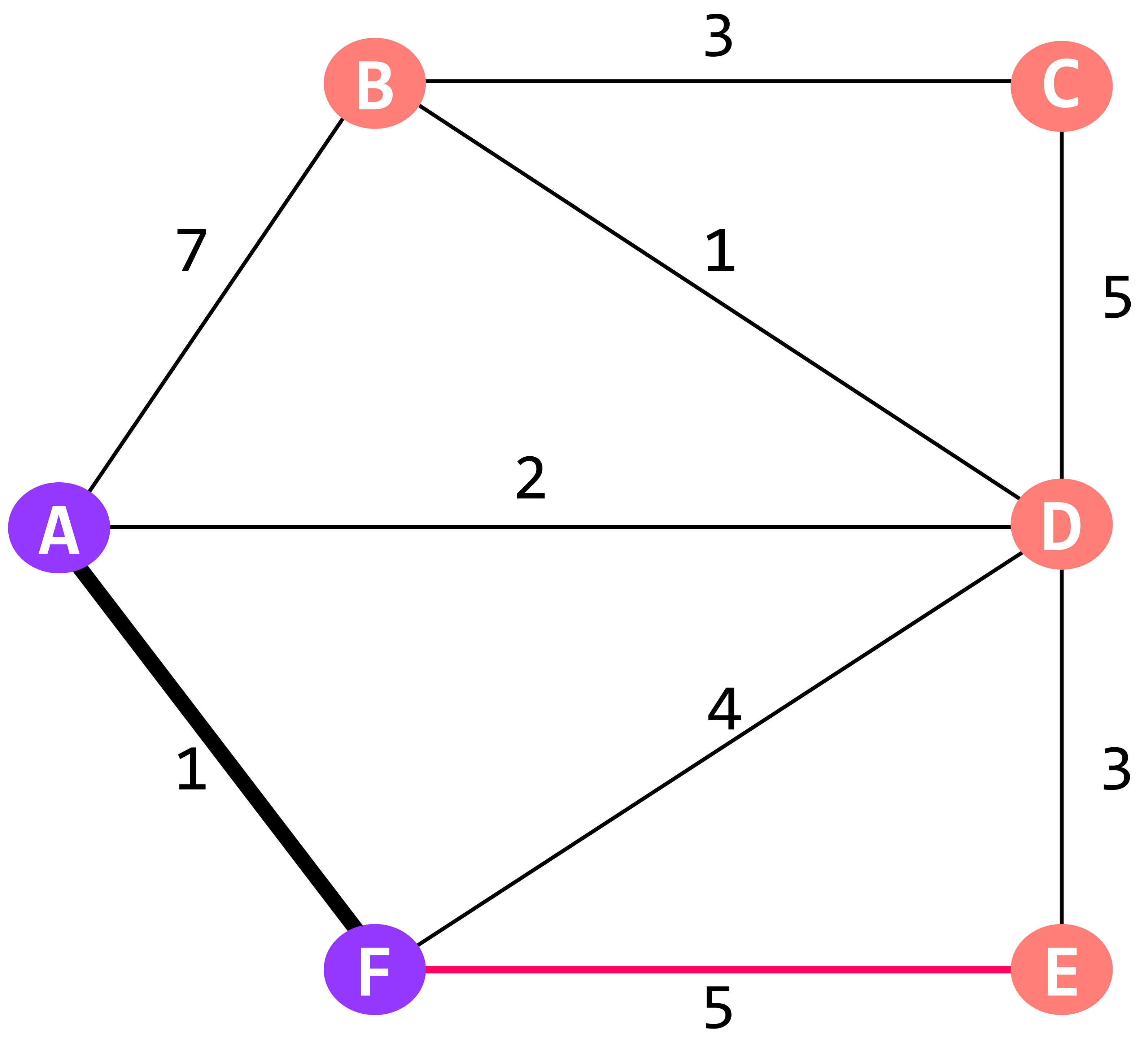

A's routing table

dst	route	cost
B	A-B	7
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D	A-D	2
E	A-F	6
F	A-F	1

= the cost from A to F + the cost from F to E

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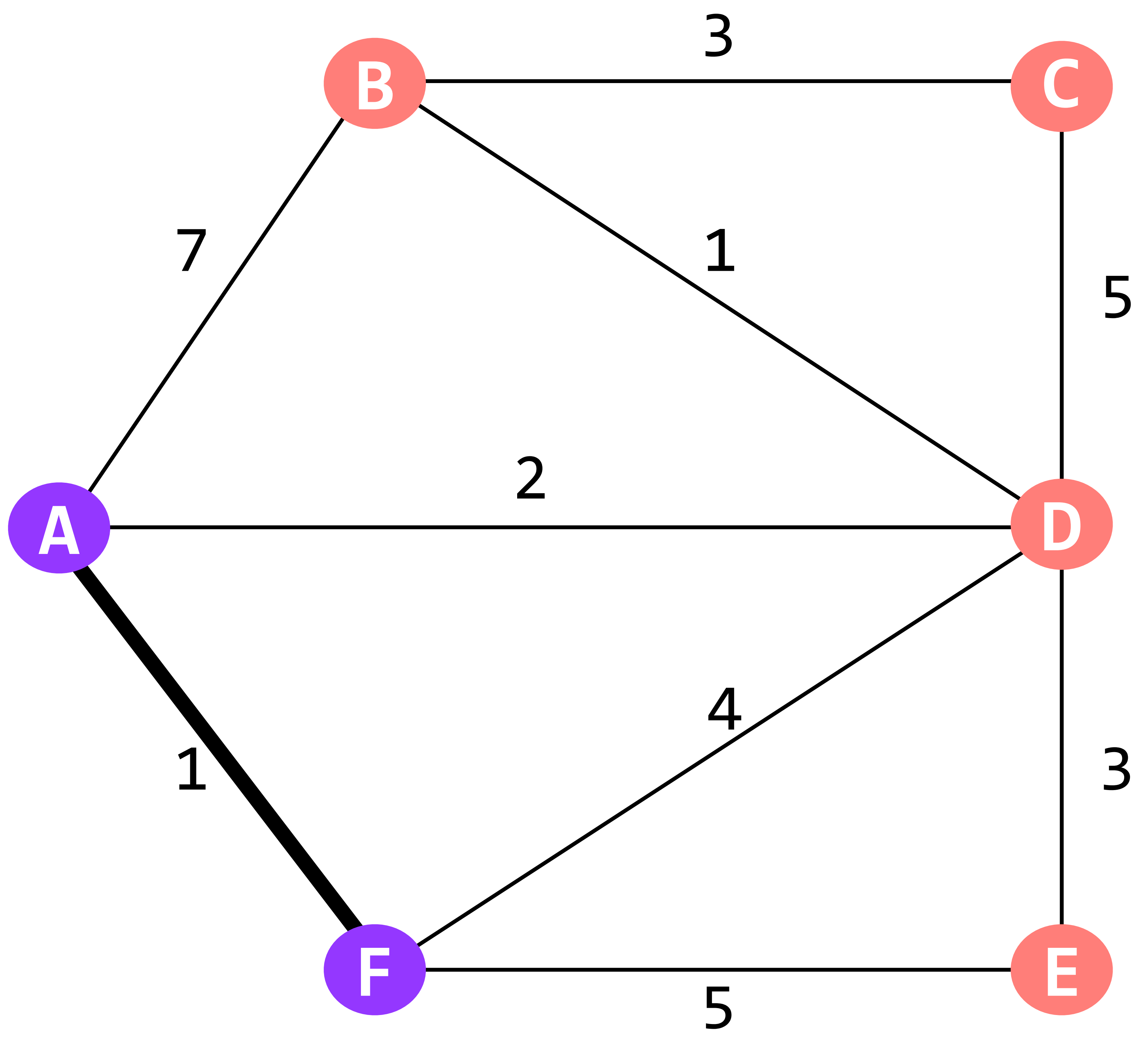

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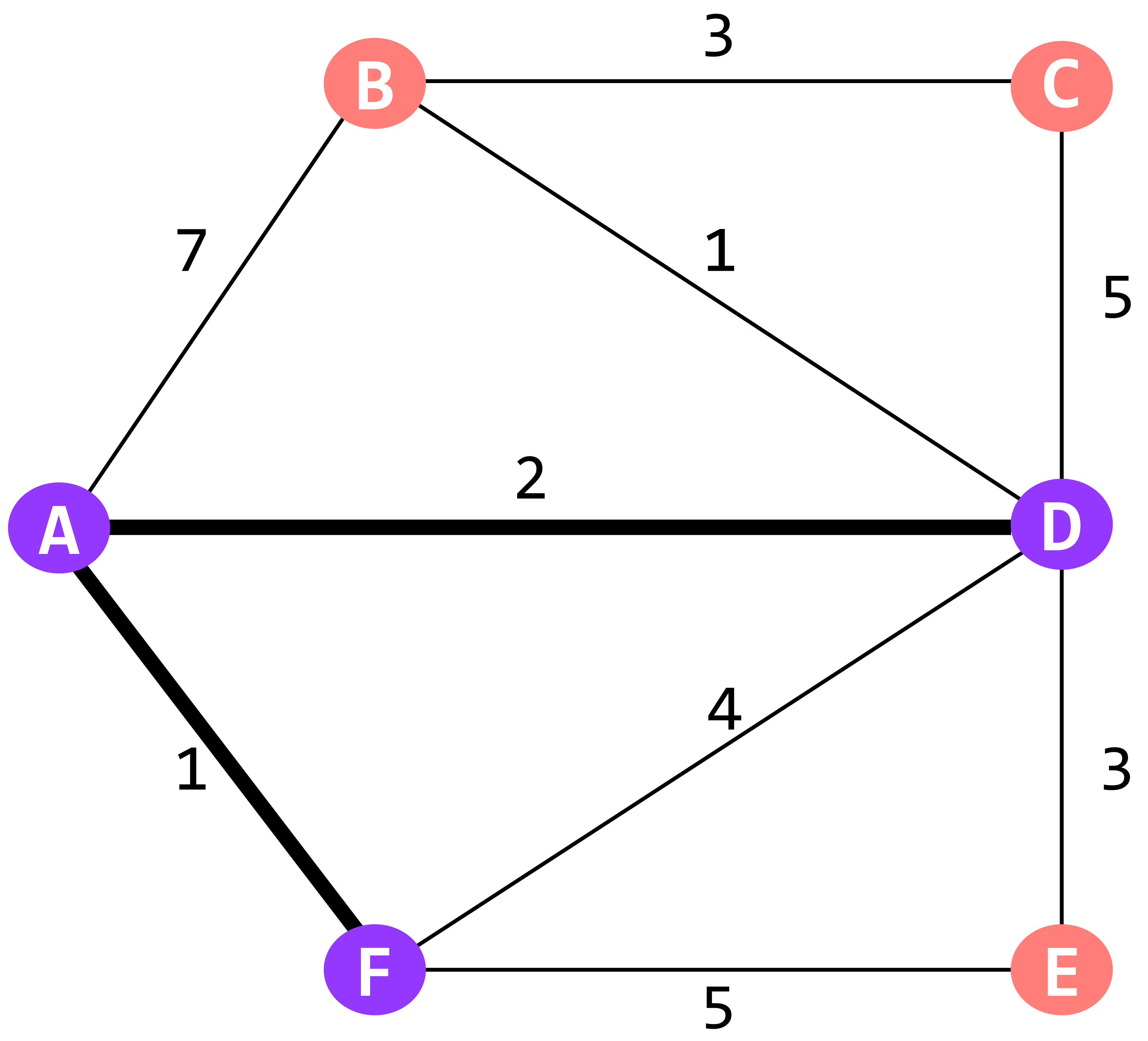

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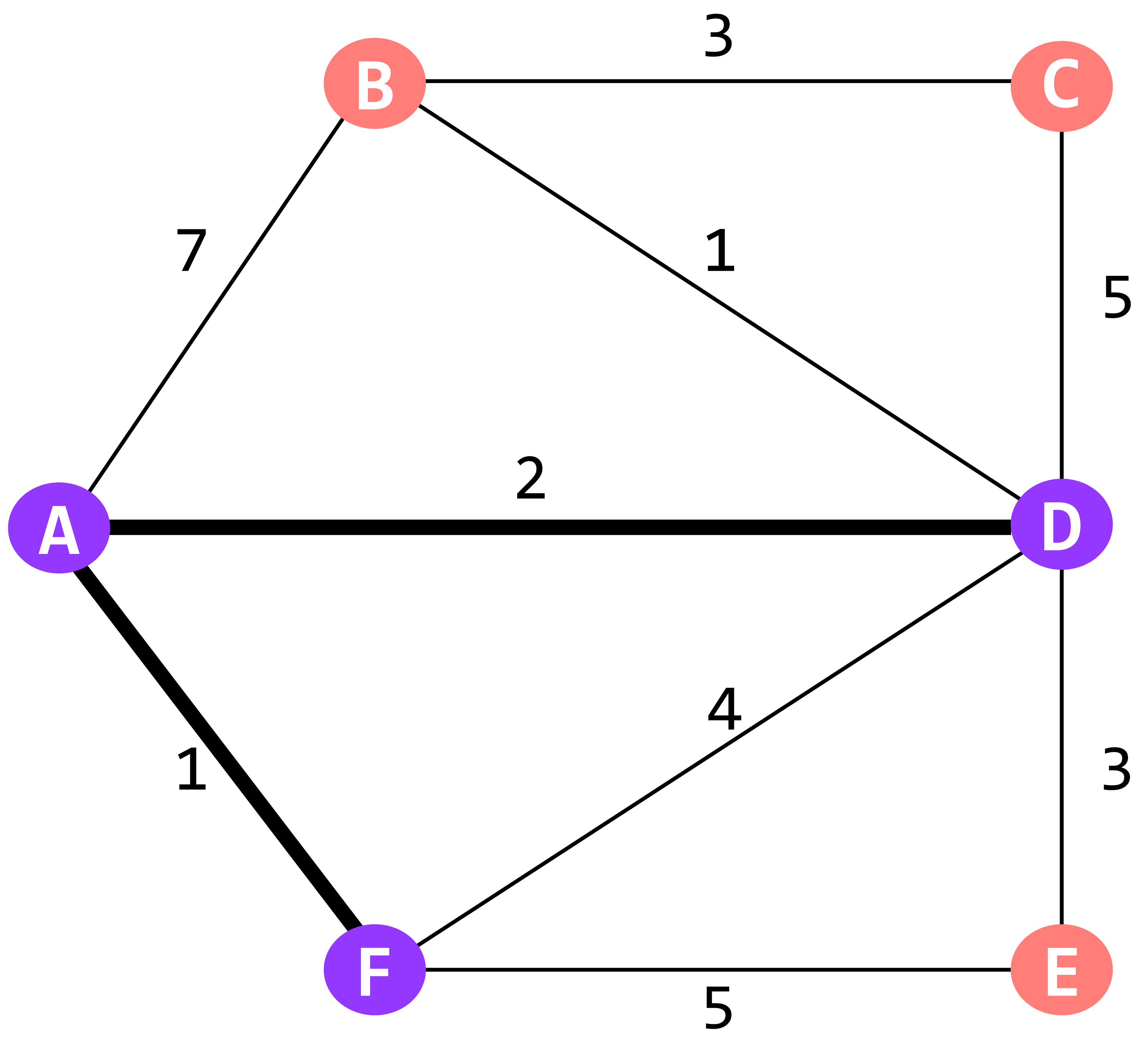

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question: what will A's routing table look like after we're done visiting all of D's neighbors?

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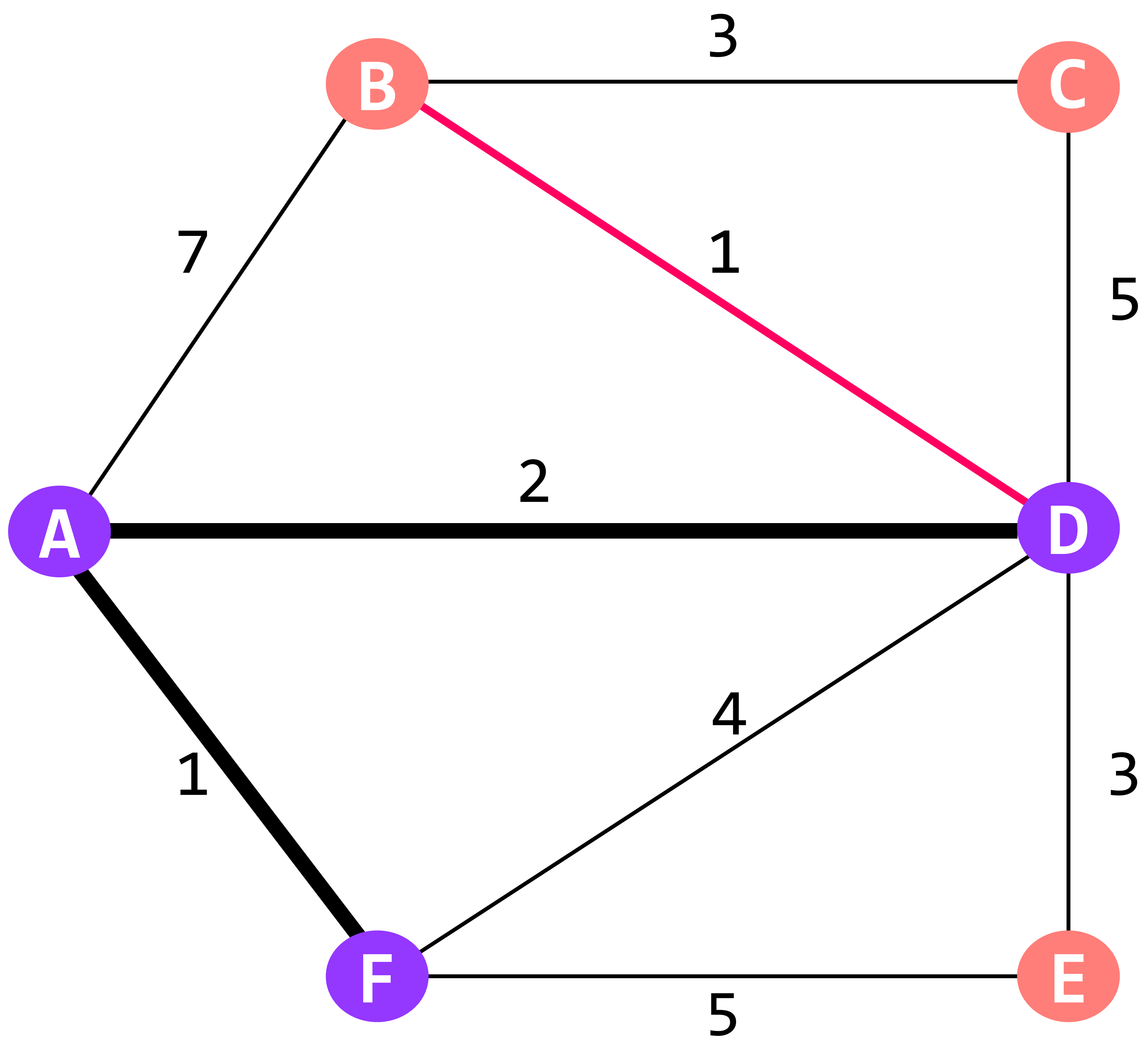

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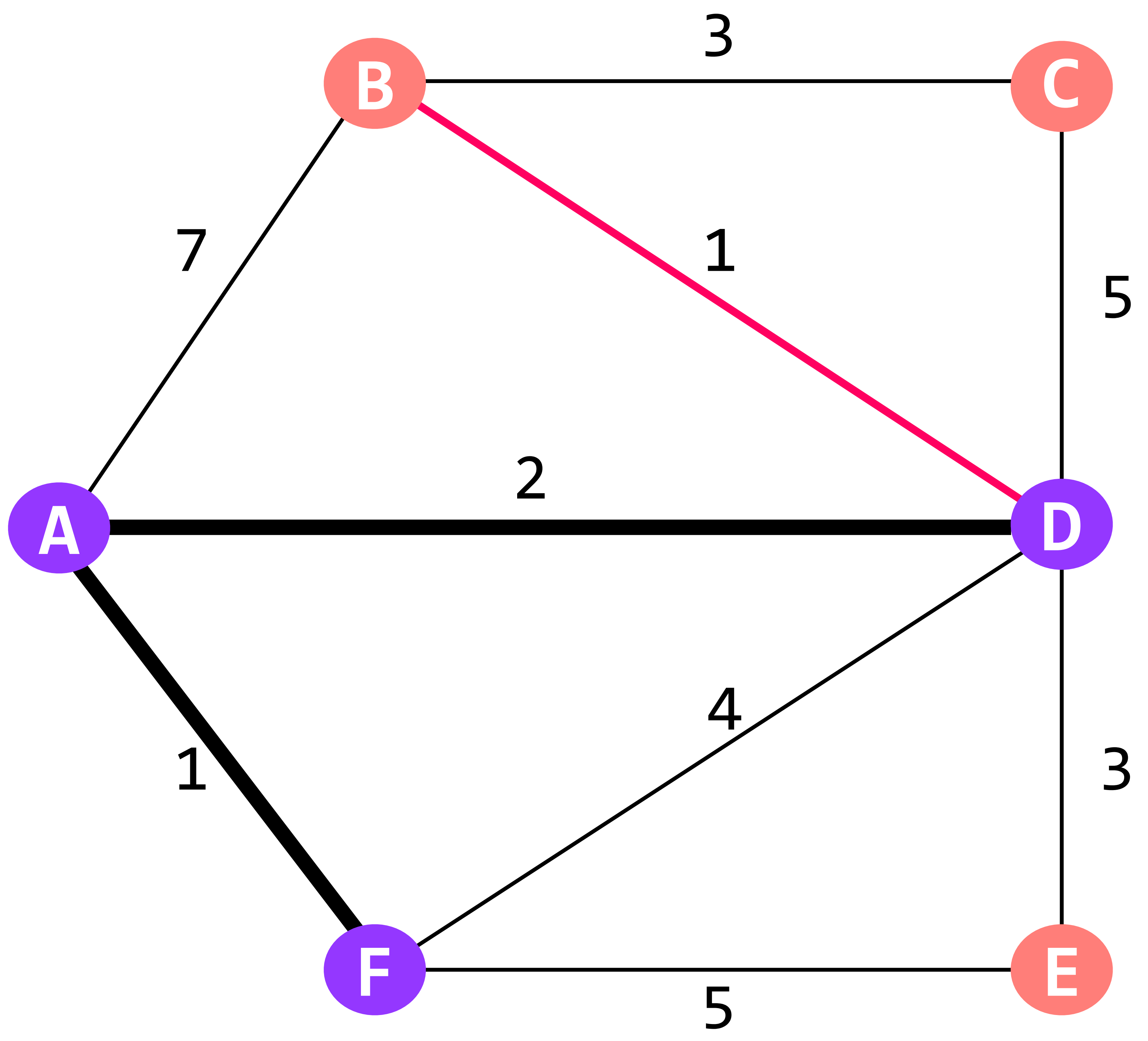

A's routing table

dst	route	cost
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C	?	∞
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E	A-F	6
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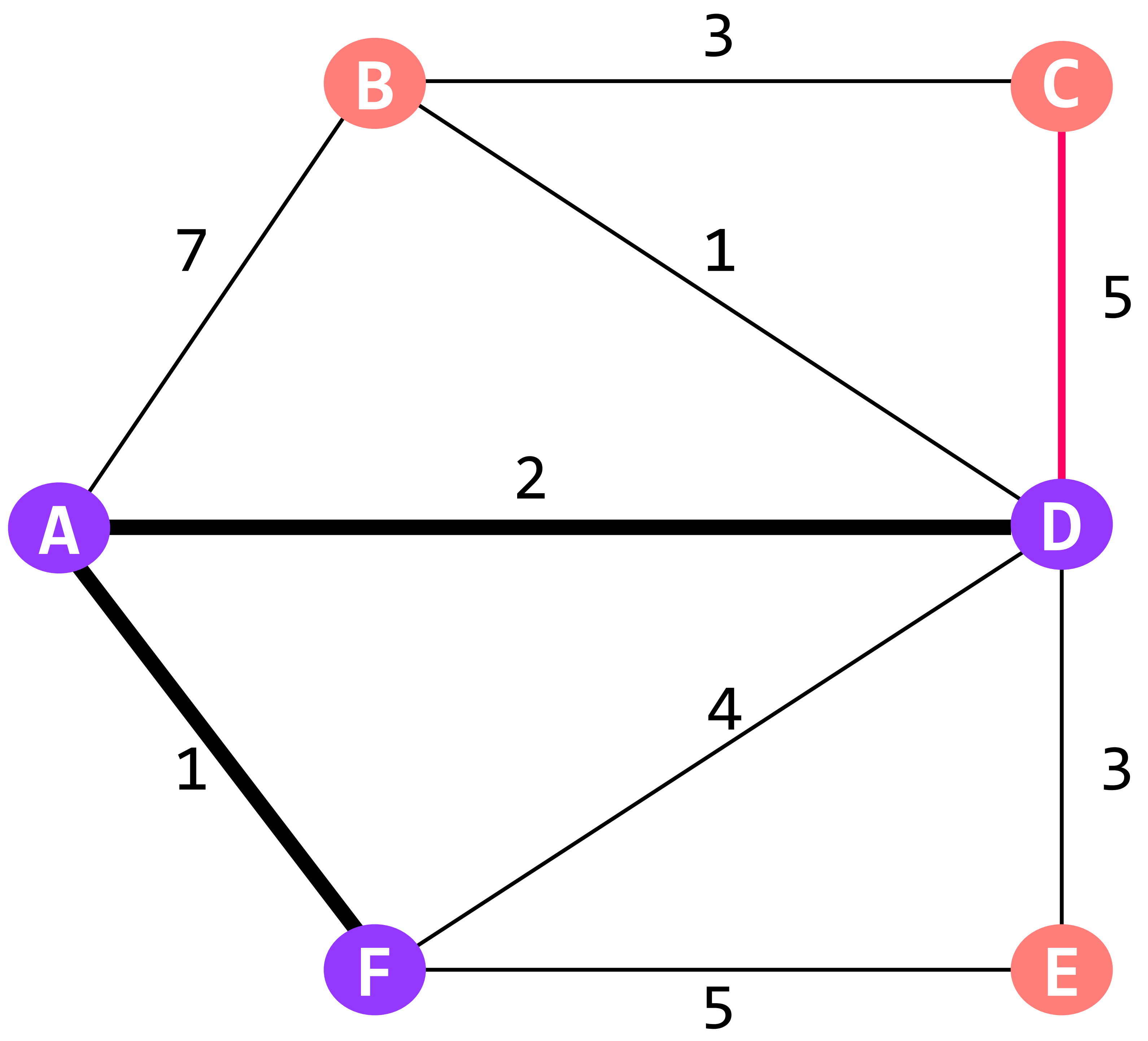

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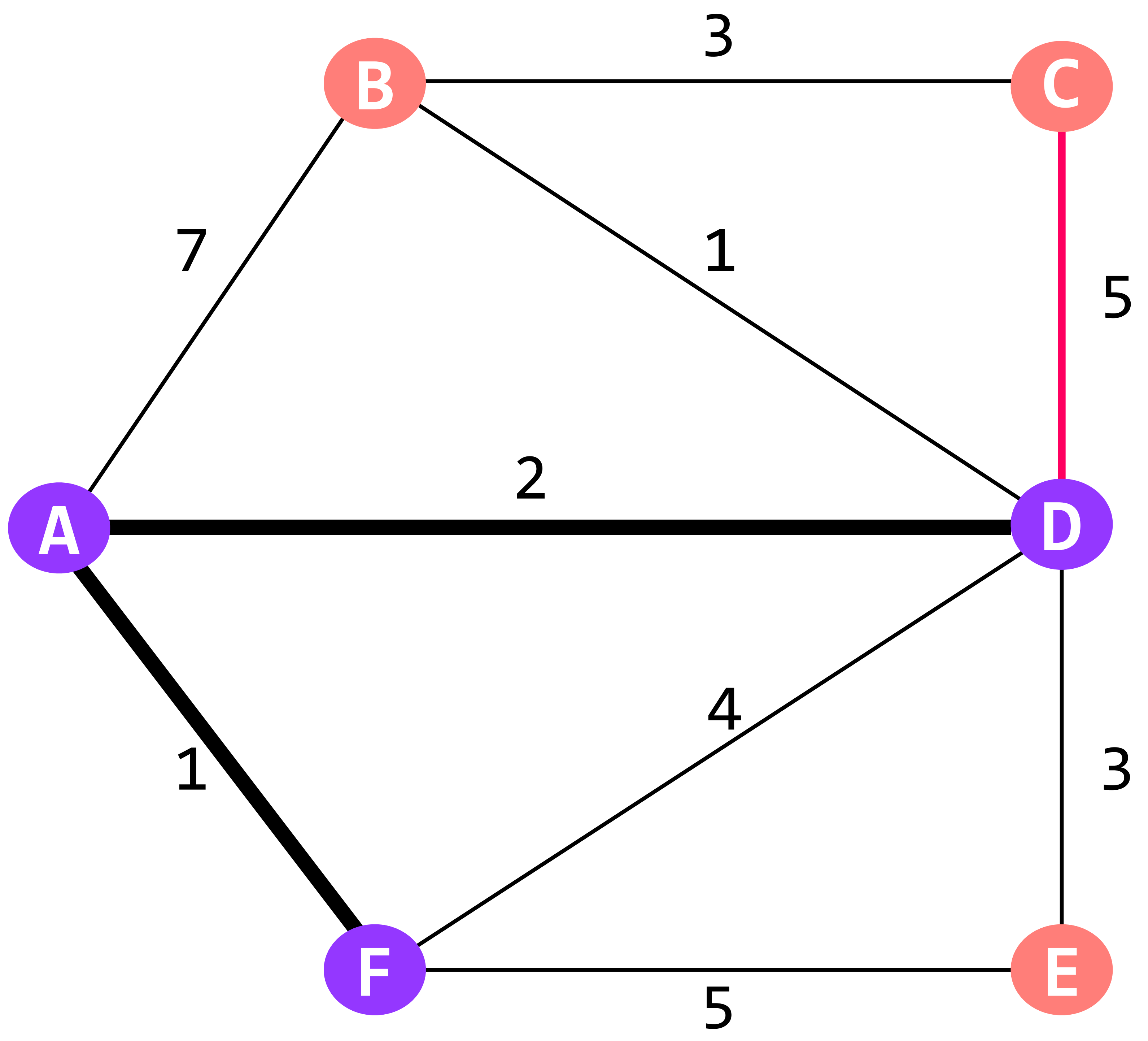

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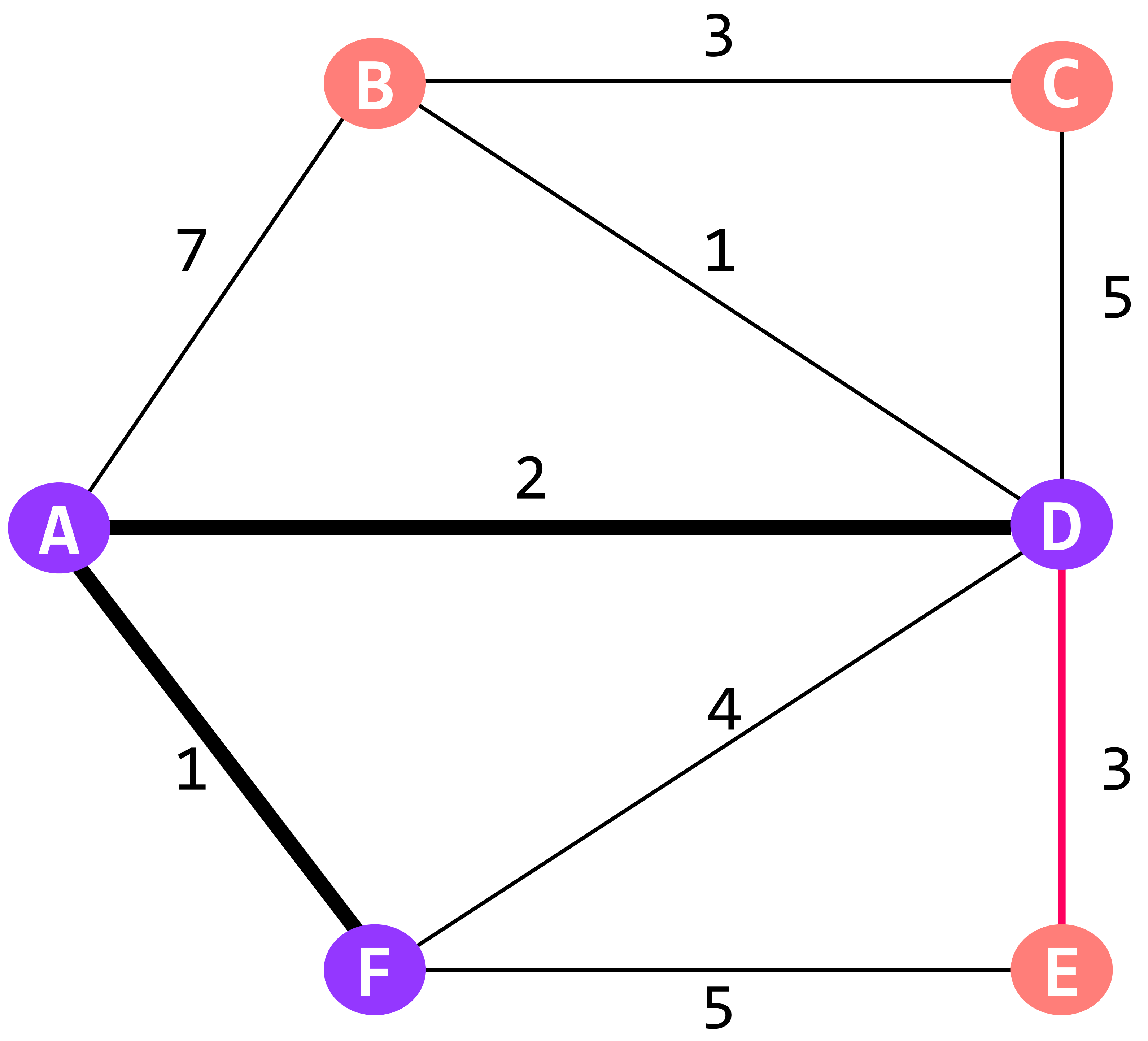

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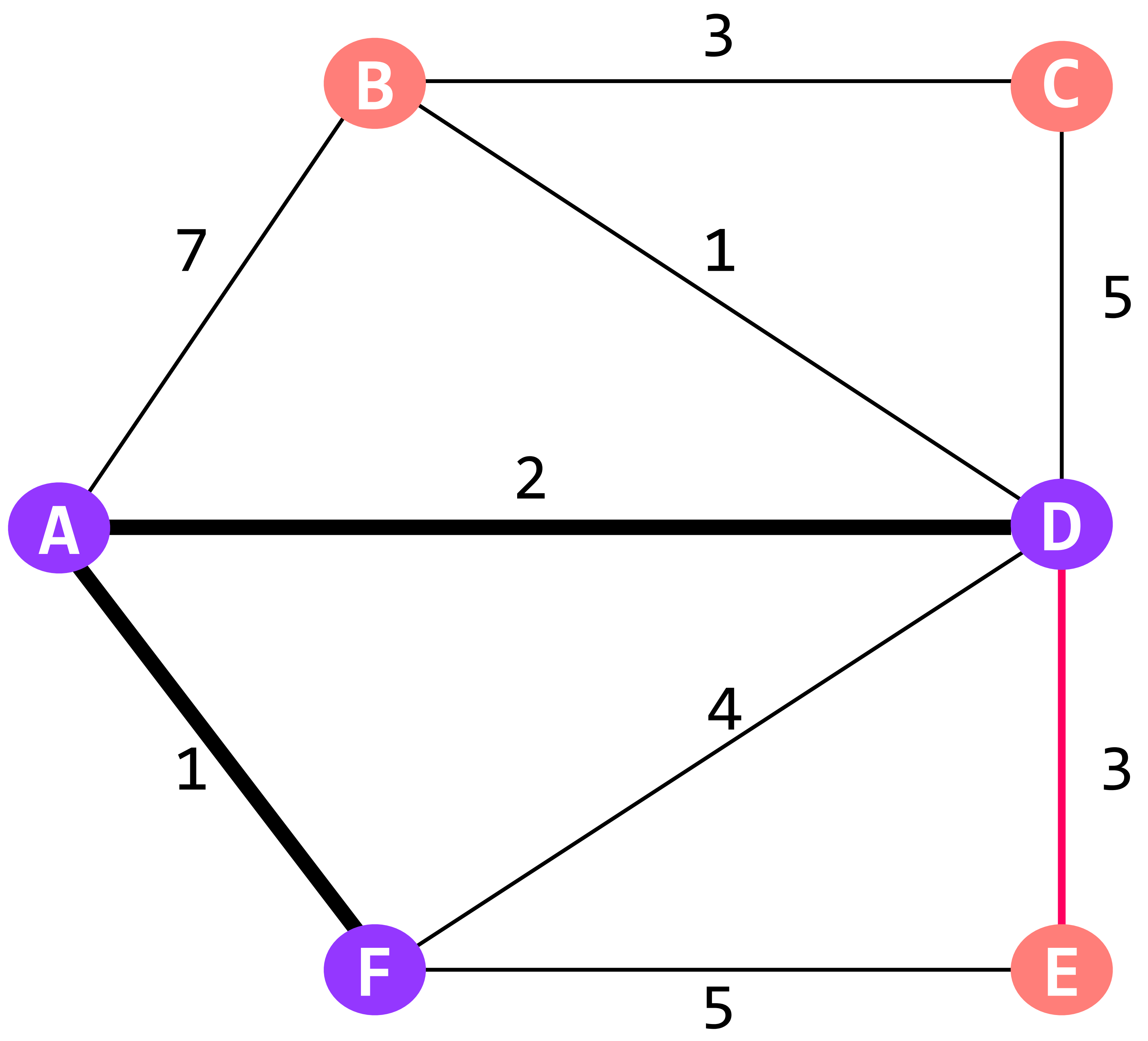

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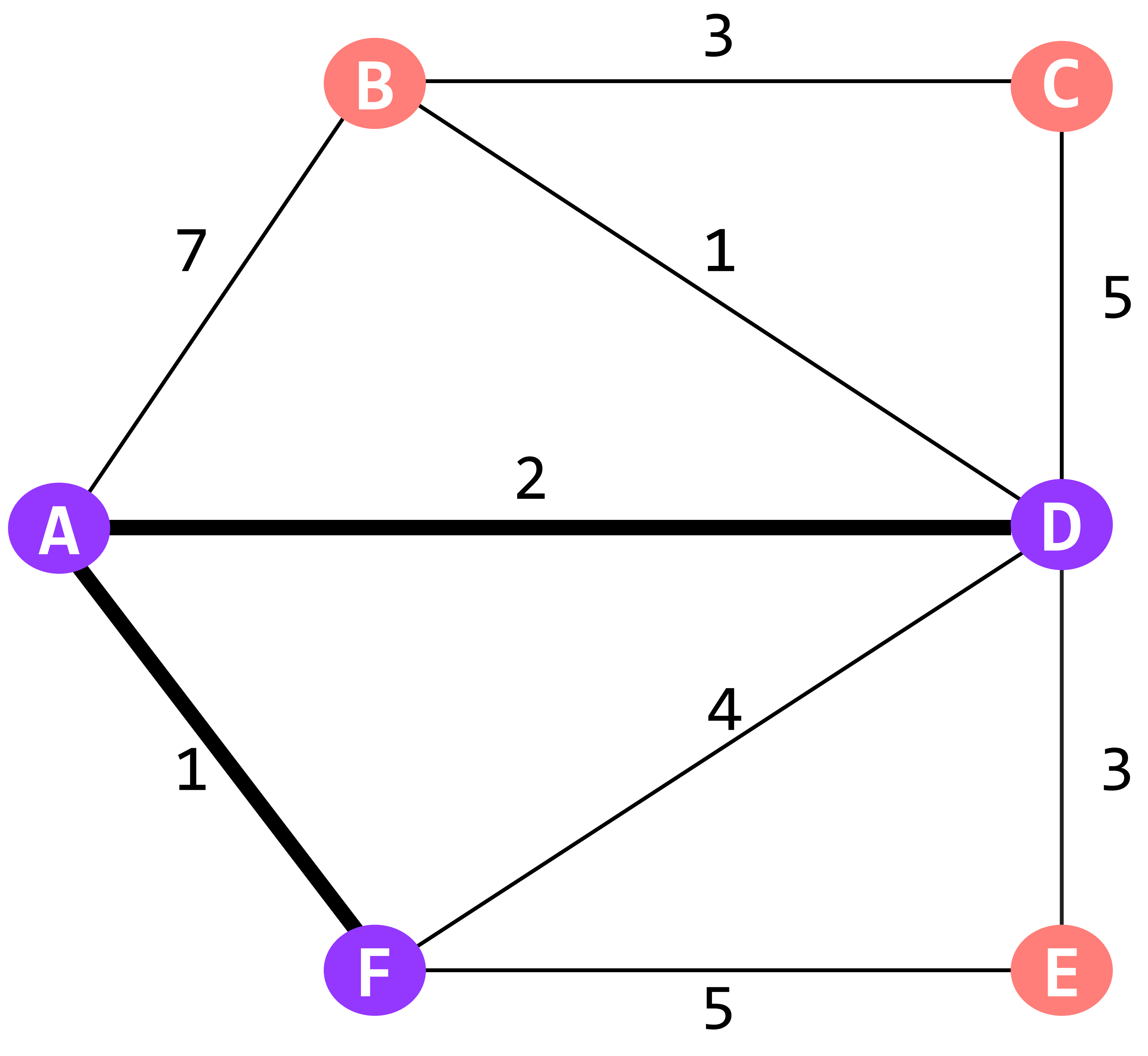

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dst	route	cost
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we don't need to "visit" F; we already know the shortest path to it

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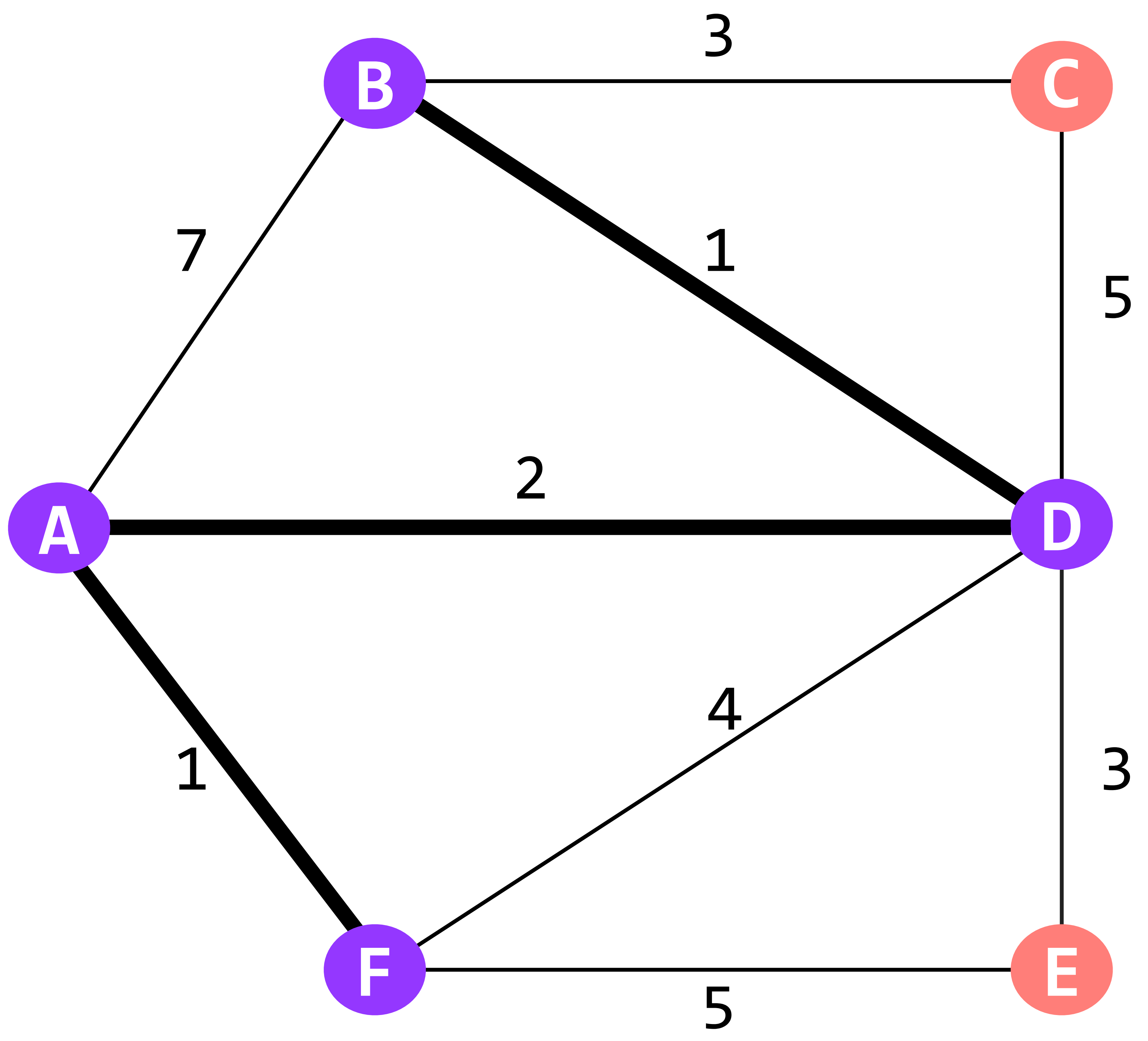

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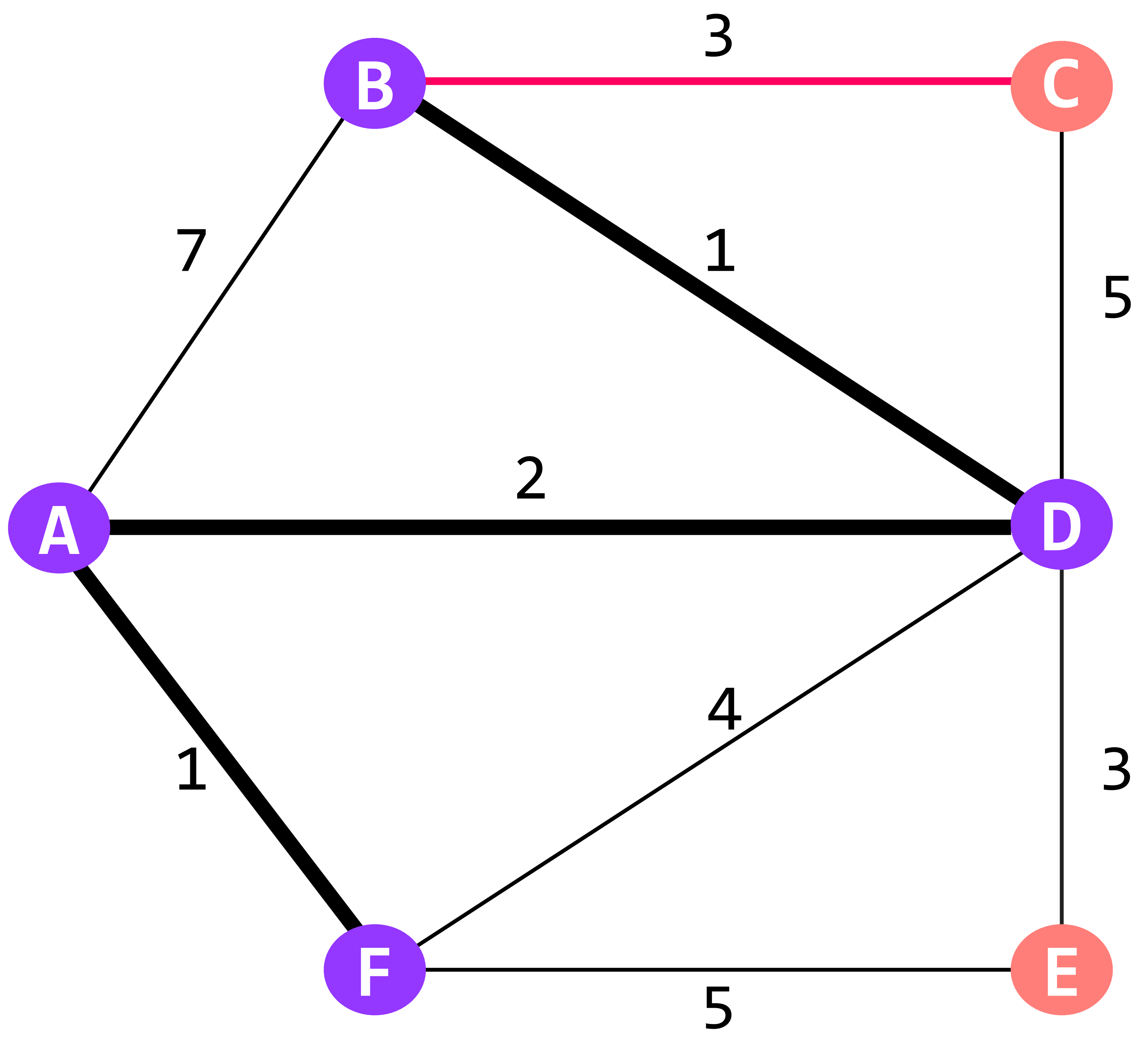

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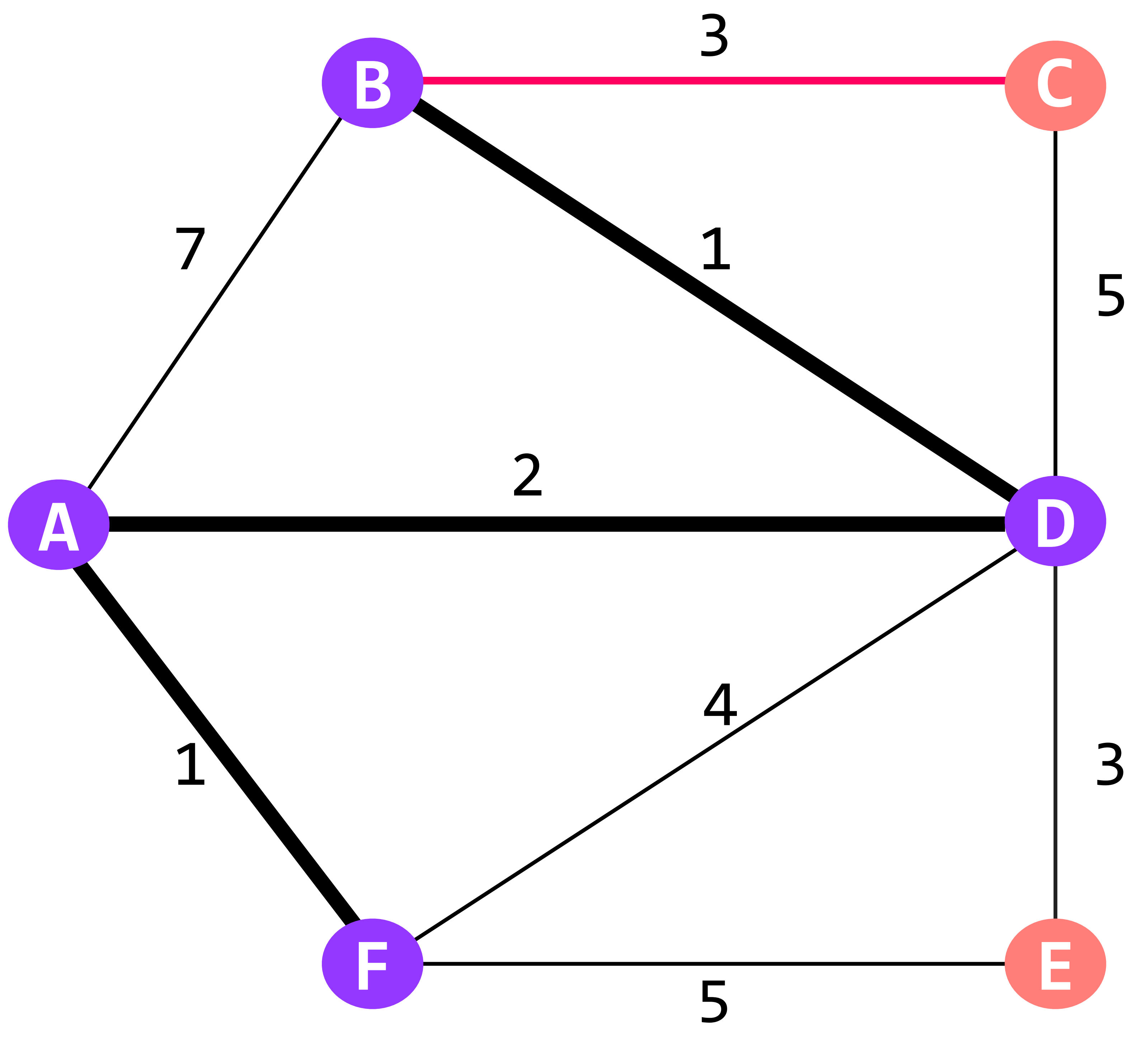

A's routing table

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B	A-D	3
C	A-D	6
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E	A-D	5
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notice that A's *route* doesn't change, but the cost needs to update
(and the actual path of the packets from A to C has changed)

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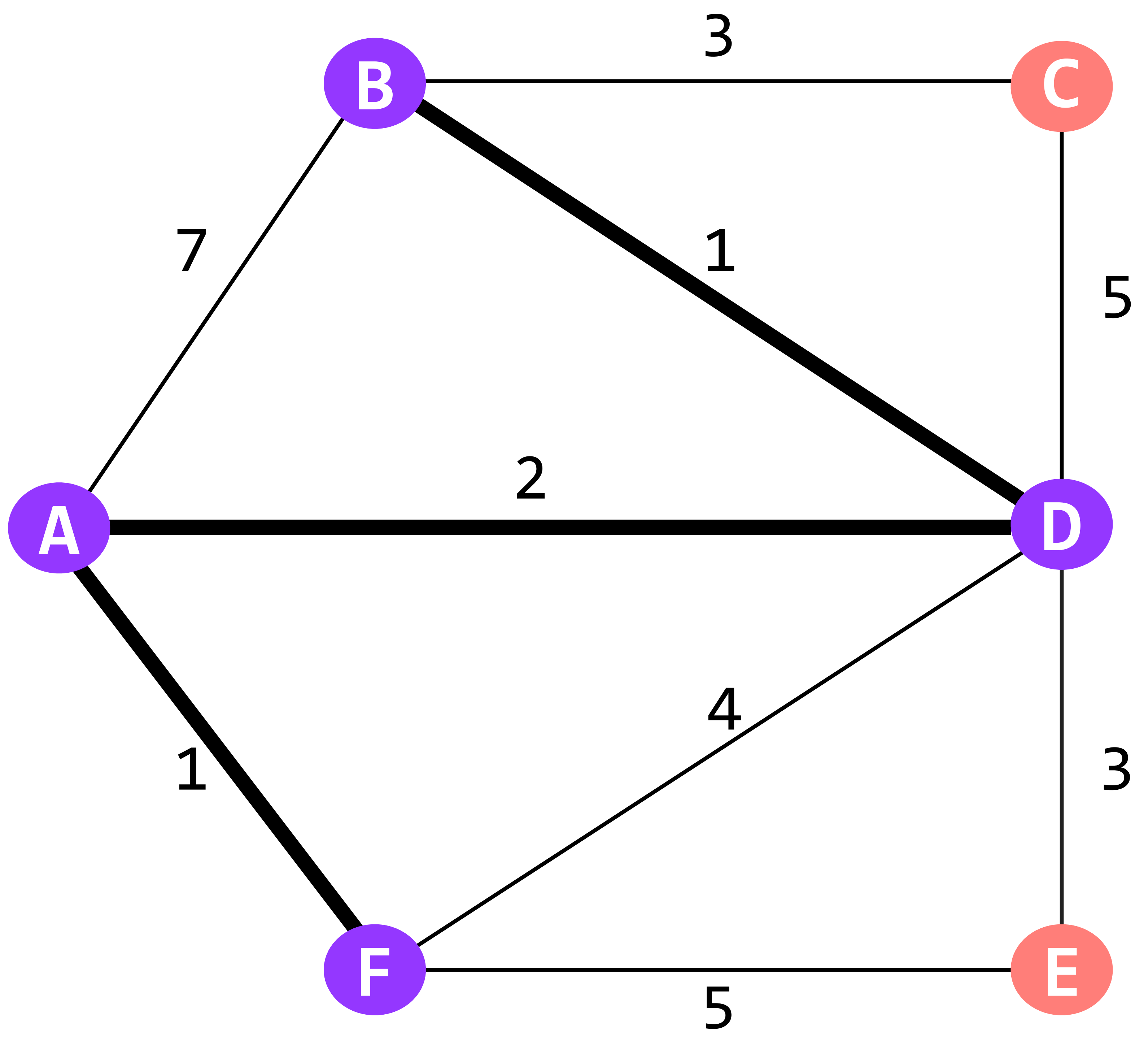

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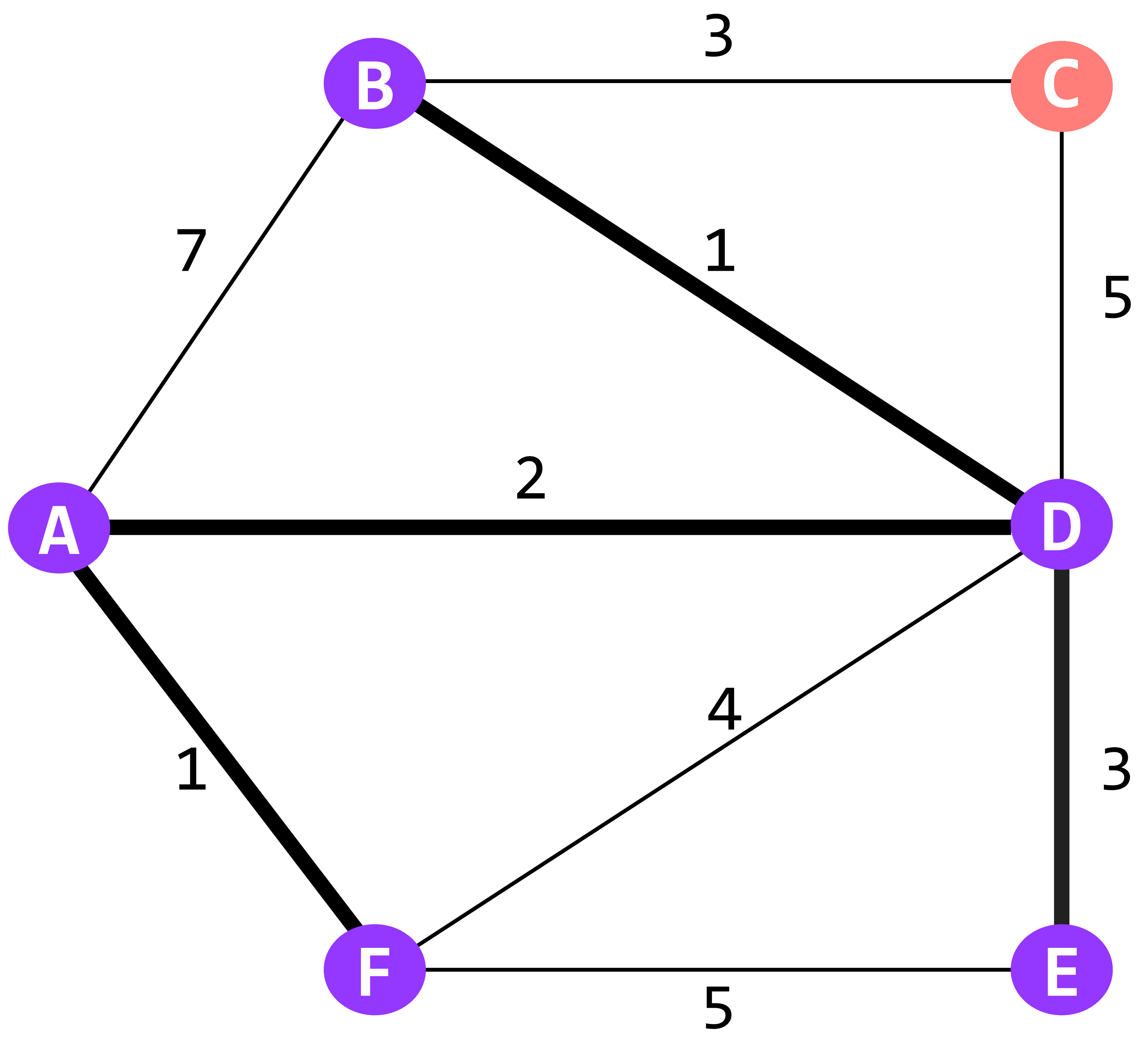

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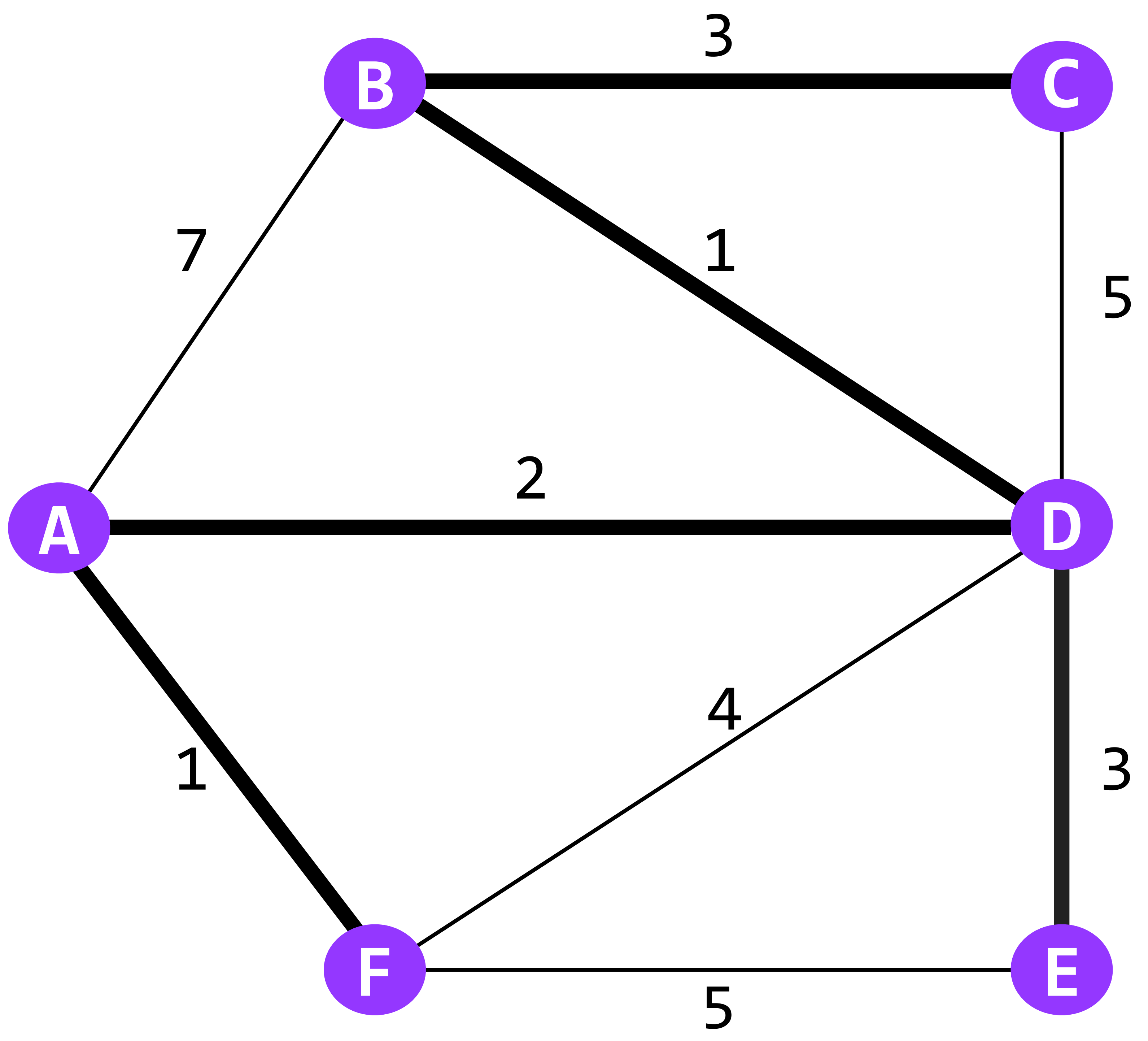

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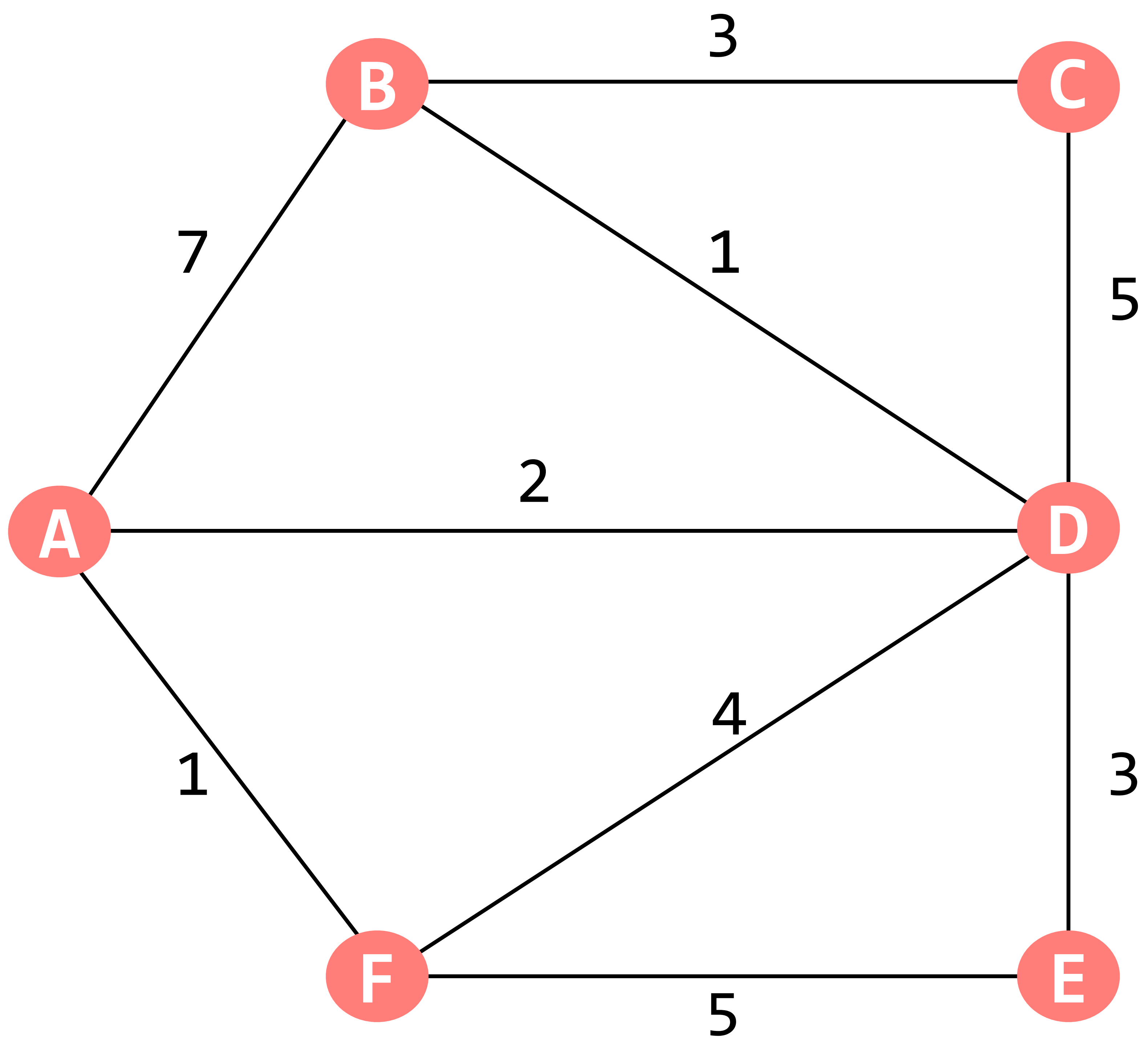

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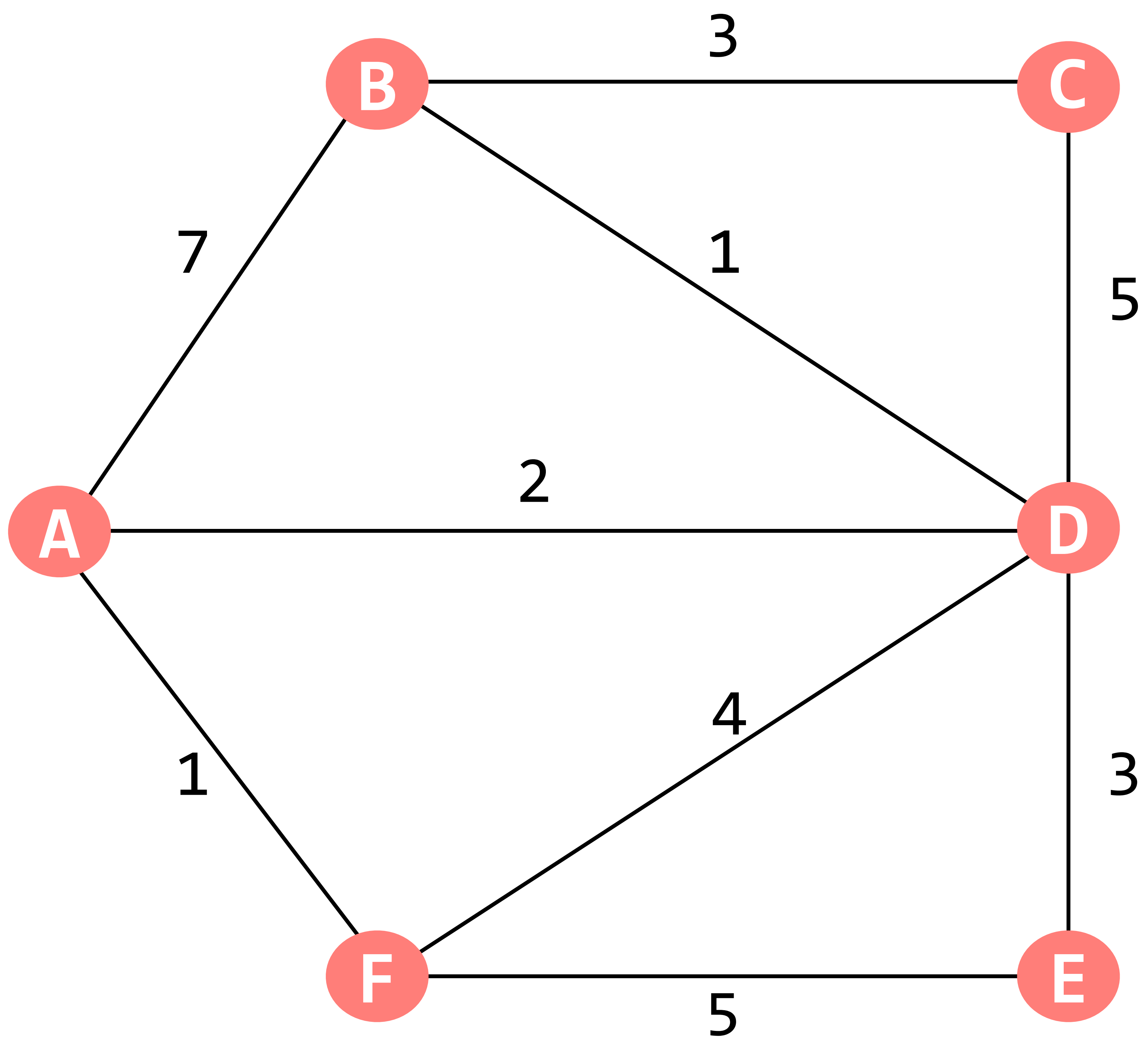

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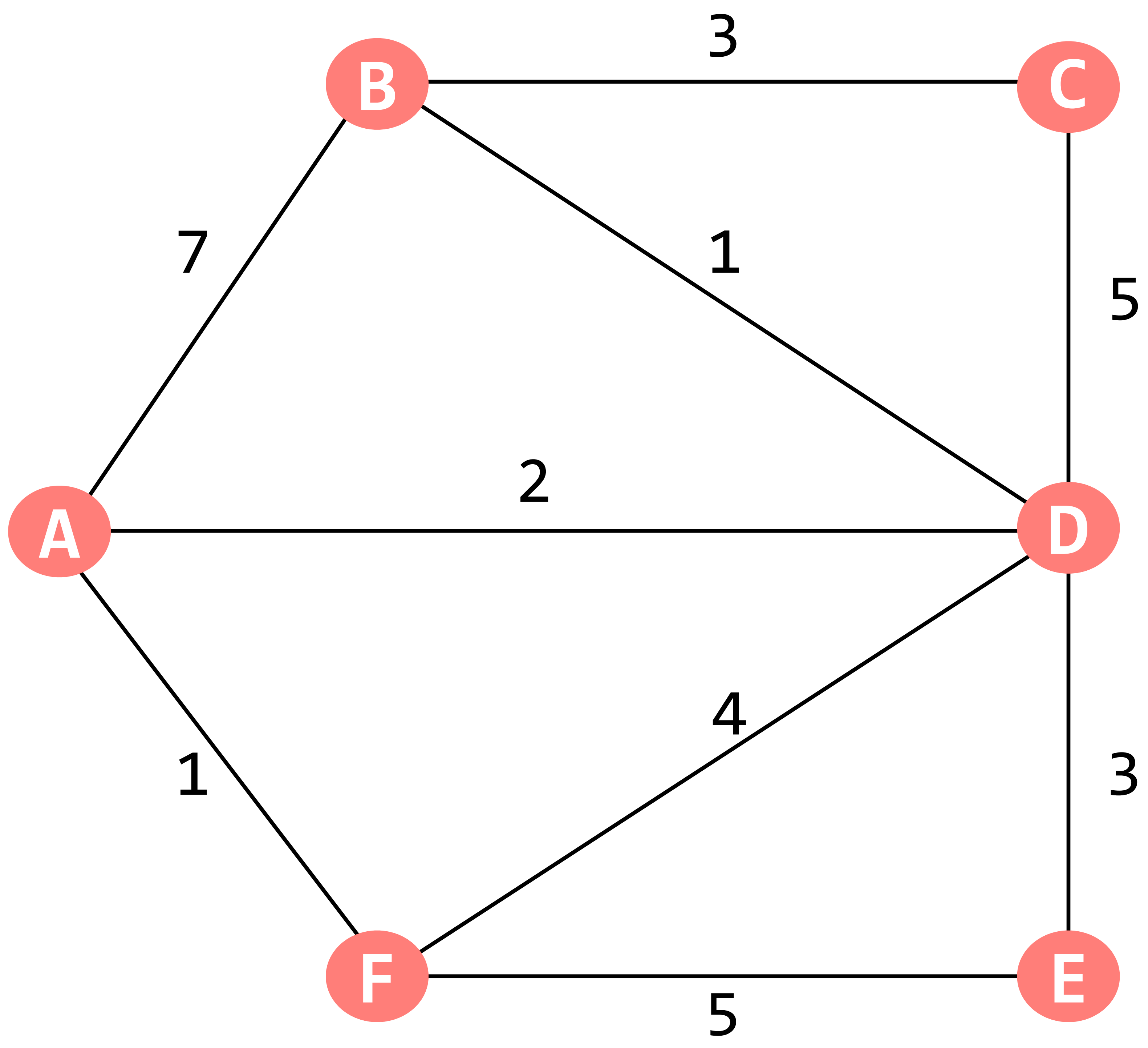

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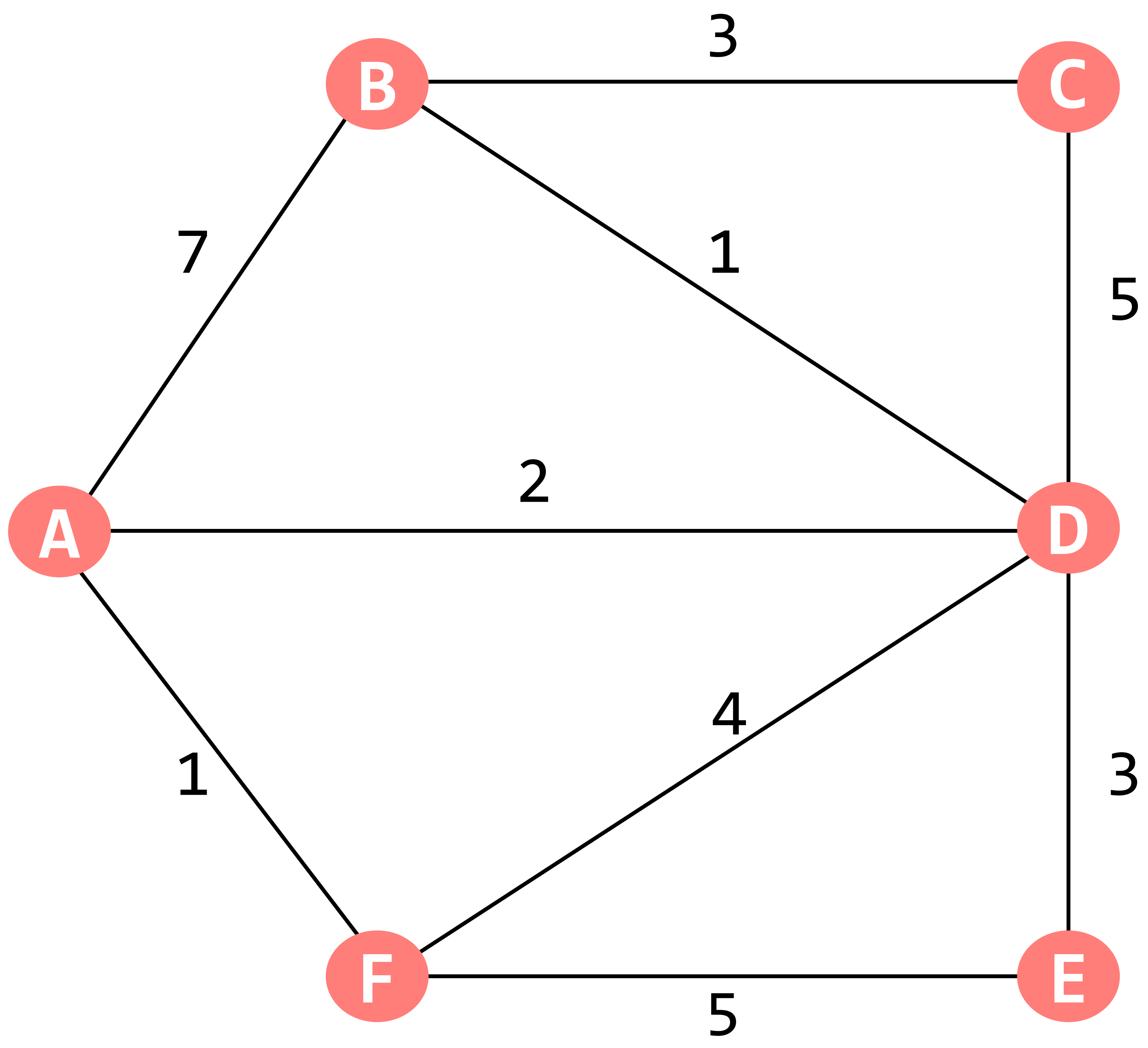

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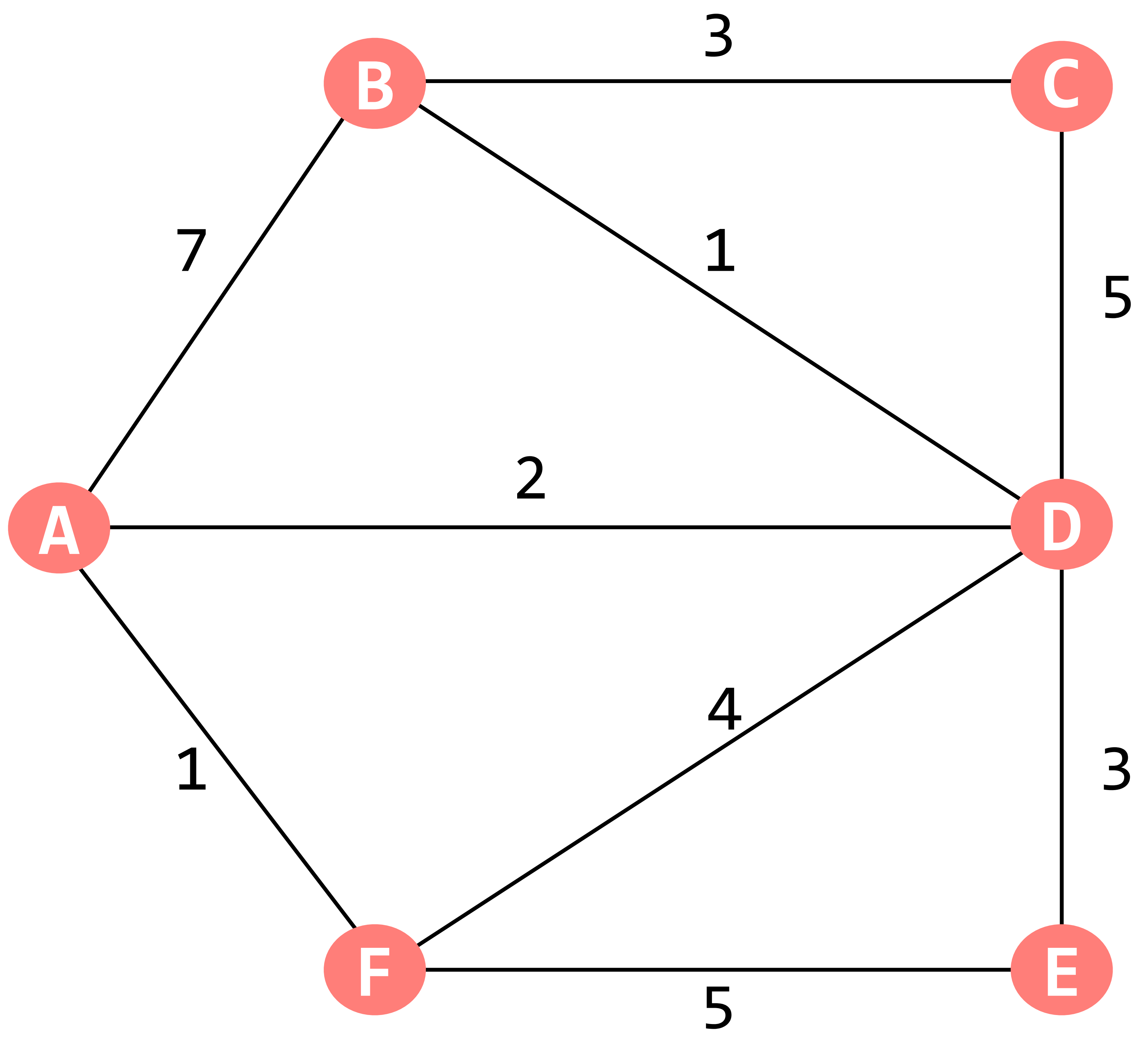

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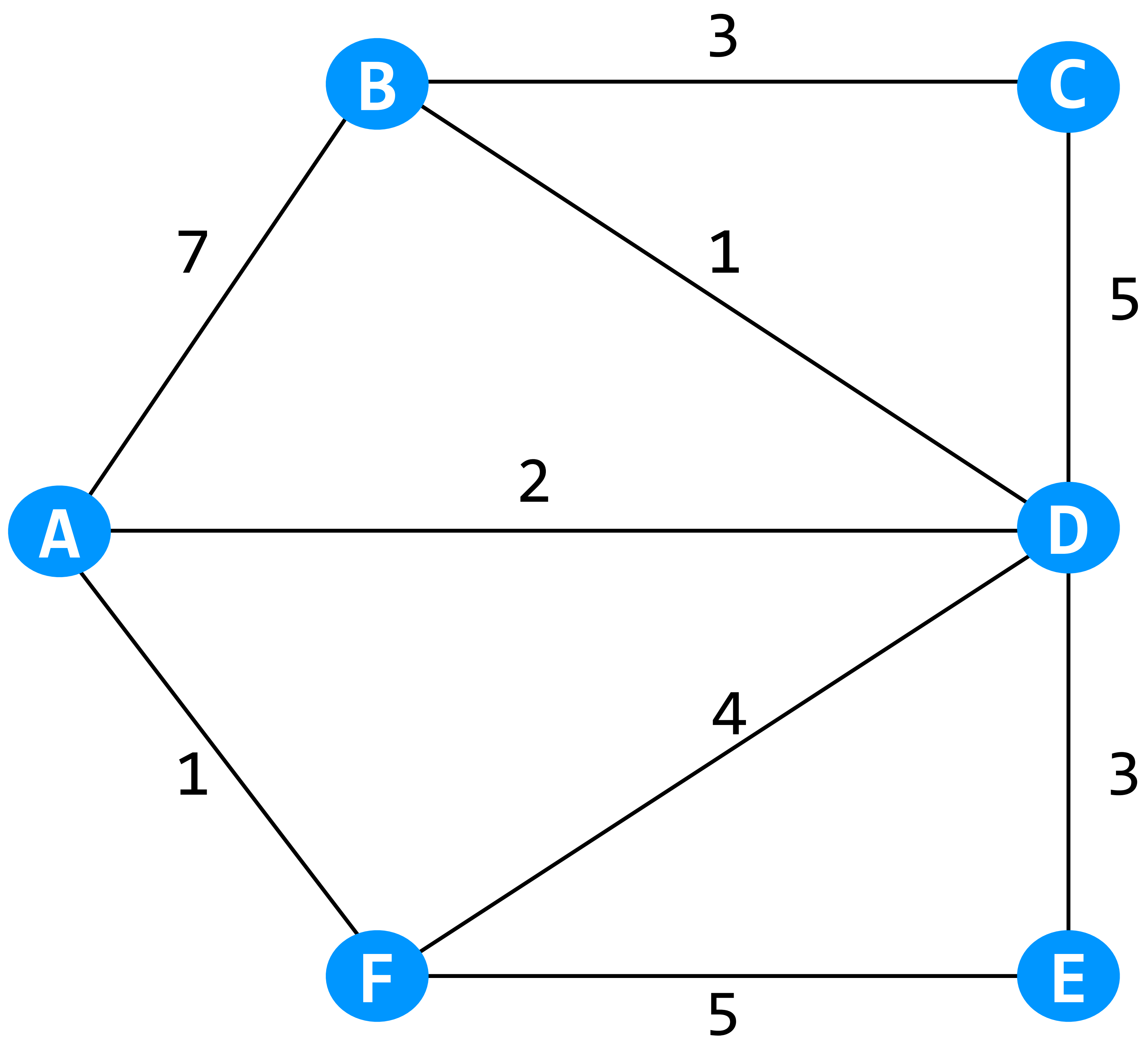
the **overhead** of flooding

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



link state	distance vector
what's in an advertisement	
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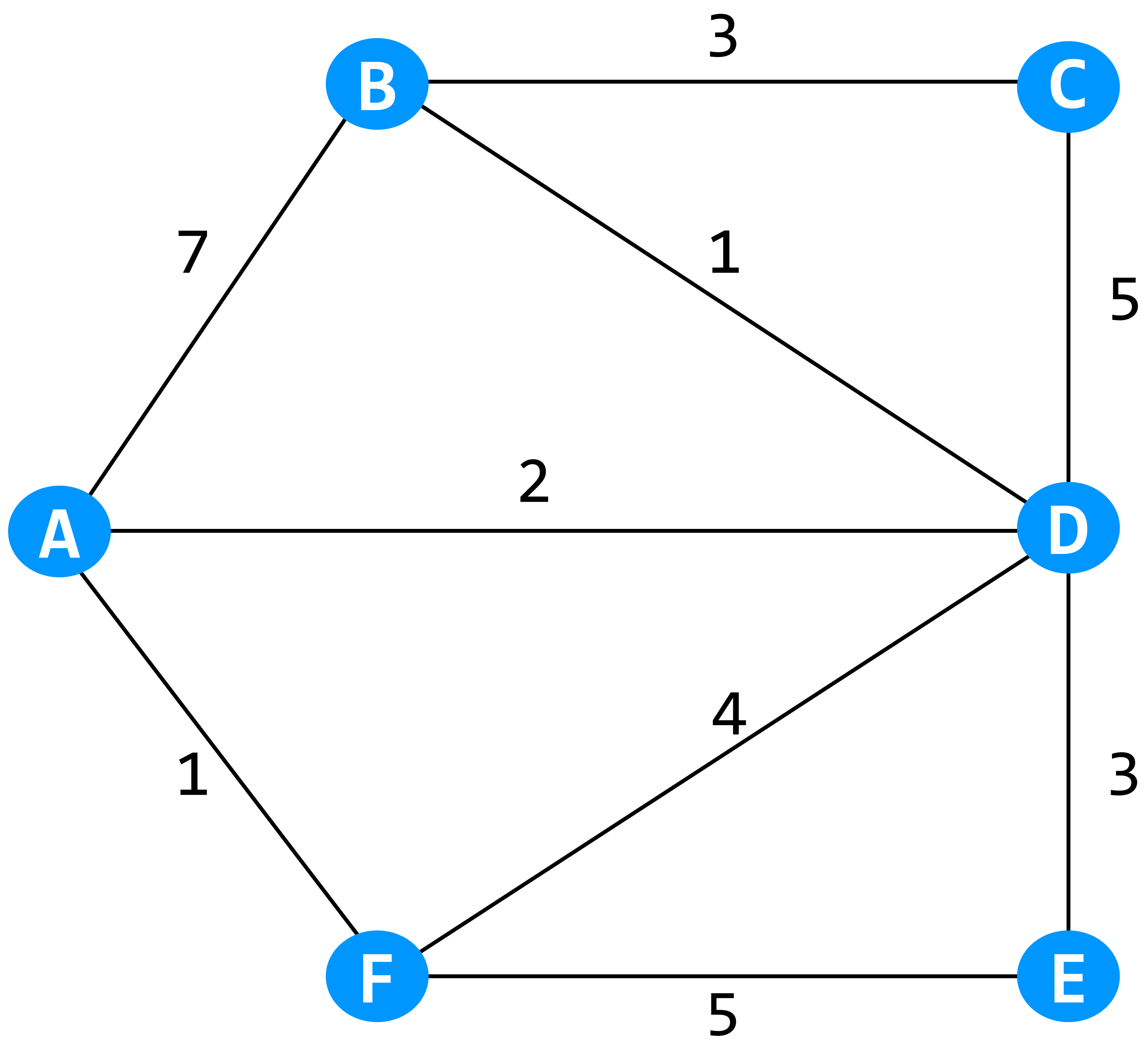

link state	distance vector
what's in an advertisement	
its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	
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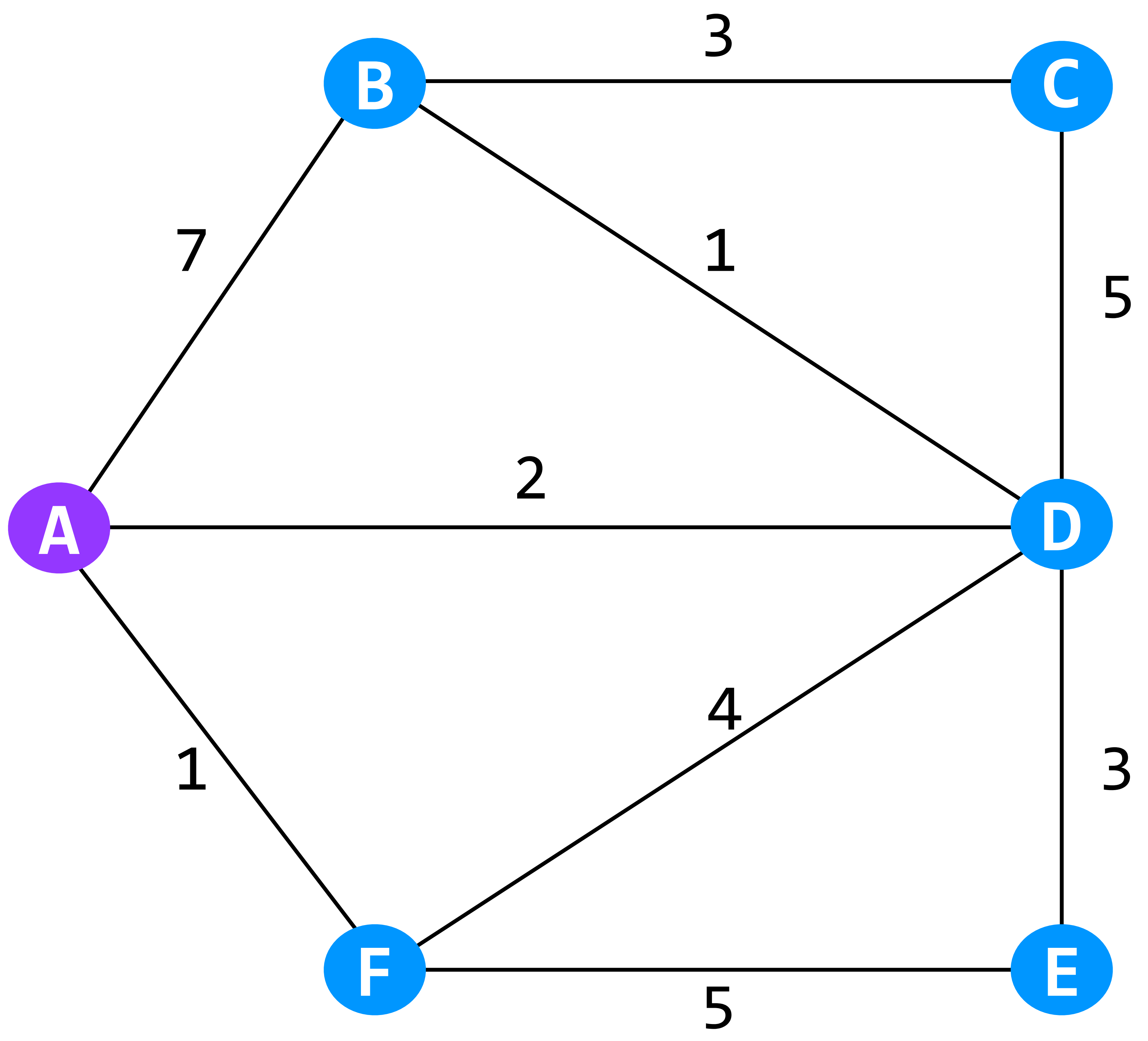

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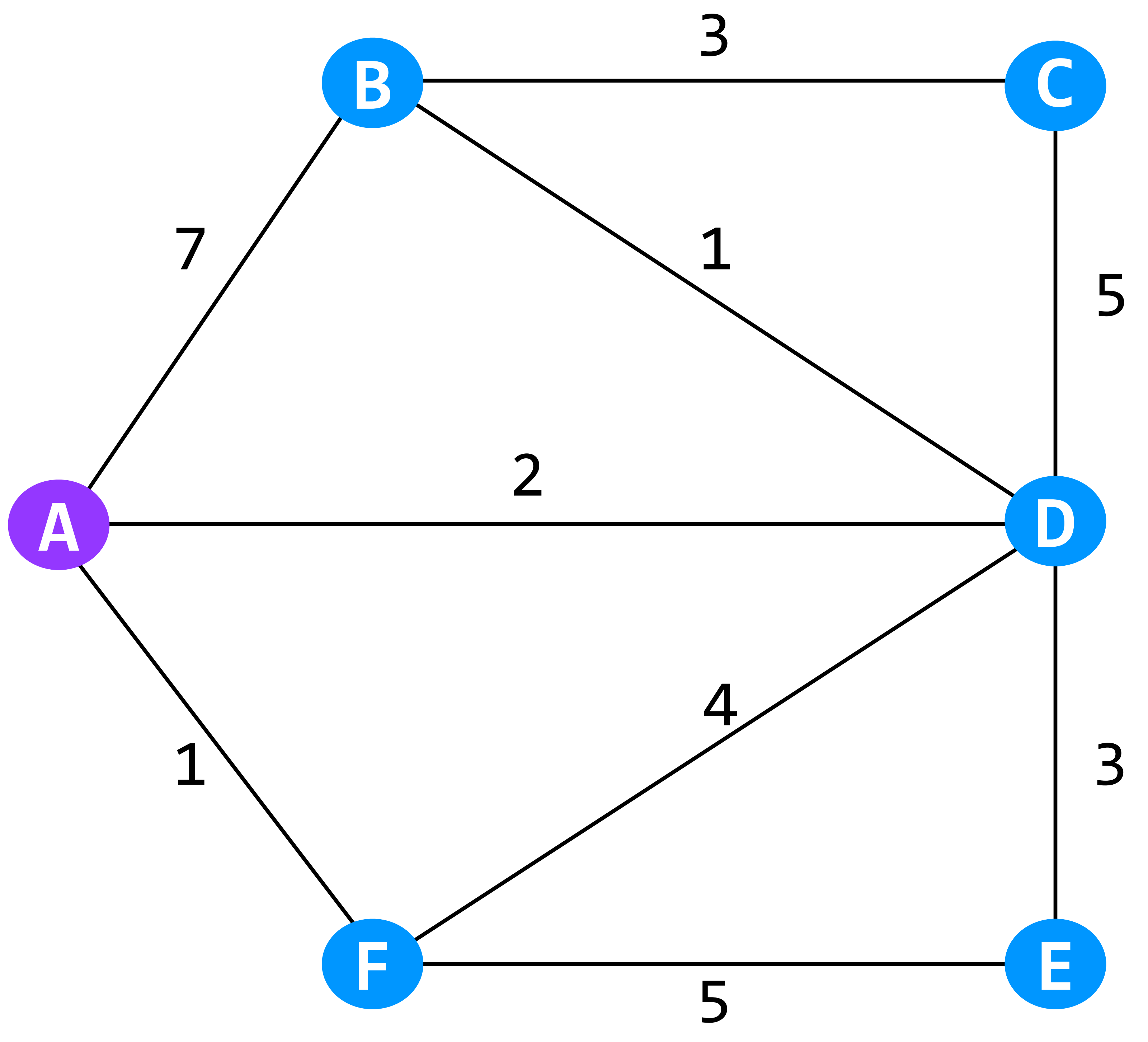

`A's first advertisement: [(B,7),(D,2),(F,1)]`

A could also include `(A,0)` here

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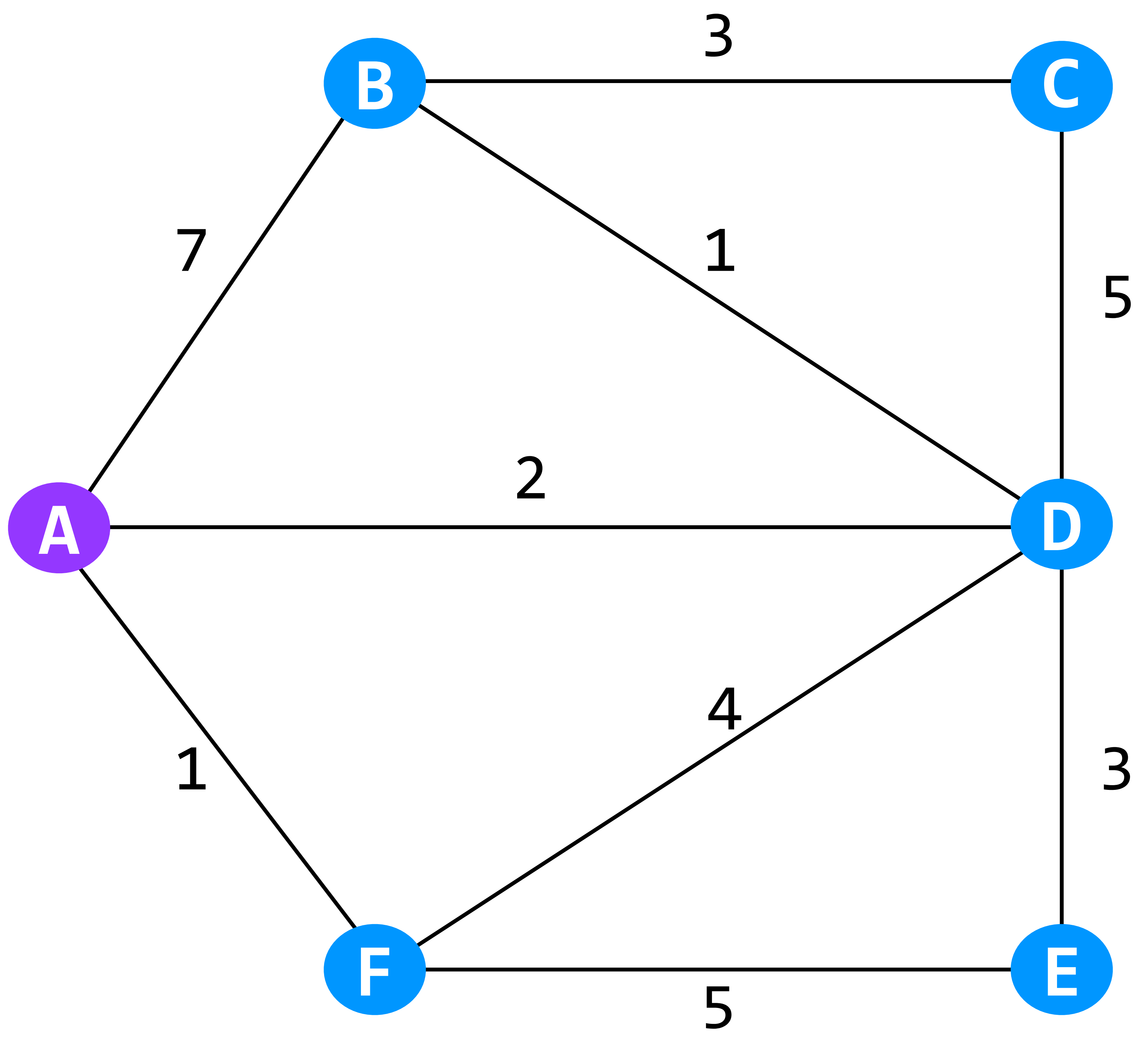

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A's advertisement reflects its routing table, and right now, A only knows about its neighbors

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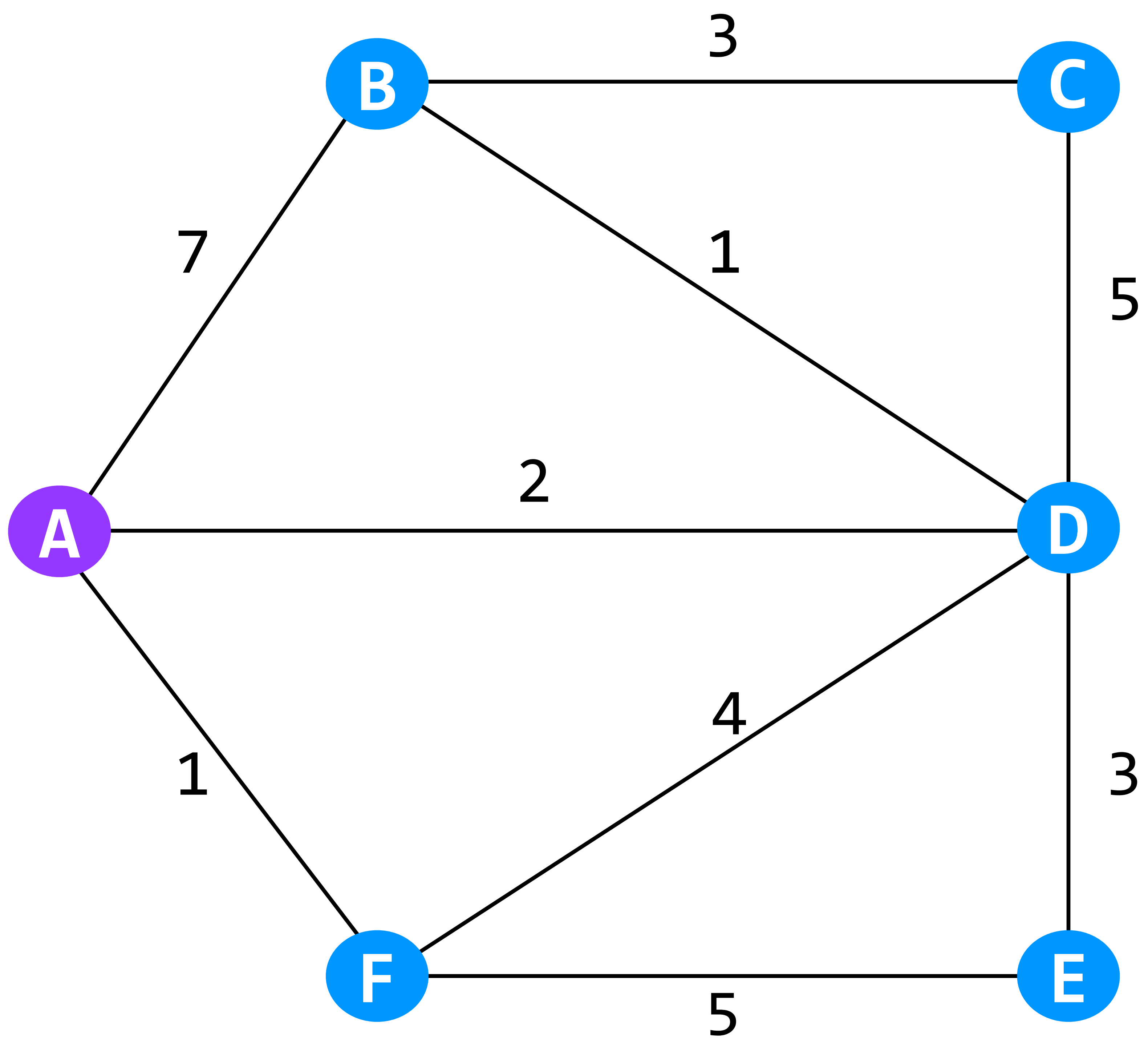

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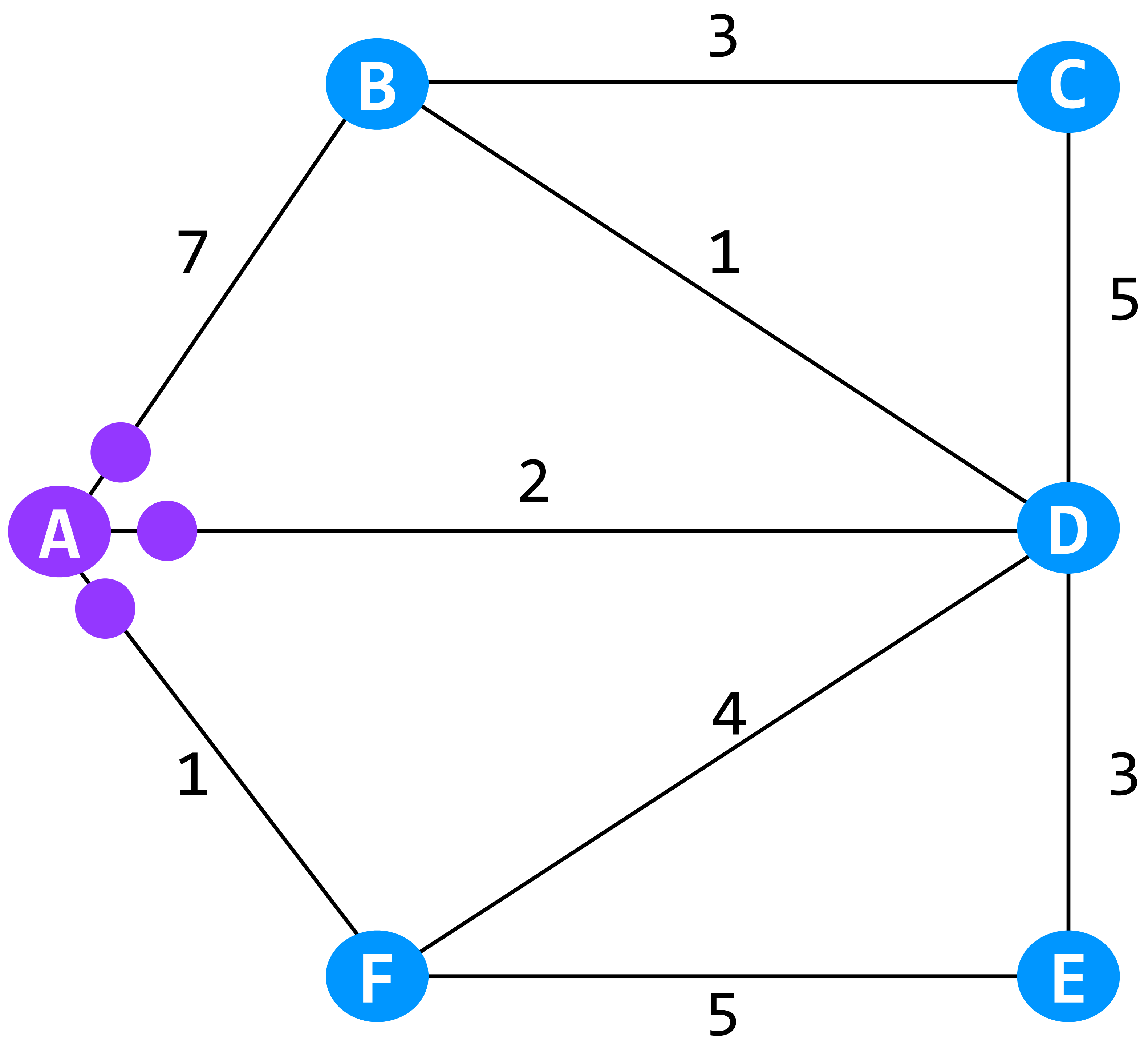

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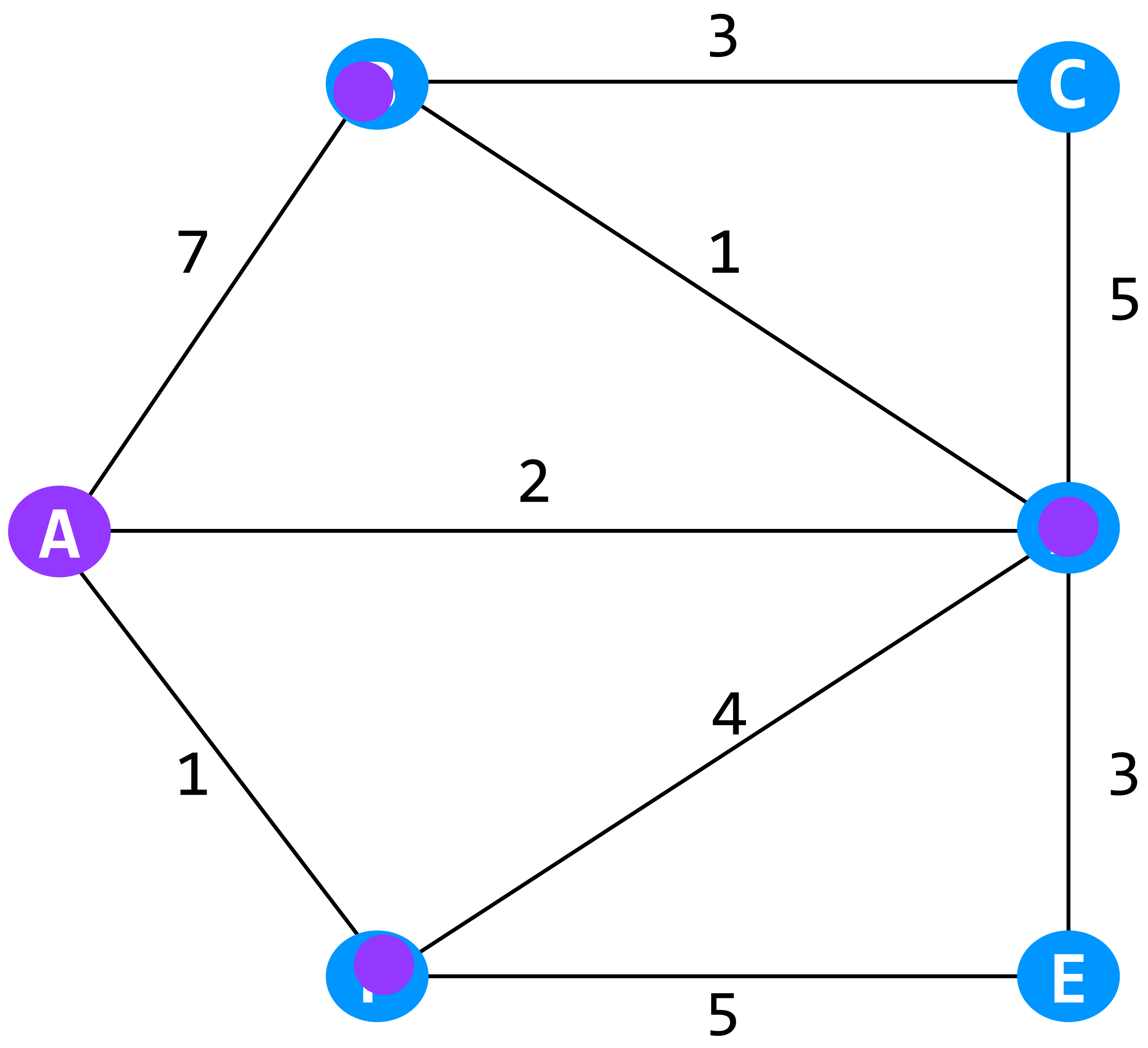

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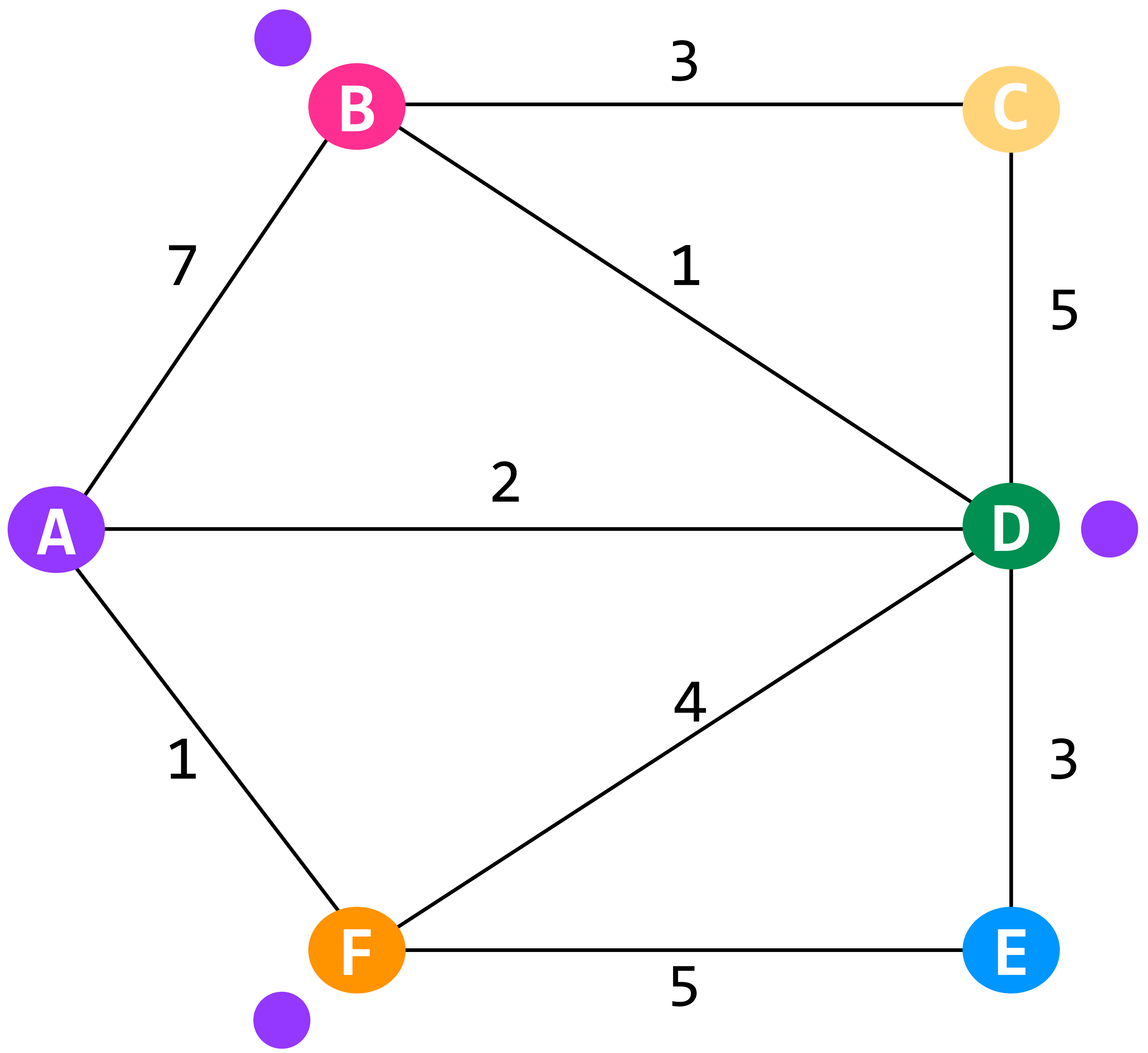

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A’s routing table

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A’s neighbors **do not** forward A’s advertisements; they *do* send advertisements of their own to A

link state	distance vector
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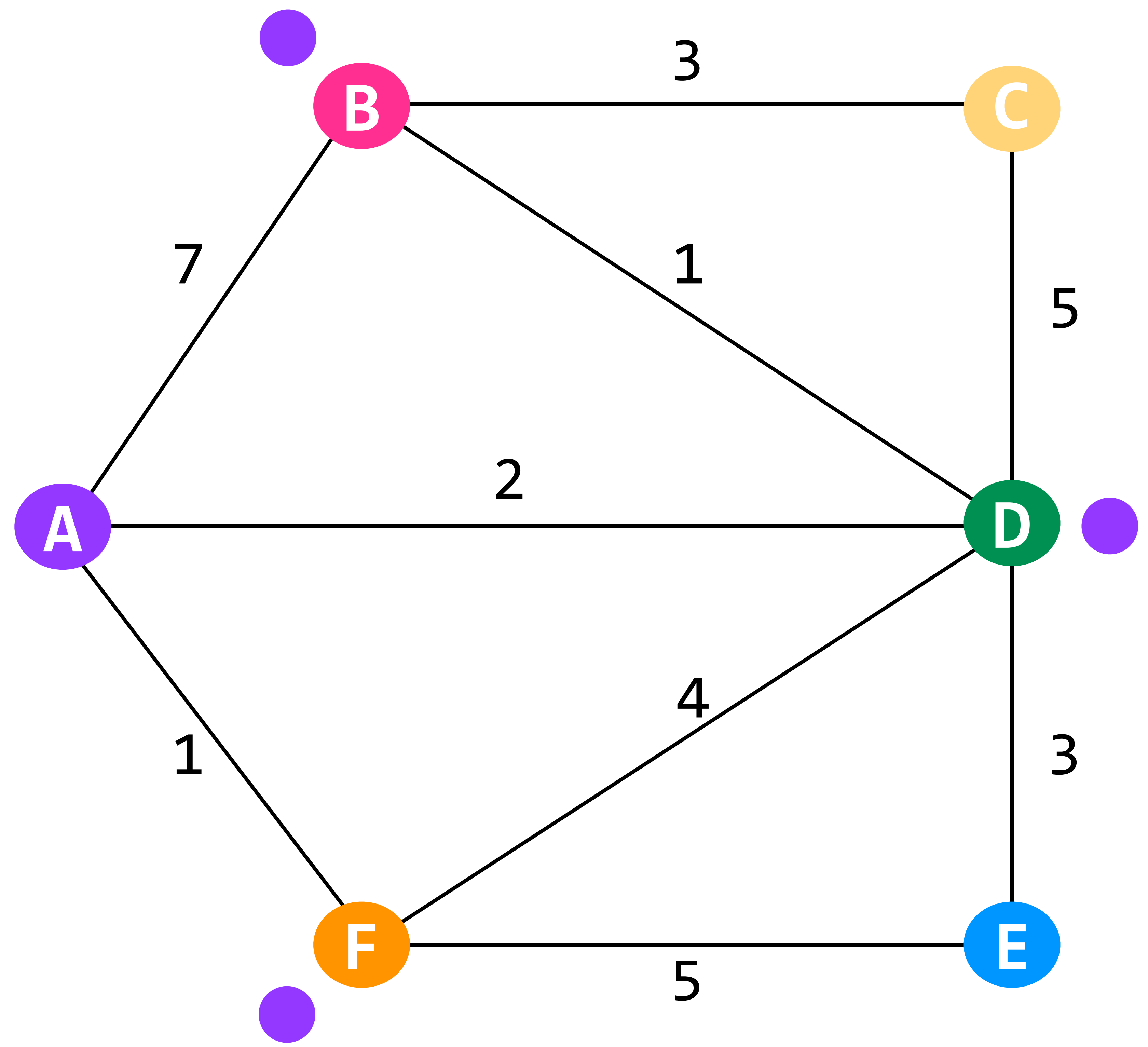


```
A's first advertisement: [(B,7),(D,2),(F,1)]
```

A's routing table

dst	route	cost
B	A-B	7
D	A-D	2
F	A-F	1

A's neighbors **do not** forward A's advertisements; they *do* send advertisements of their own to A

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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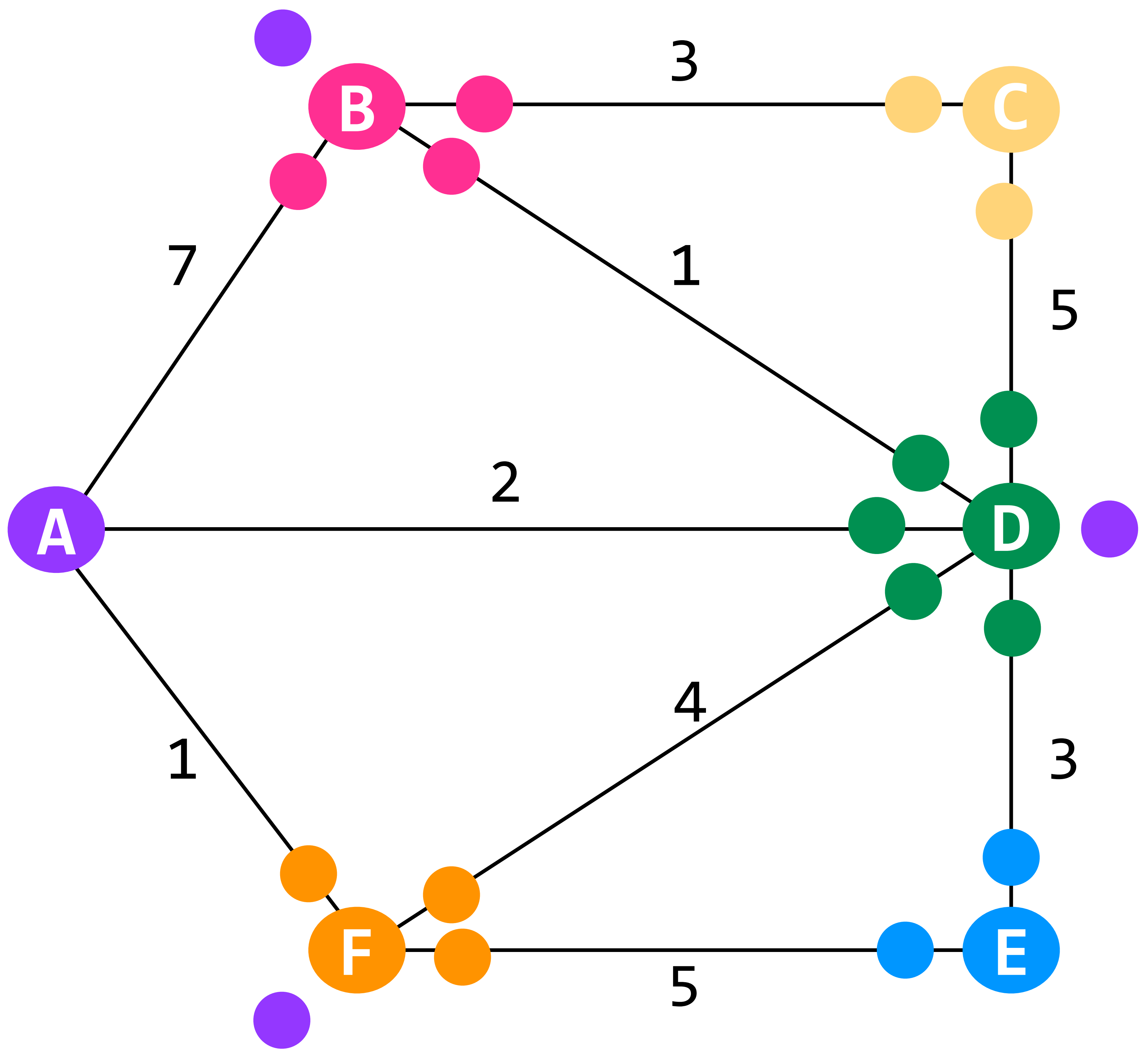

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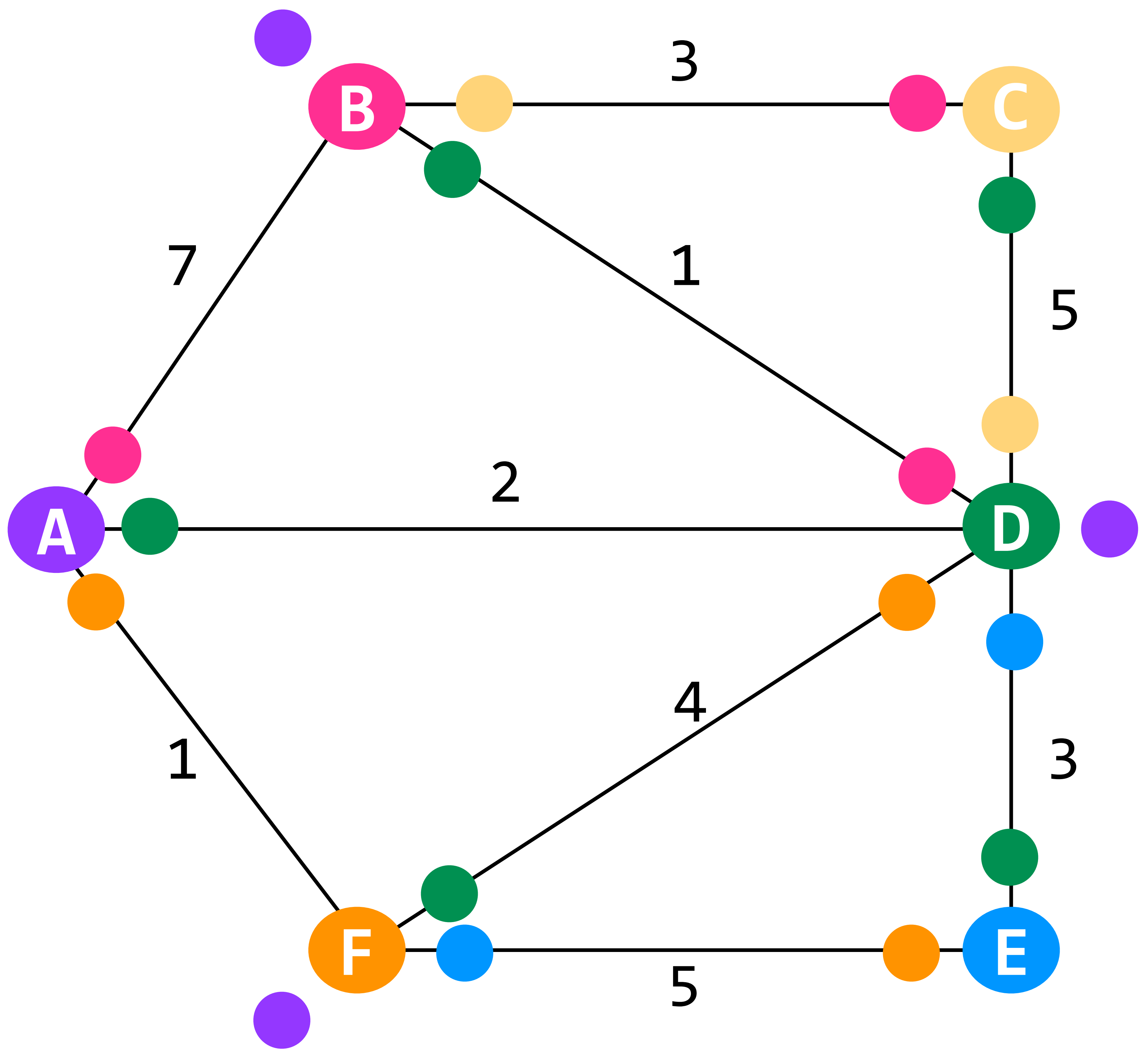


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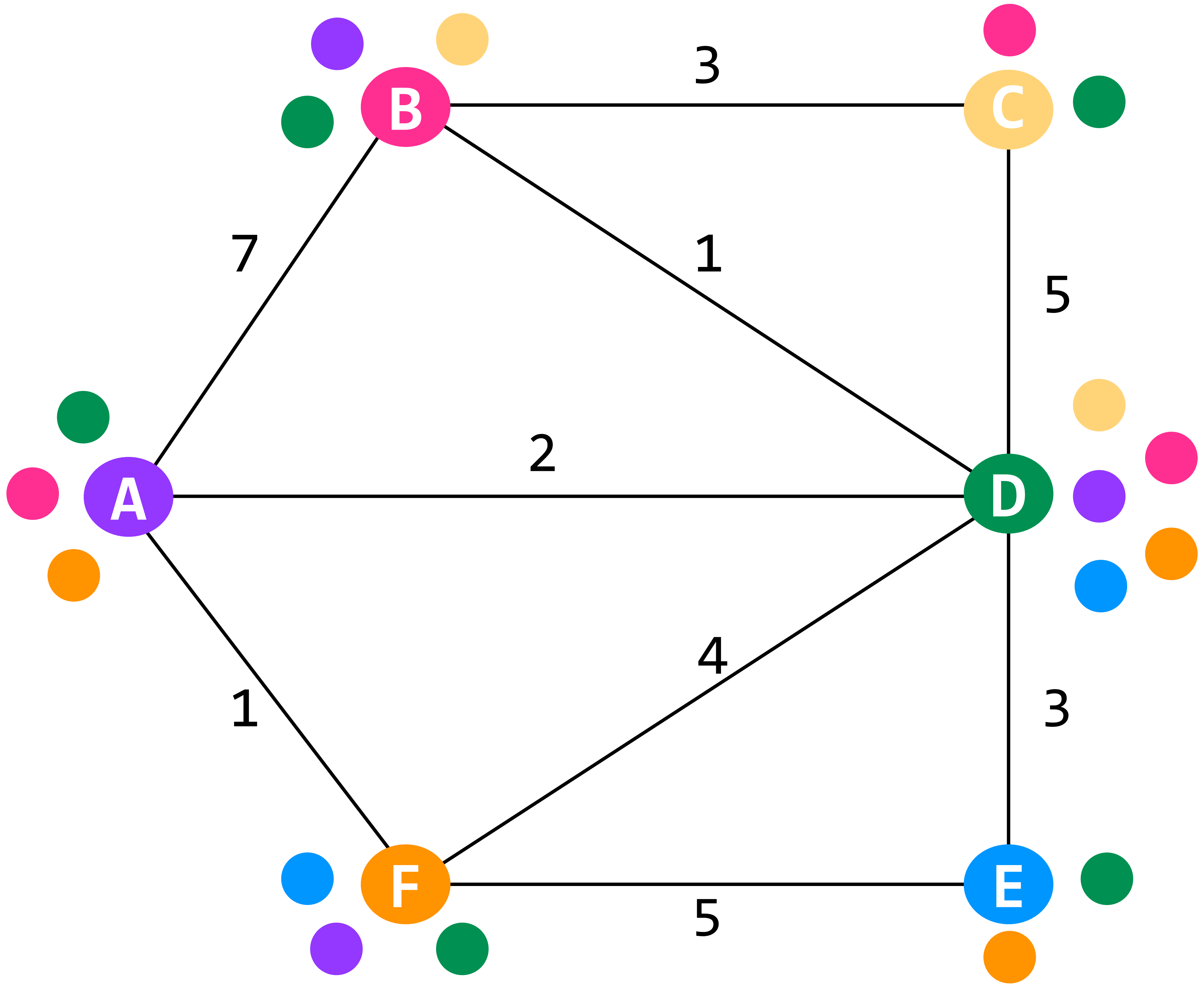
Katrina LaCurts | lacurts@mit.edu | 6.1800 2024

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



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A's routing table

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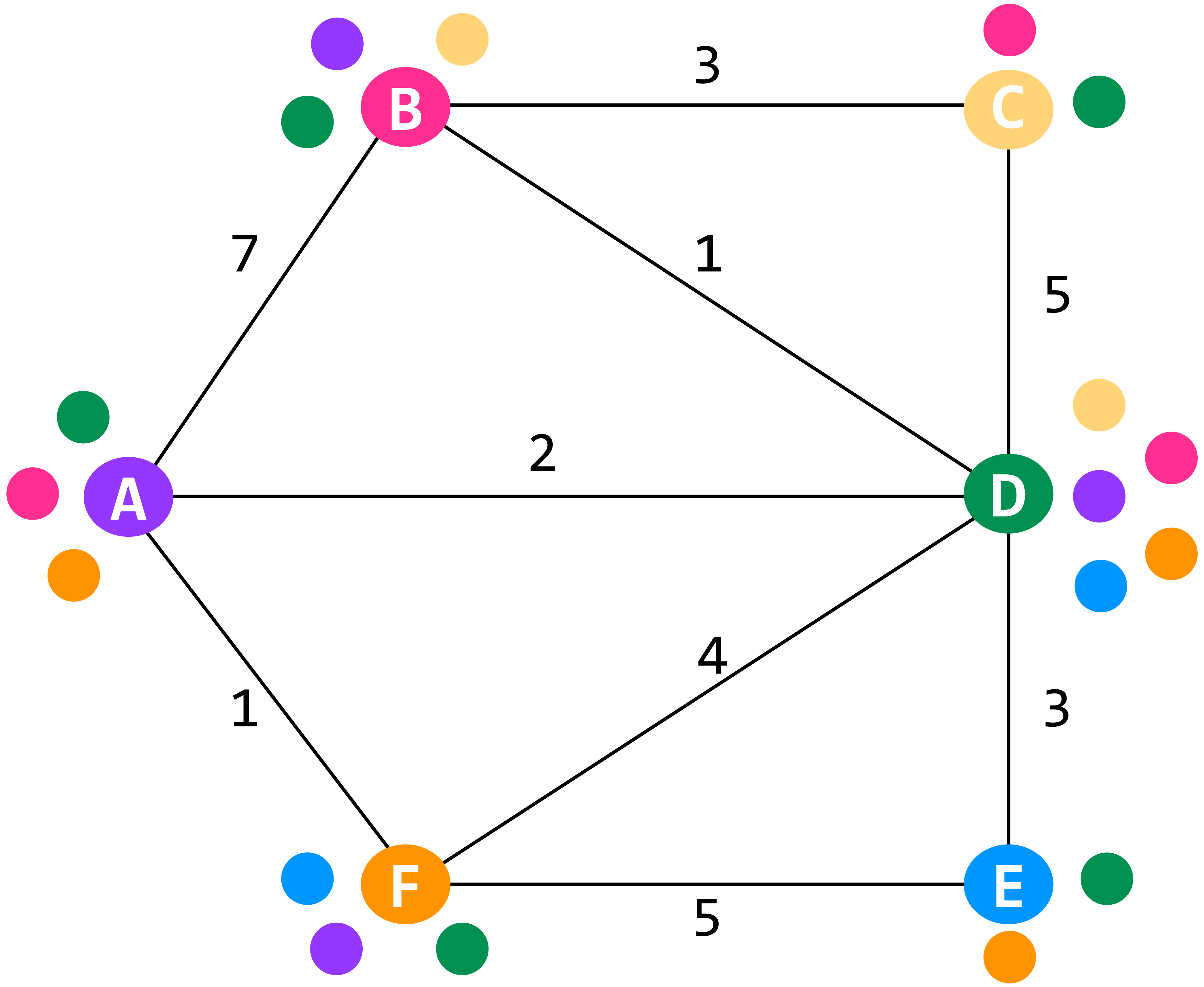


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A's first advertisement: [(B,7),(D,2),(F,1)]
```

A's routing table

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B	A-B	7
D	A-D	2
F	A-F	1

question: what are the contents of B's first advertisement?

	link state	**distance vector**
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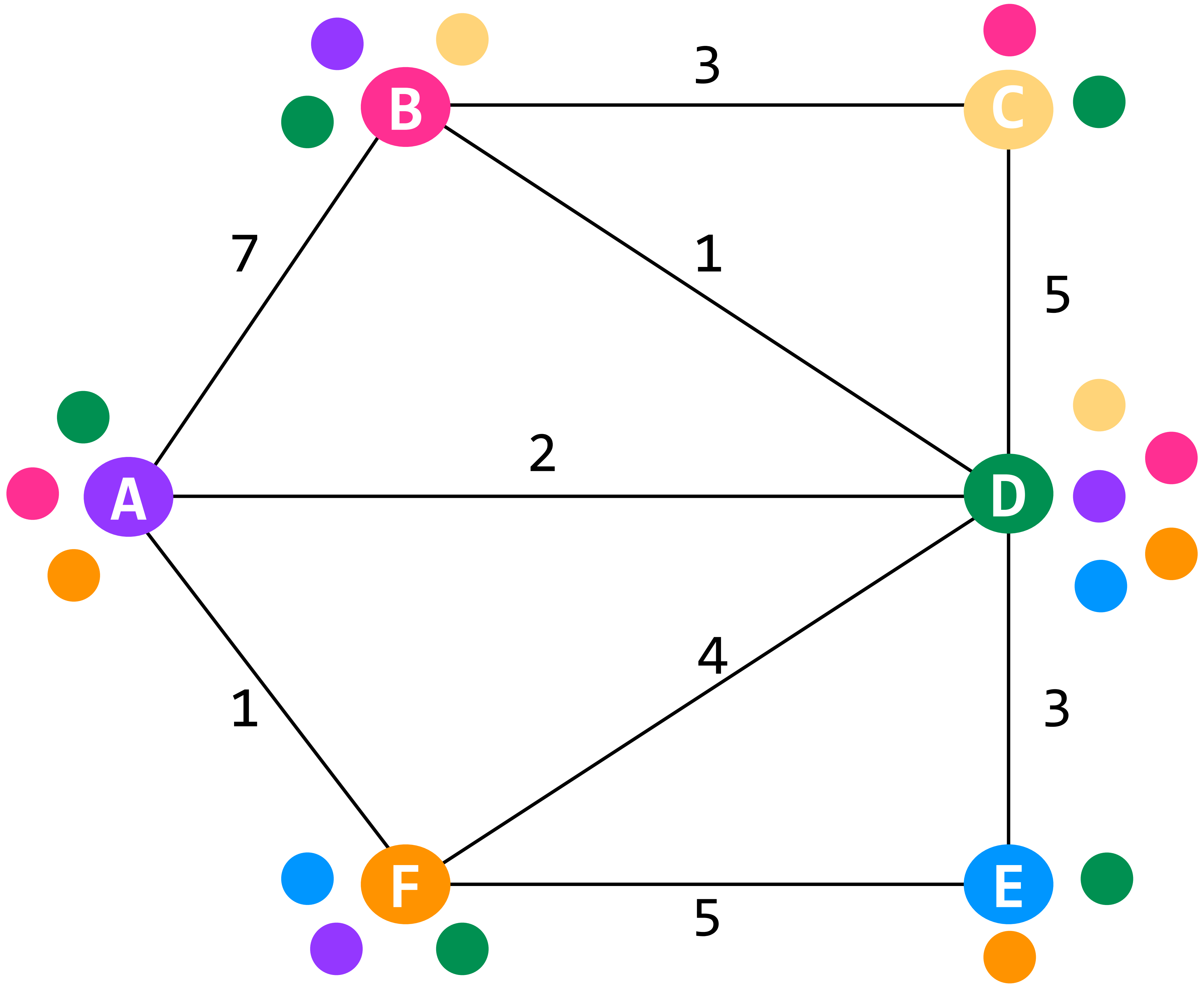

A's routing table

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F	A-F	1

`B's` *first* `adv: [(A,7), (C,3), (D,1)]`

`D's` *first* `adv: [(A,2) (B,1), (C,5), (E,3), (F,4)]`

`F's` *first* `adv: [(A,1), (D,4), (E,5)]`

A receives advertisements from B, D, and F

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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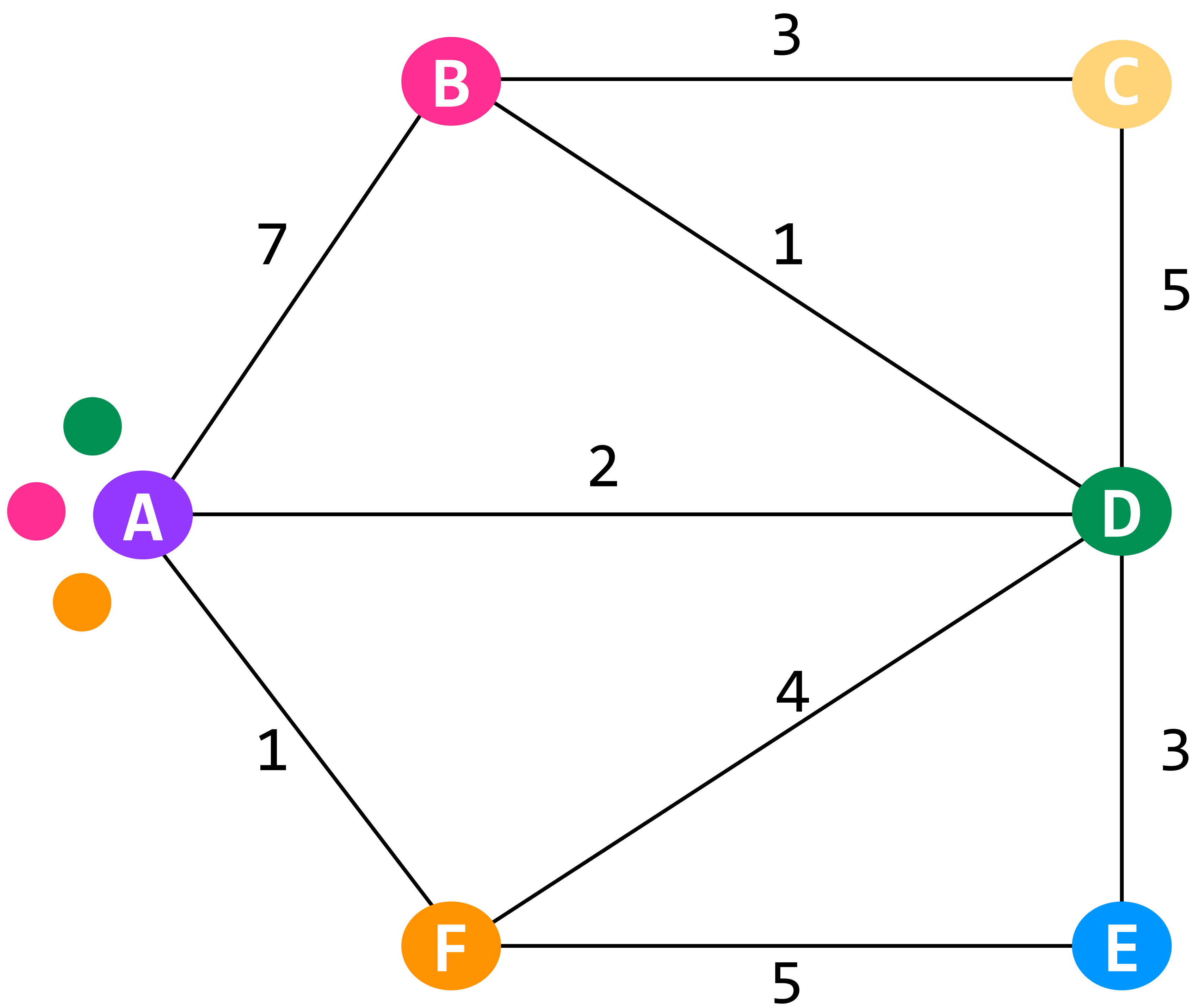
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



A's routing table

dst	route	cost
B	A-B	7
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F	A-F	1

```
B's first adv: [(A,7), (C,3), (D,1)]
D's first adv: [(A,2), (B,1), (C,5), (E,3), (F,4)]
F's first adv: [(A,1), (D,4), (E,5)]
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	link state	distance vector
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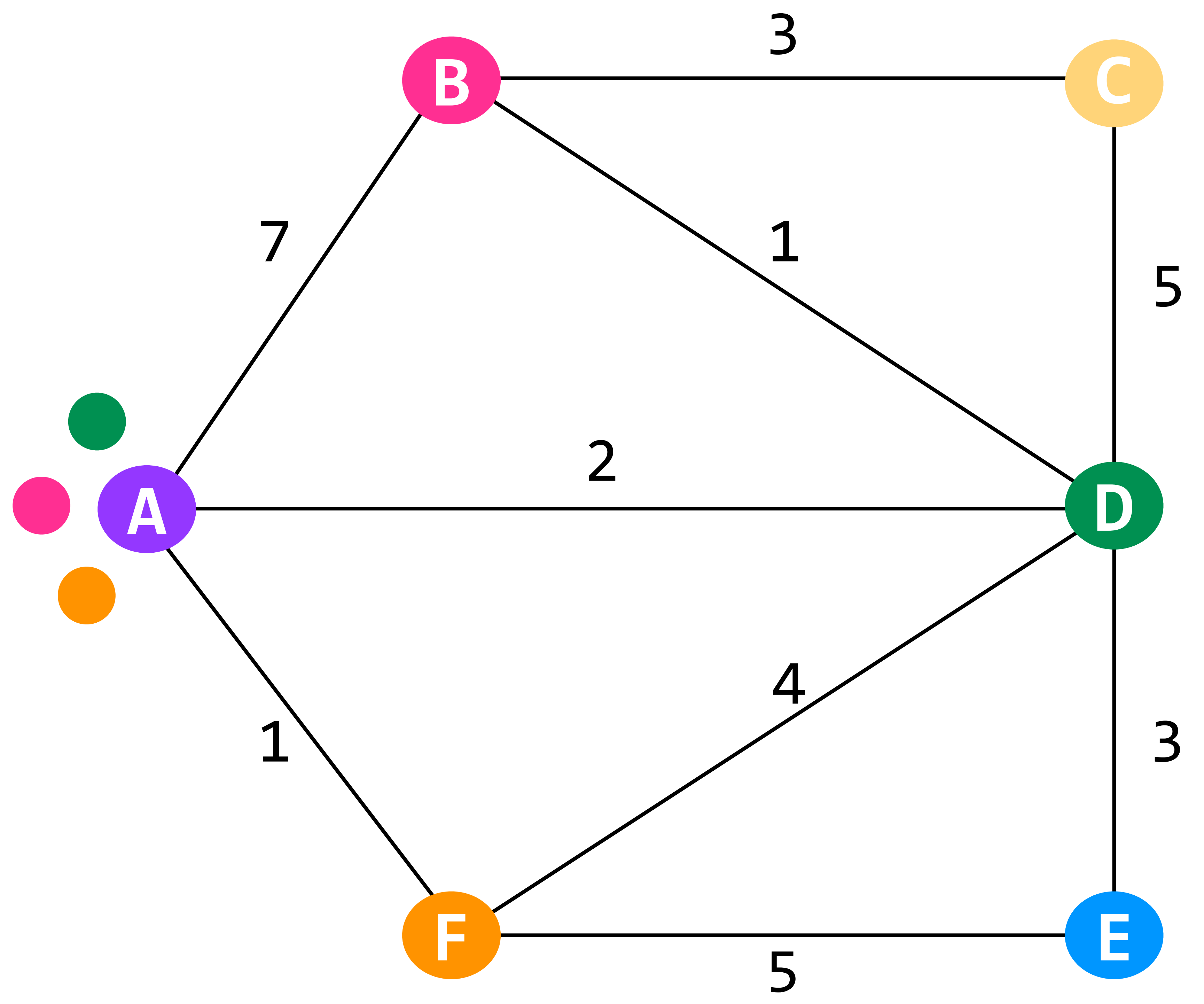

`B's first adv: [(A,7), (C,3), (D,1)]`

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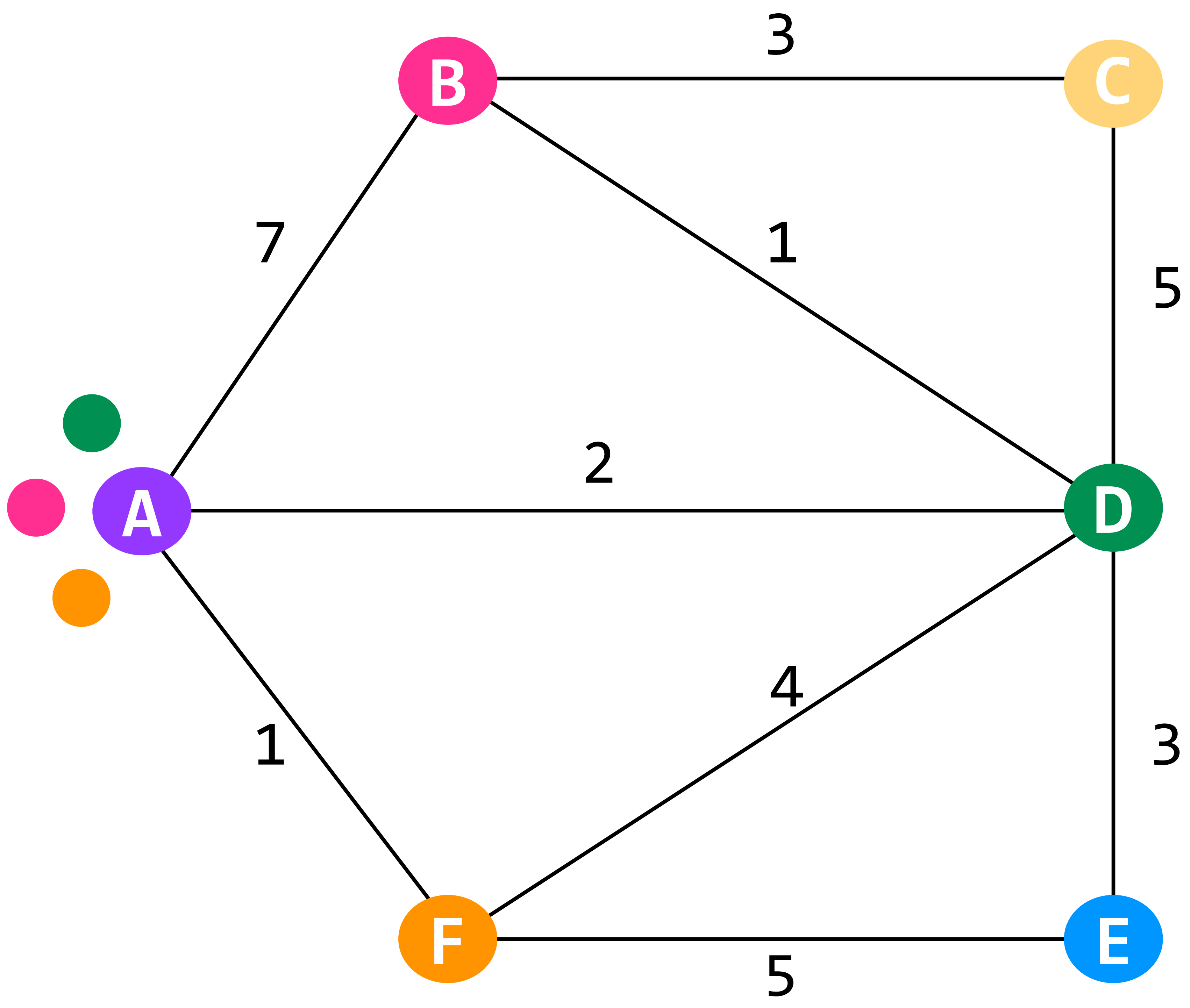


```
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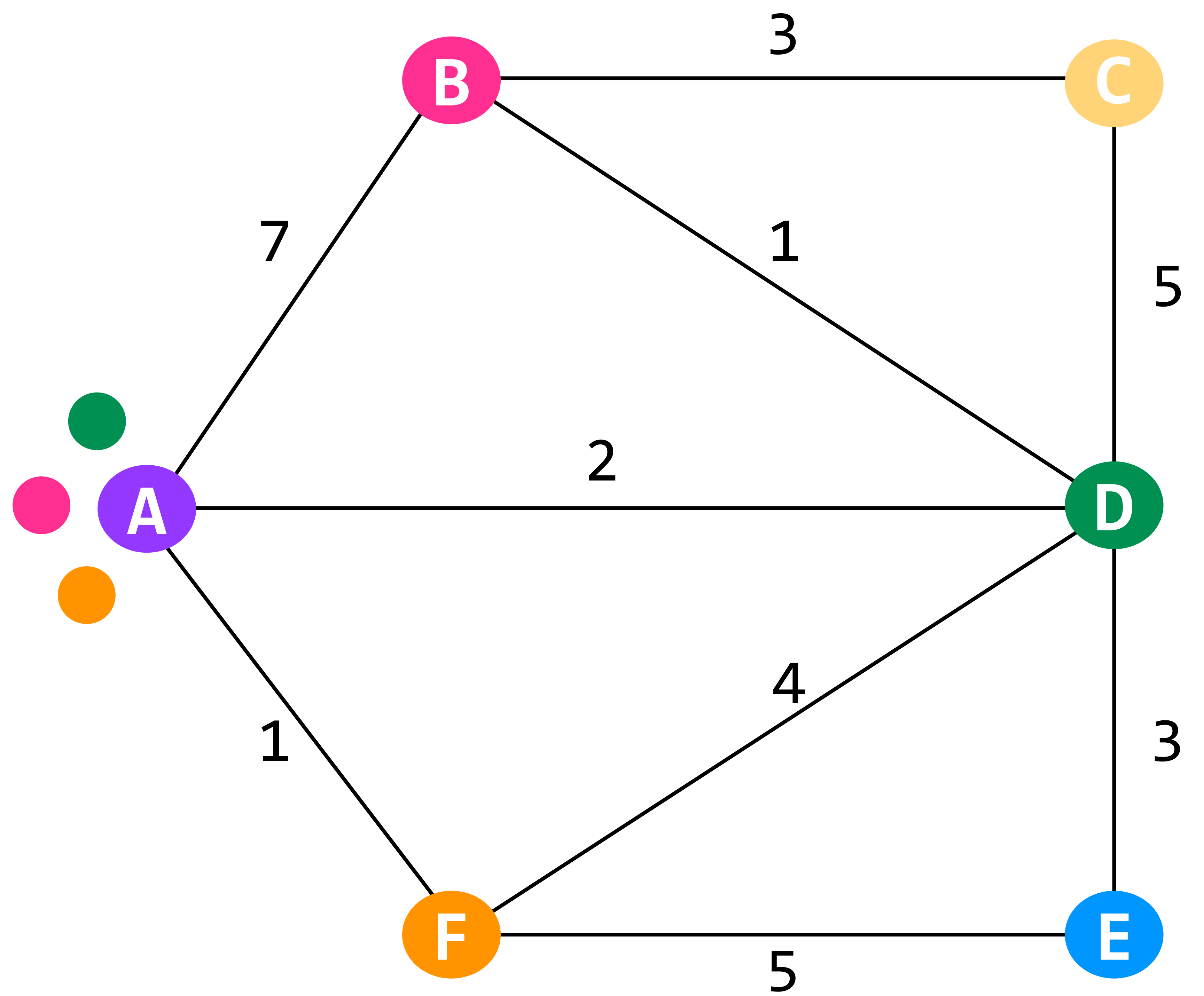

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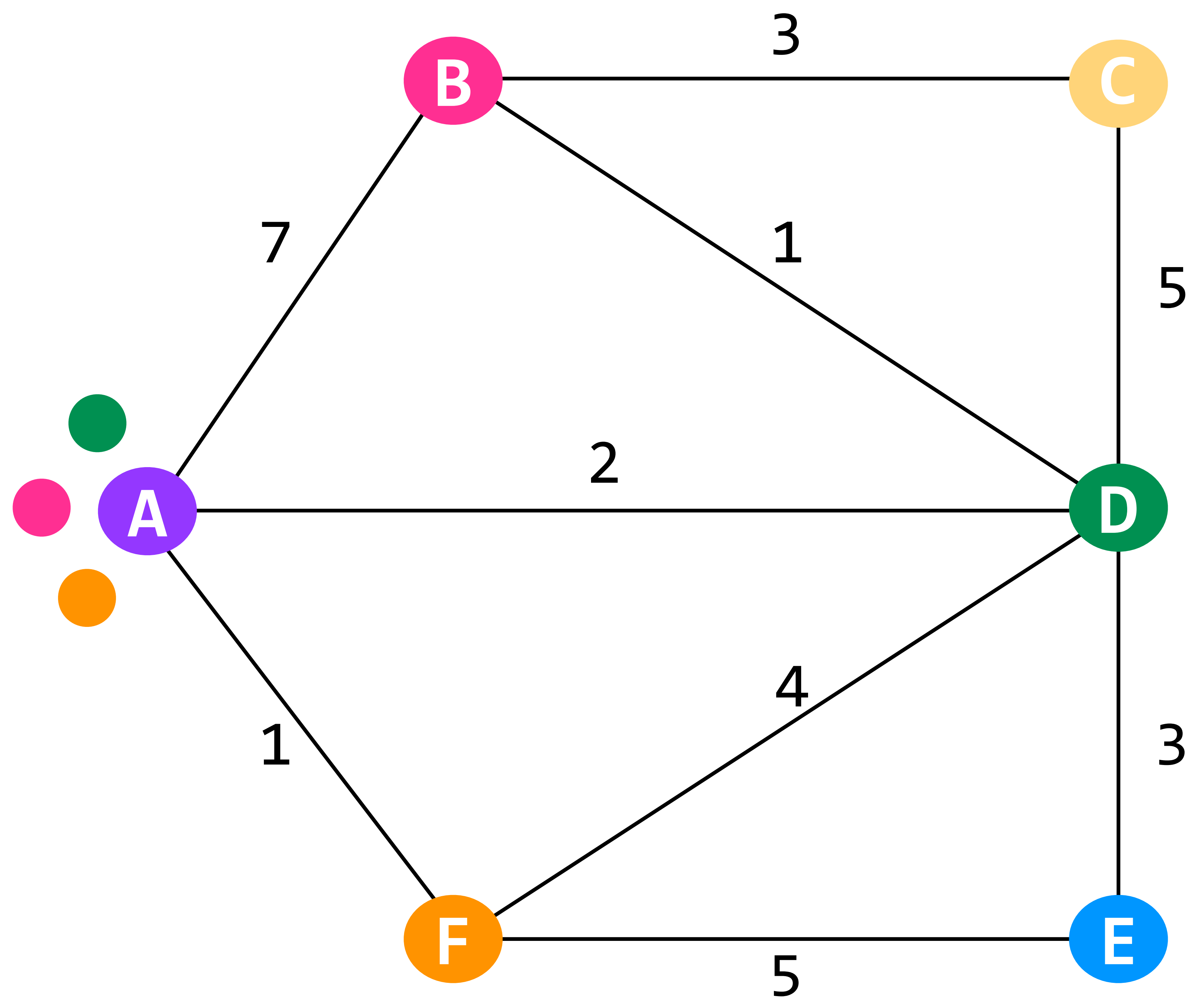

A's routing table

```
dst | route | cost
 B  |  A-B  |  7
 C  |  A-B  | 10
 D  |  A-D  |  2
 F  |  A-F  |  1
```

A's cost to B + B's cost to C

`B's first adv: [(A,7), (C,3), (D,1)]`

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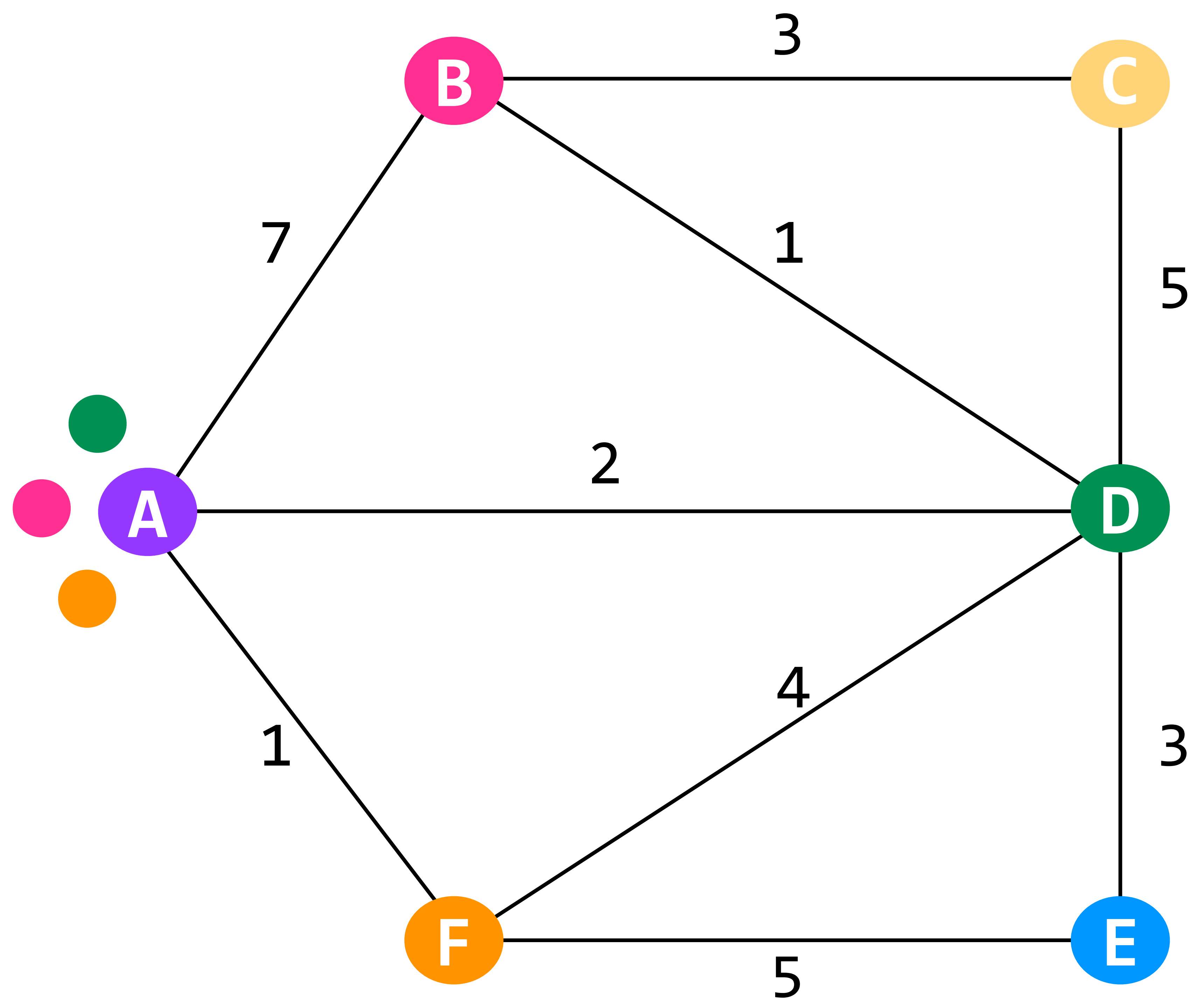

A's routing table

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 B  |  A-B  |  7
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`B's` *`first`* `adv: [(A,7), (C,3), (D,1)]`

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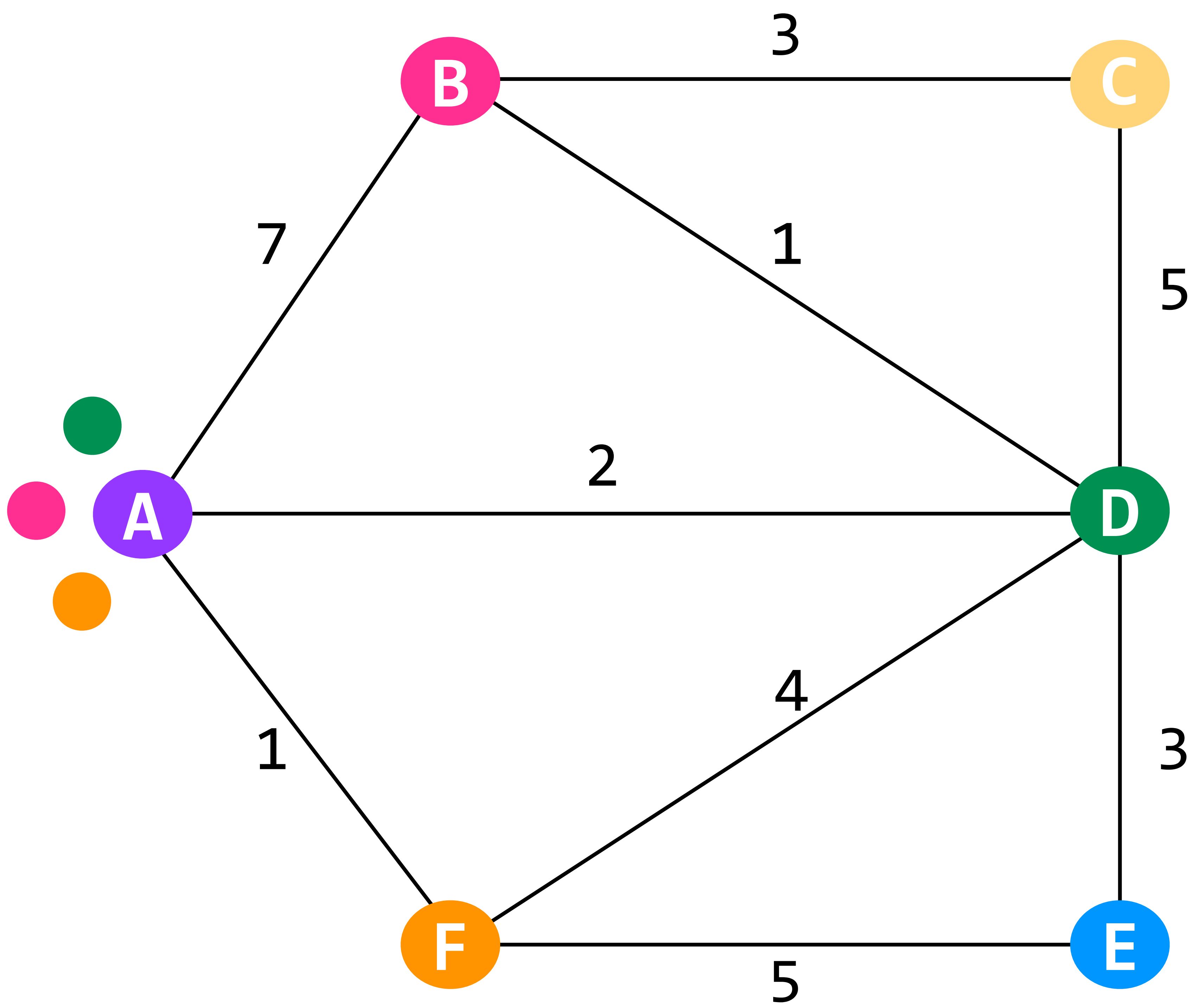

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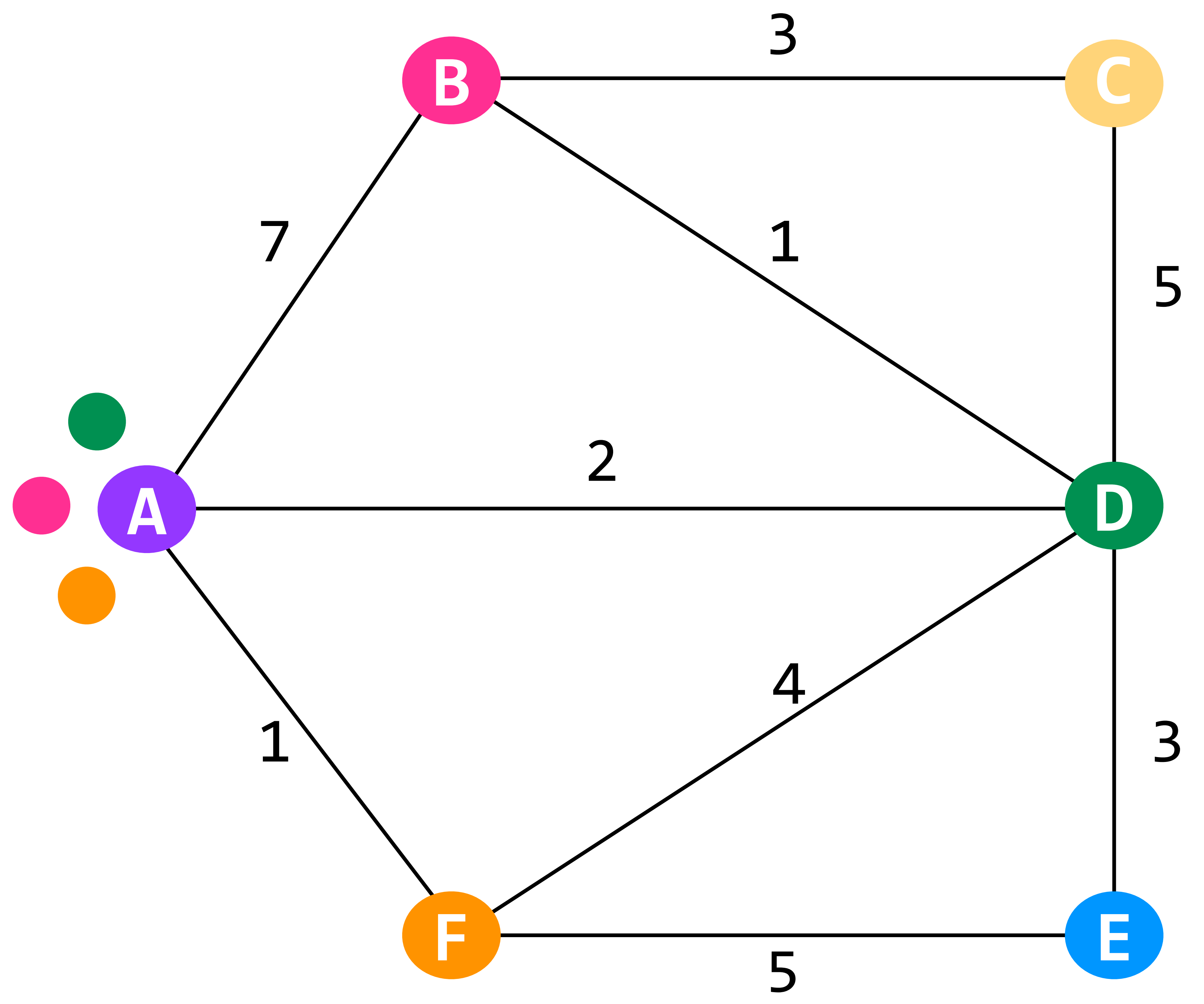

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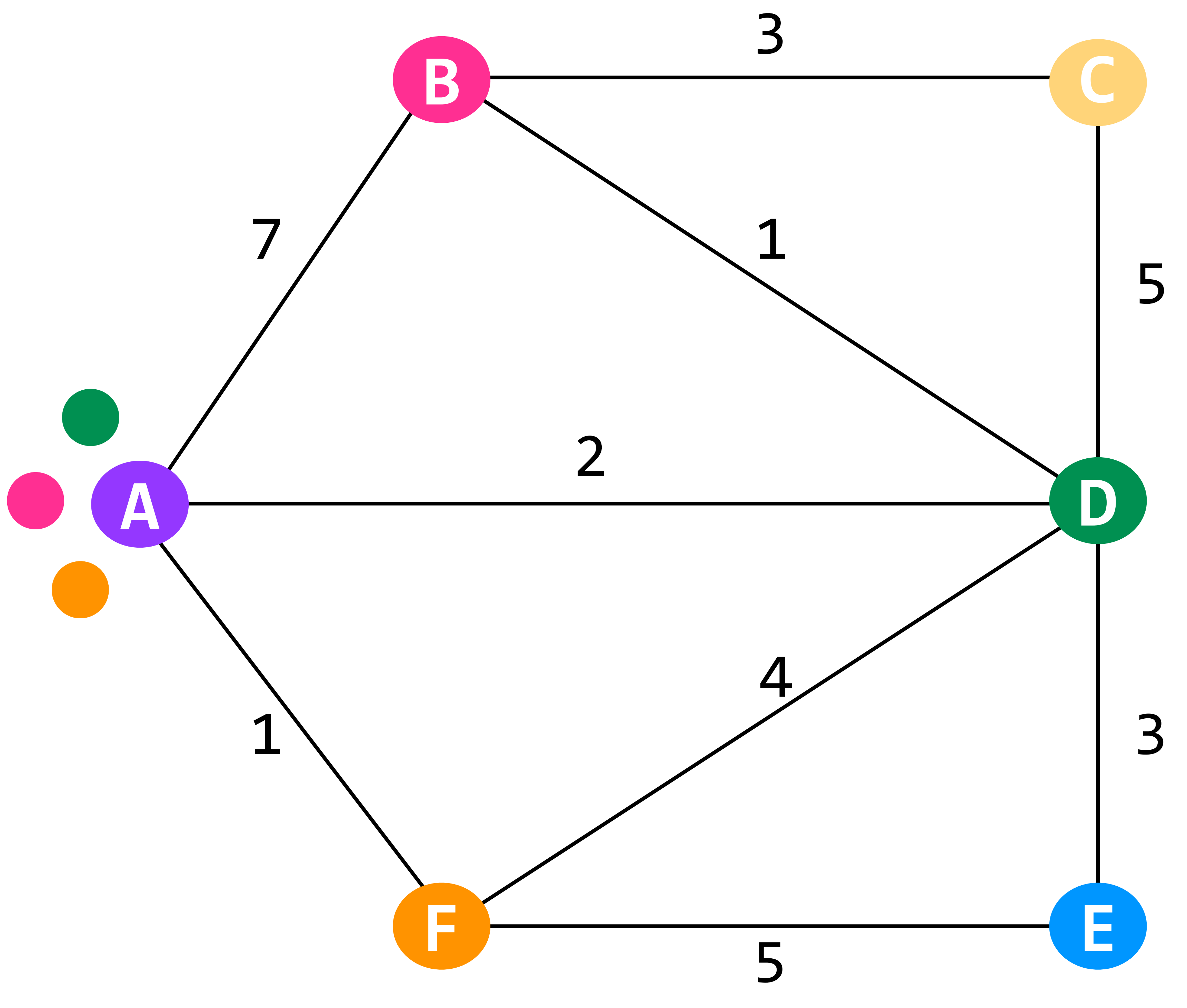

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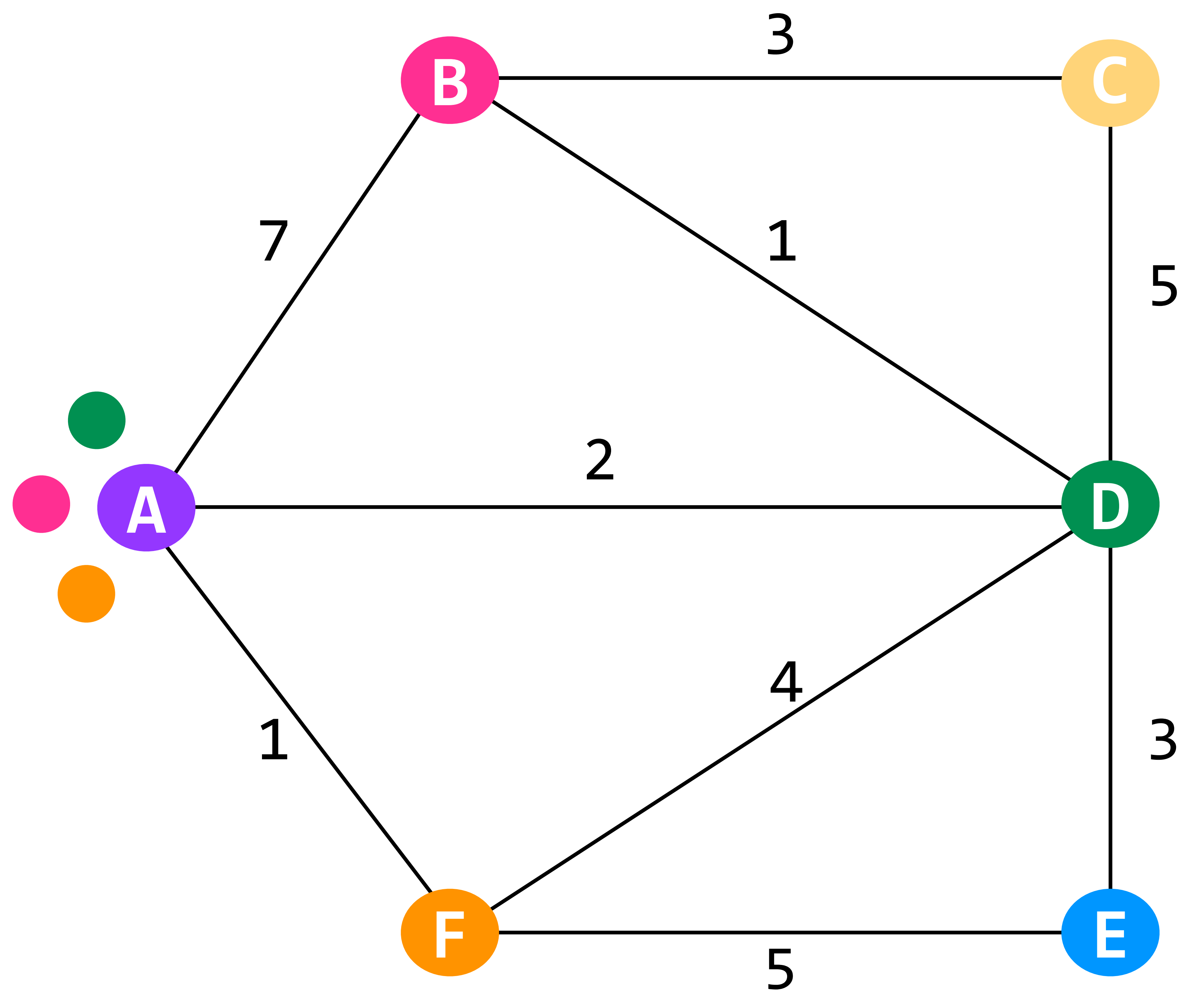

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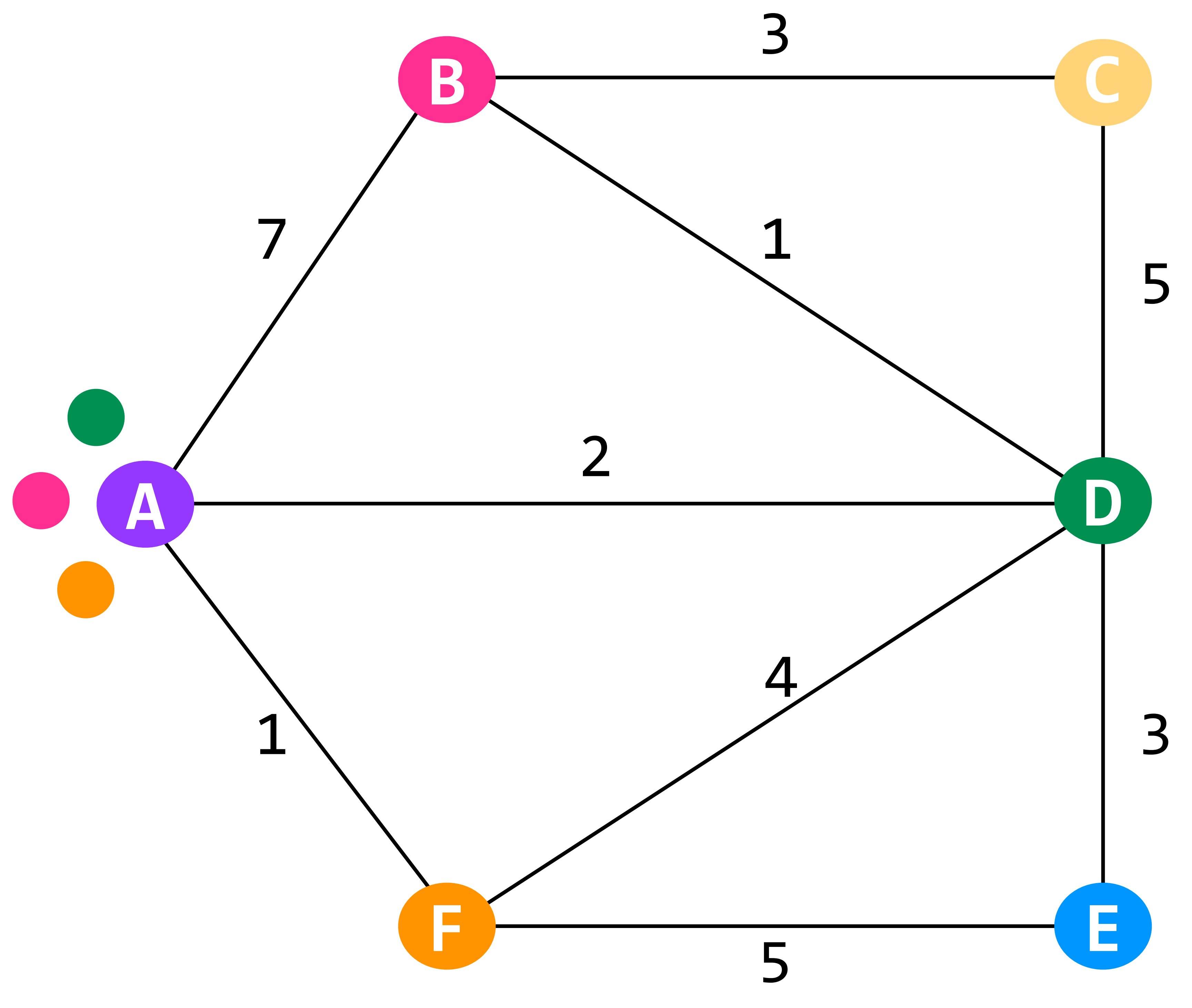

A's routing table

dst	route	cost
B	A-D	3
C	A-B	10
D	A-D	2
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D's *first* adv: [(A,2), **(B,1)**, (C,5), (E,3), (F,4)]

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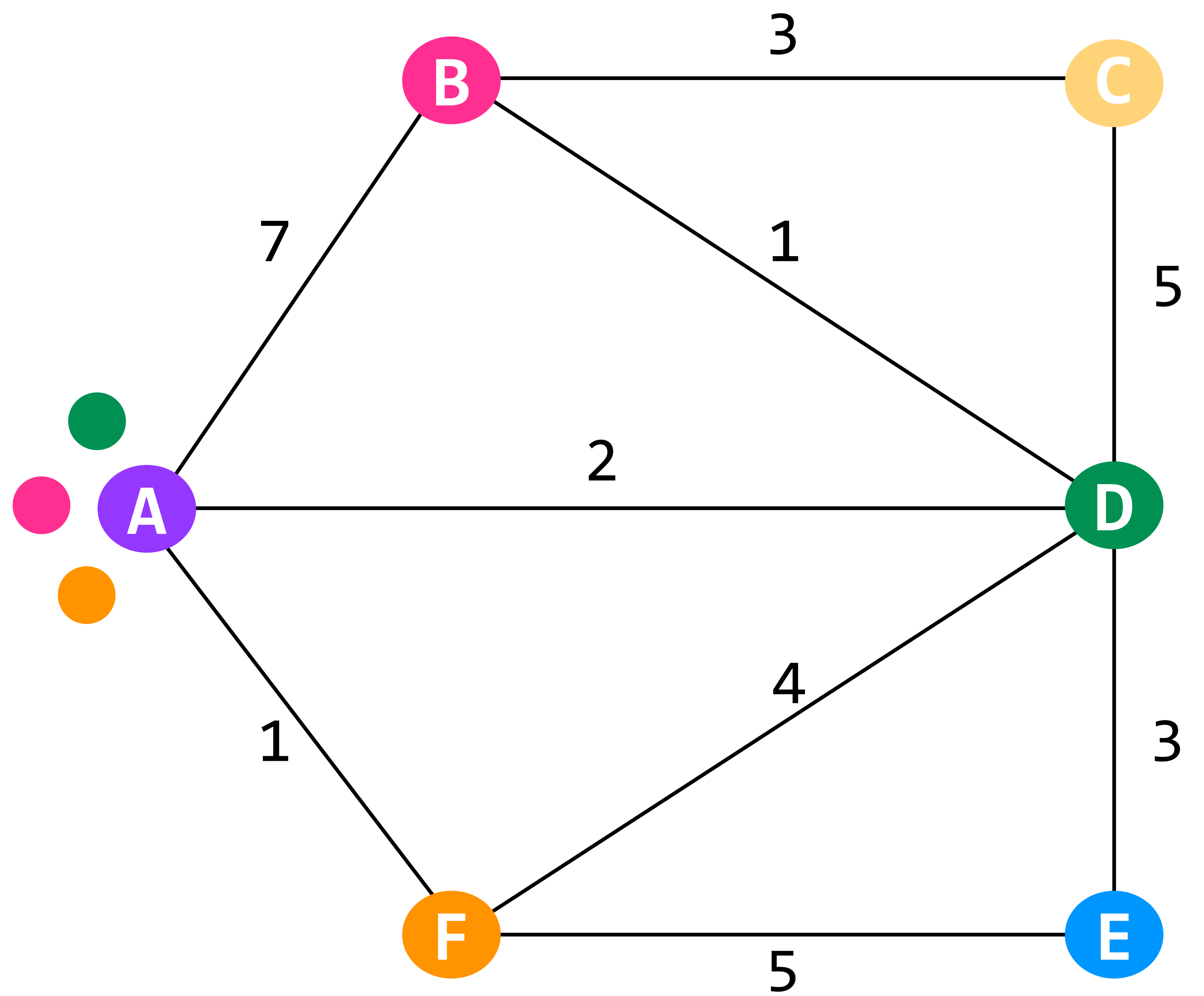

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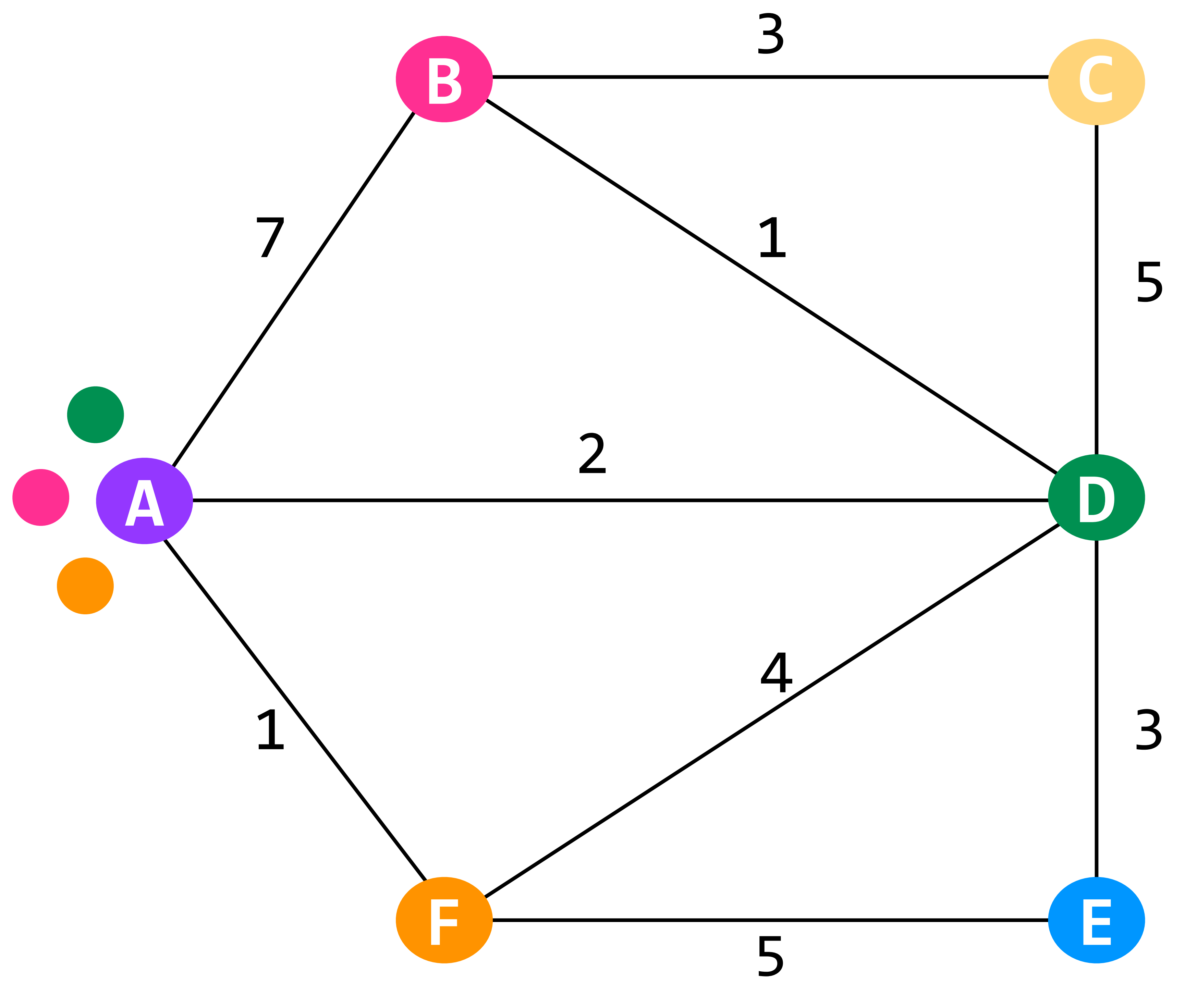

A's routing table

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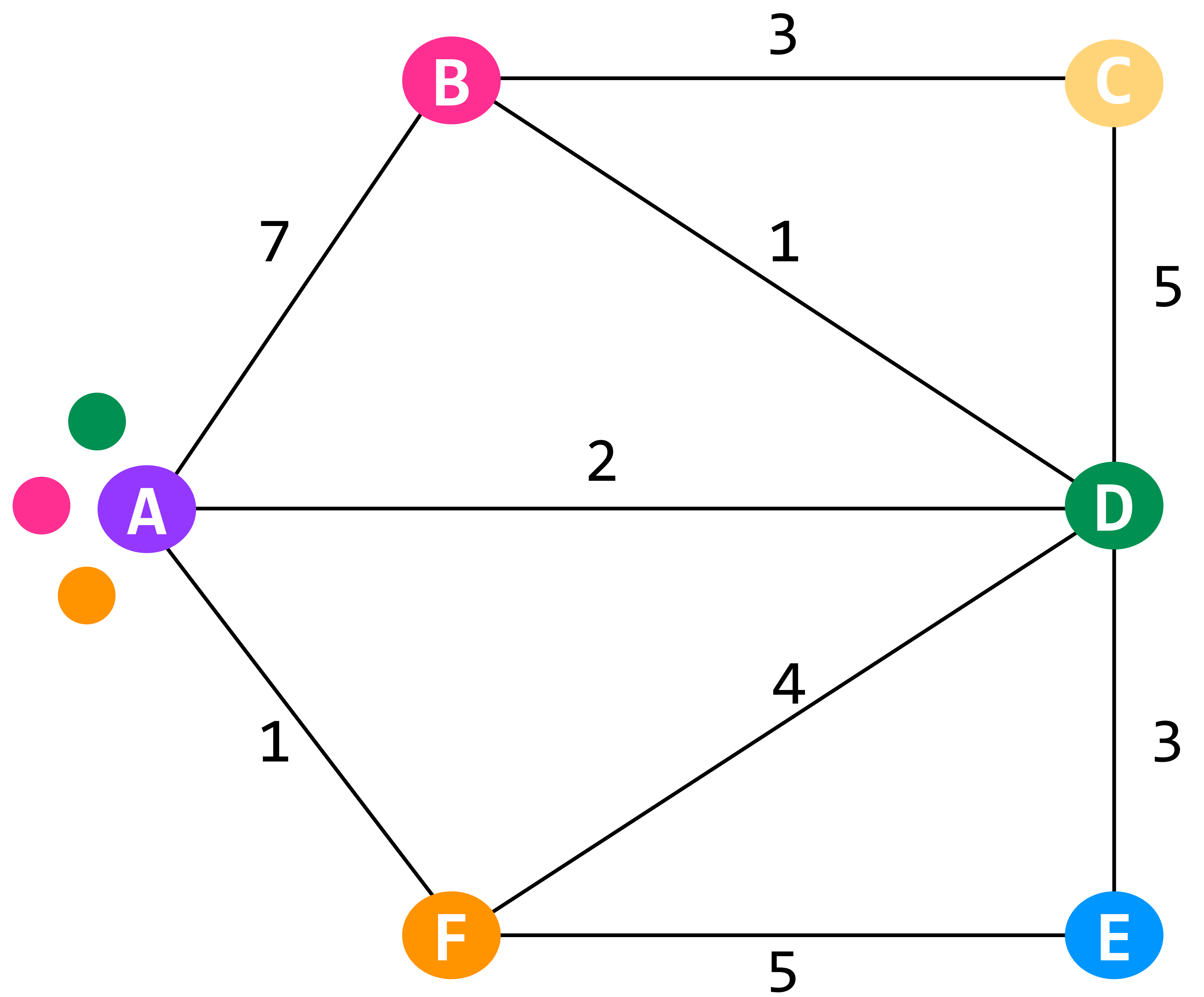

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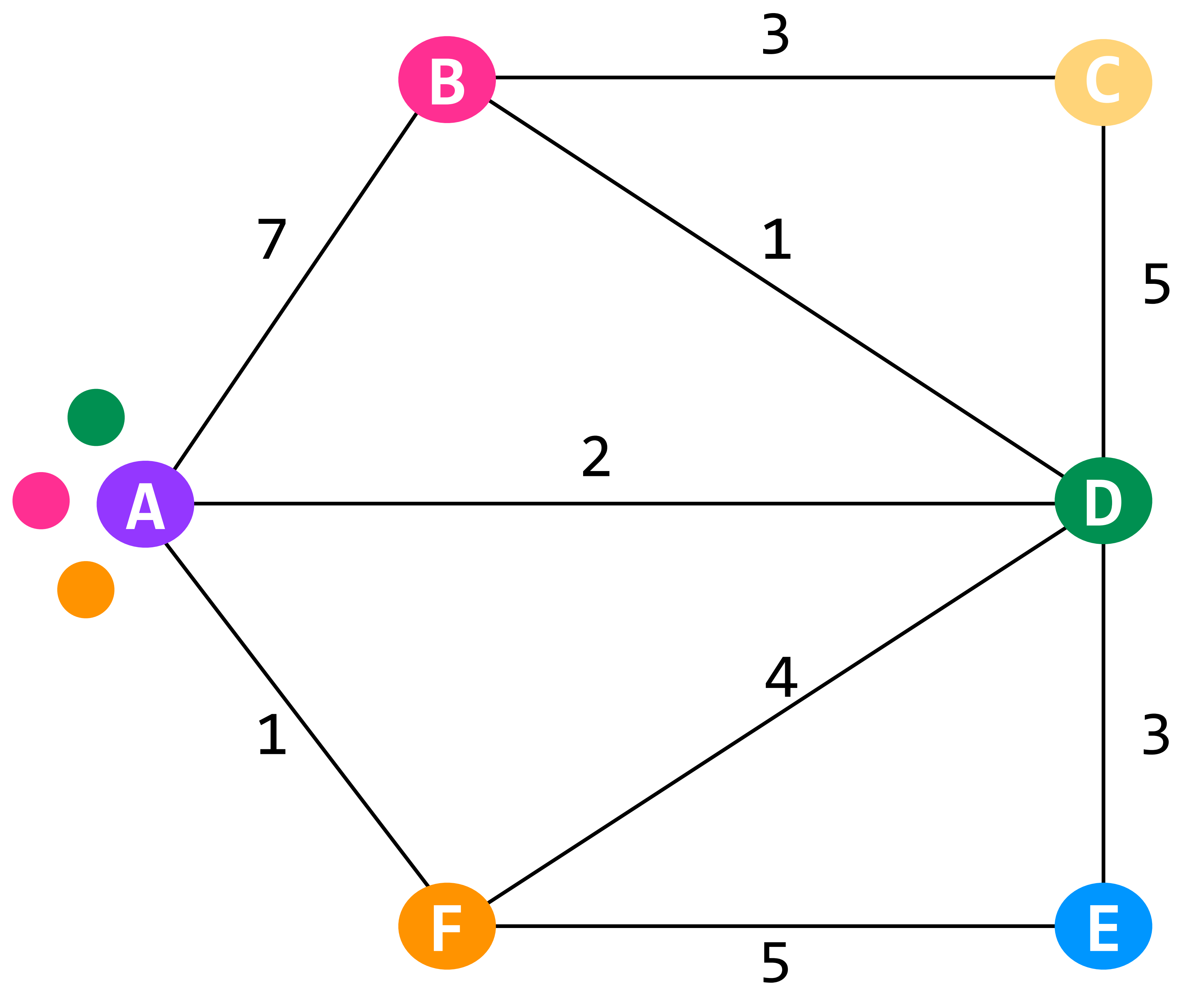

A's routing table

dst	route	cost
B	A-D	3
C	A-D	7
D	A-D	2
E	A-D	5
F	A-F	1

D's *first* adv: [(A,2), (B,1), (C,5), **(E,3)**, (F,4)]

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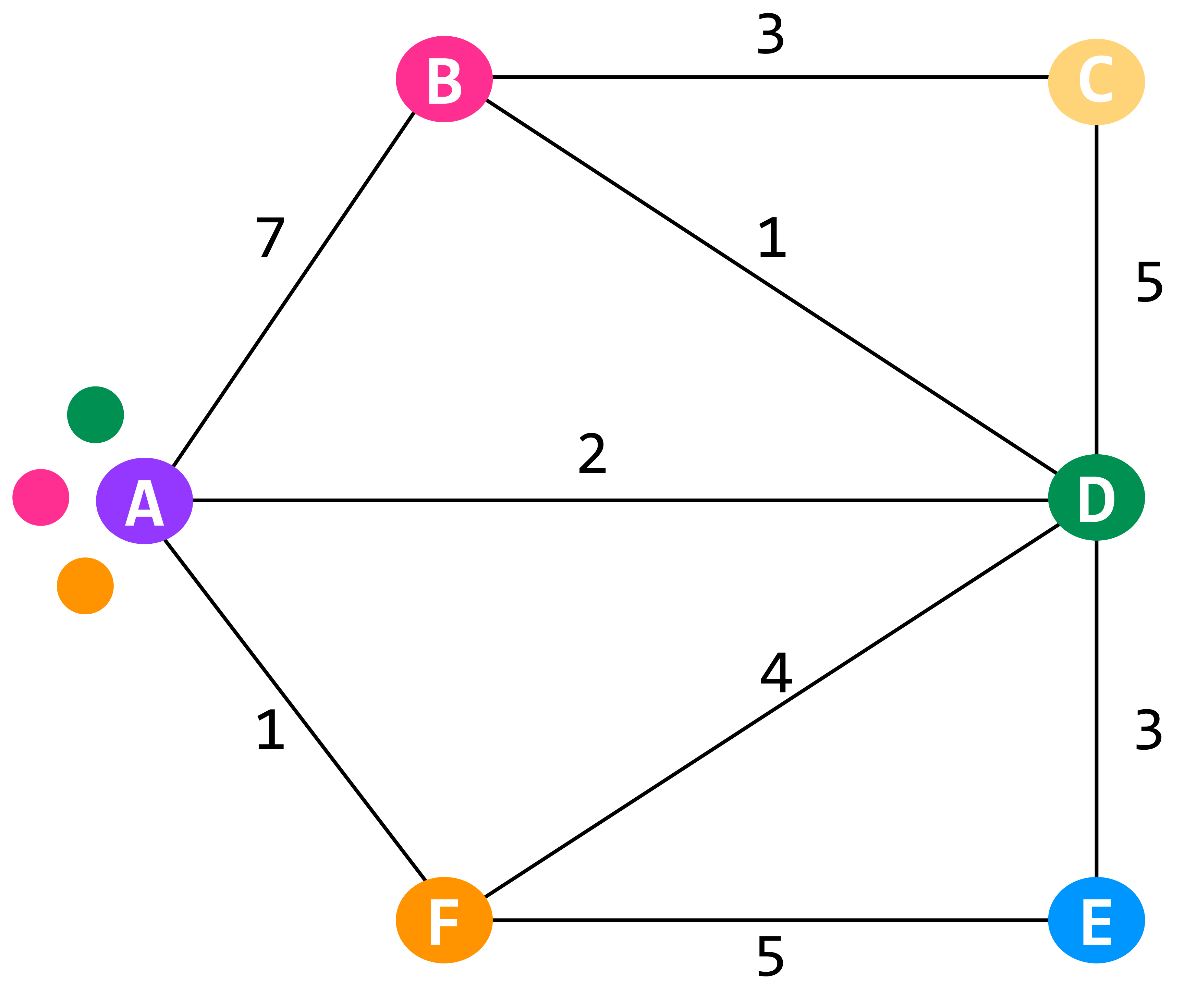

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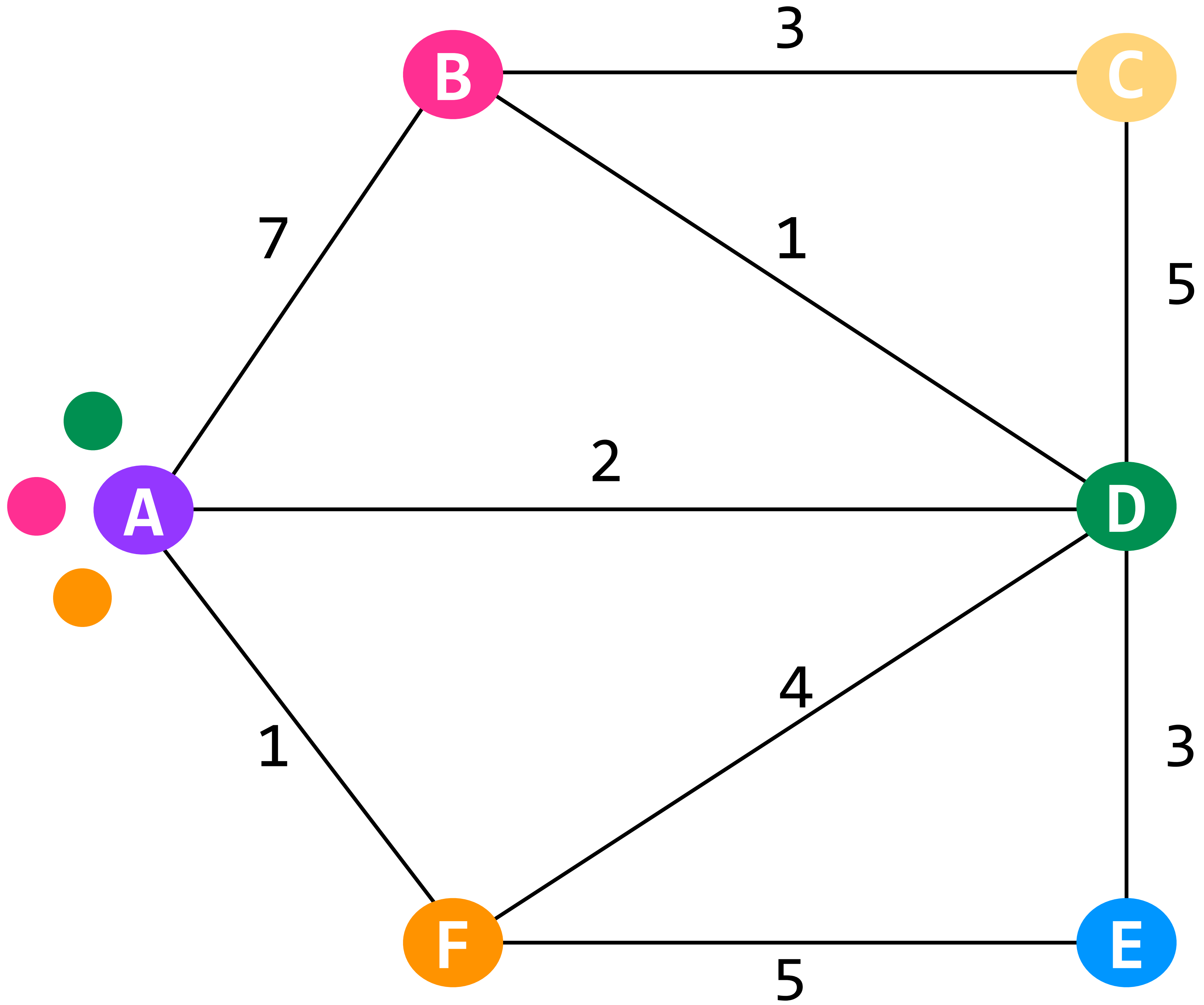

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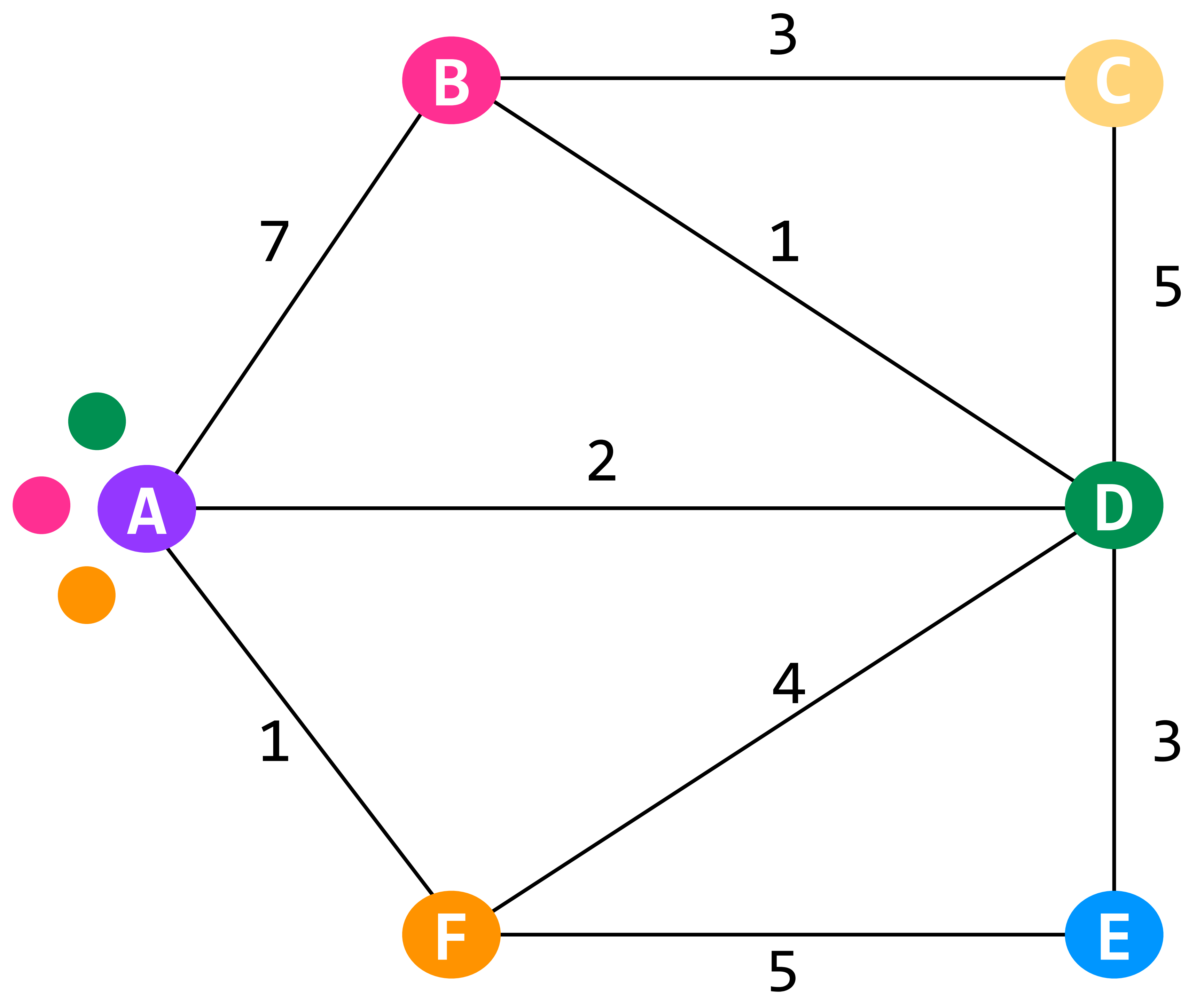

A's routing table

```
dst | route | cost
 B  |  A-D  |  3
 C  |  A-D  |  7
 D  |  A-D  |  2
 E  |  A-D  |  5
 F  |  A-F  |  1
```

```
F's first adv: [(A,1), (D,4), (E,5)]
```

link state	distance vector
what's in an advertisement	
its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	
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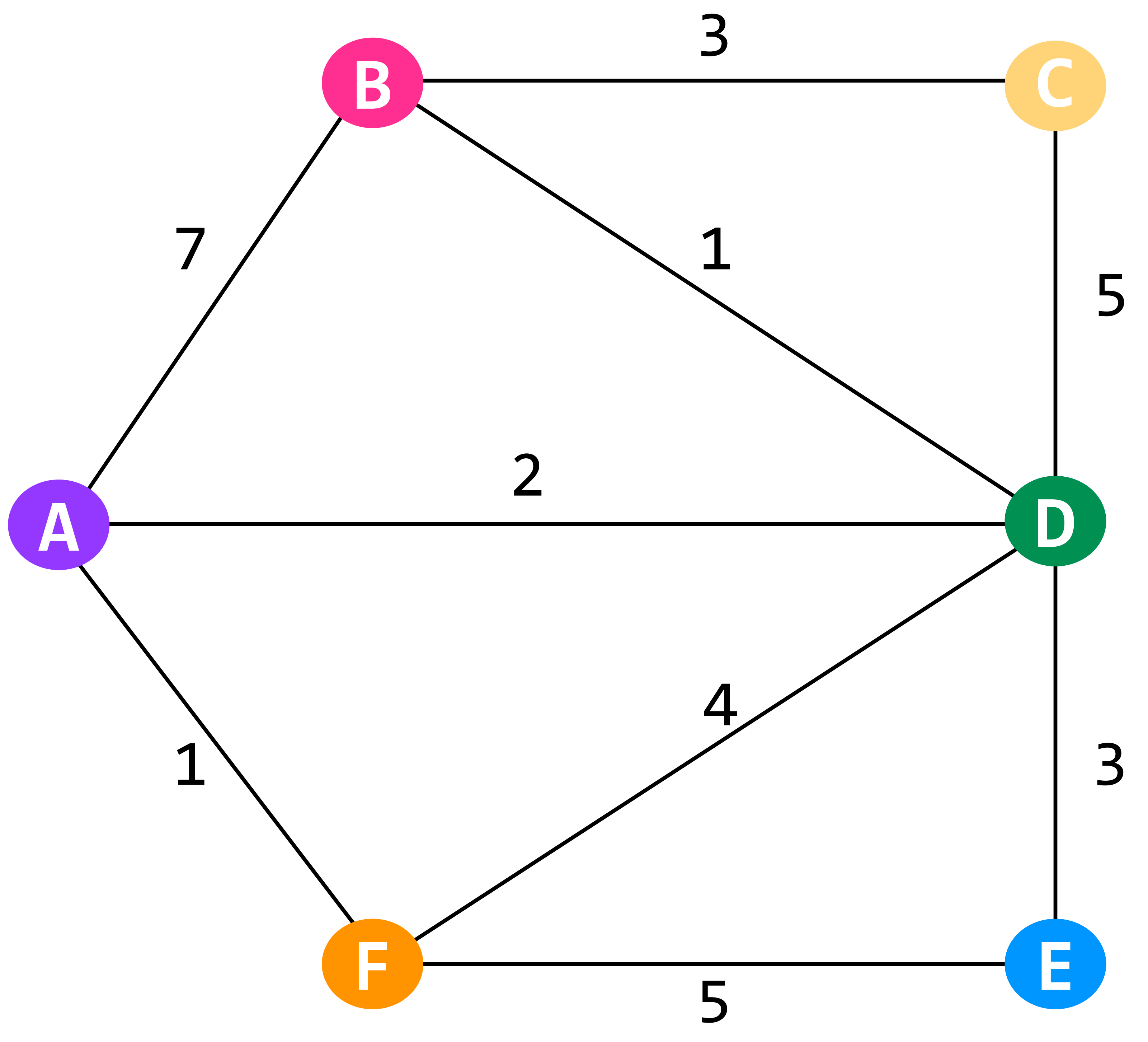
the **overhead** of flooding	

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



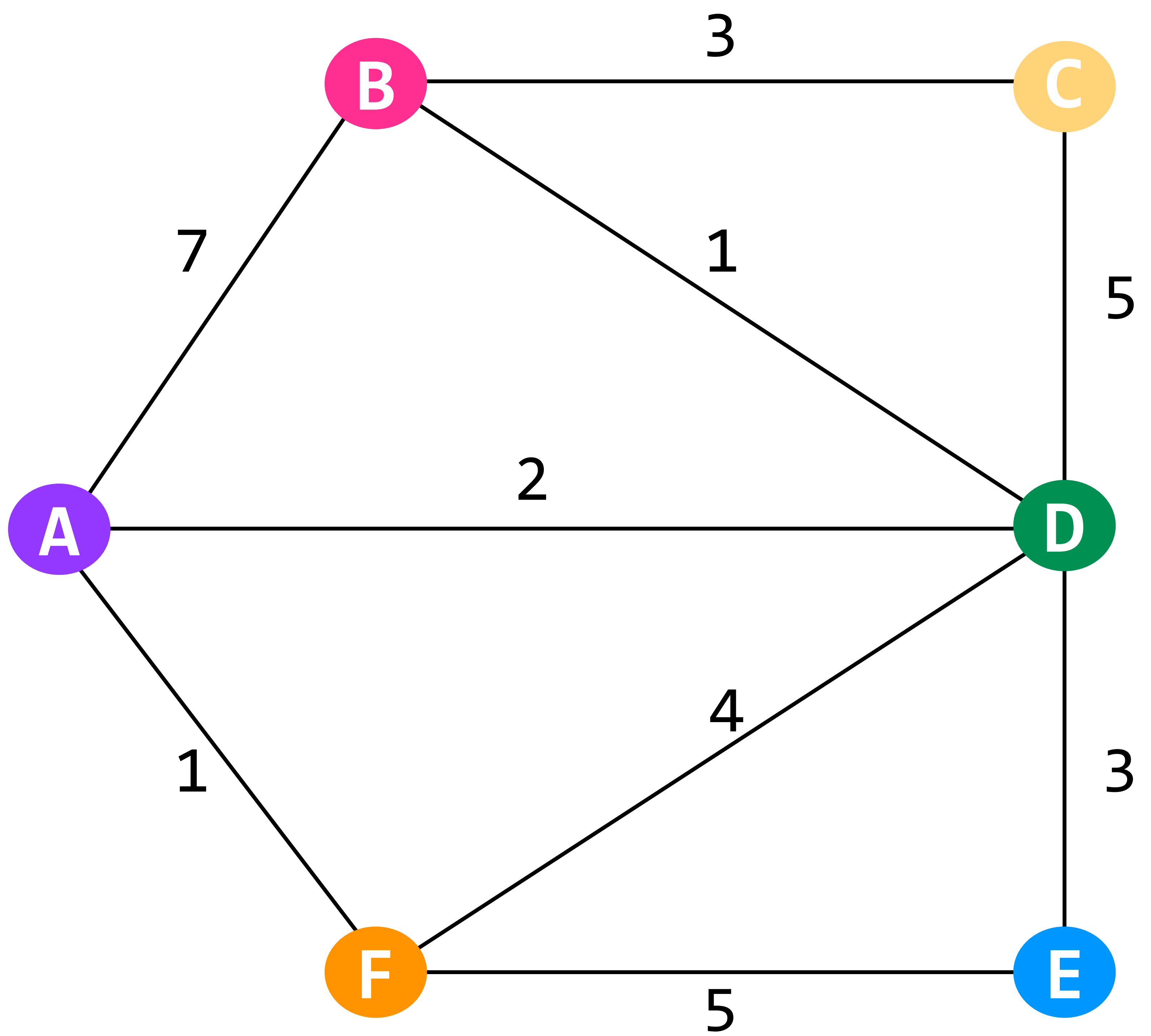
A's routing table

dst	route	cost
B	A-D	3
C	A-D	7
D	A-D	2
E	A-D	5
F	A-F	1

this is A's routing table after one round of advertisements; note that it does not have knowledge of the min-cost path to C yet

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	
what limits scale?	the **overhead** of flooding	

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



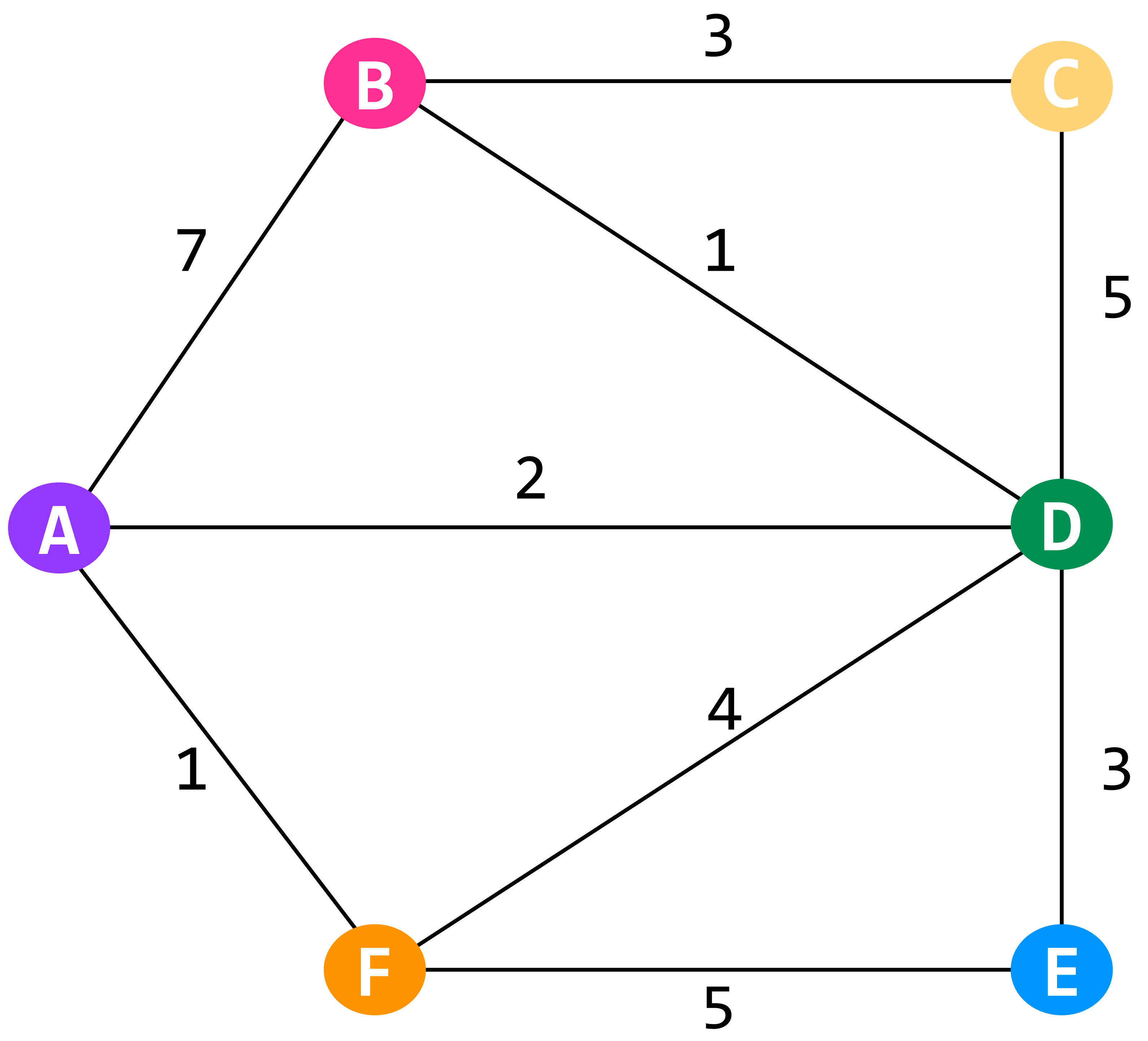
A's routing table

dst	route	cost
B	A-D	3
C	A-D	7
D	A-D	2
E	A-D	5
F	A-F	1

question: what does A's *next* advertisement look like?

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	
what limits scale?	the **overhead** of flooding	

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



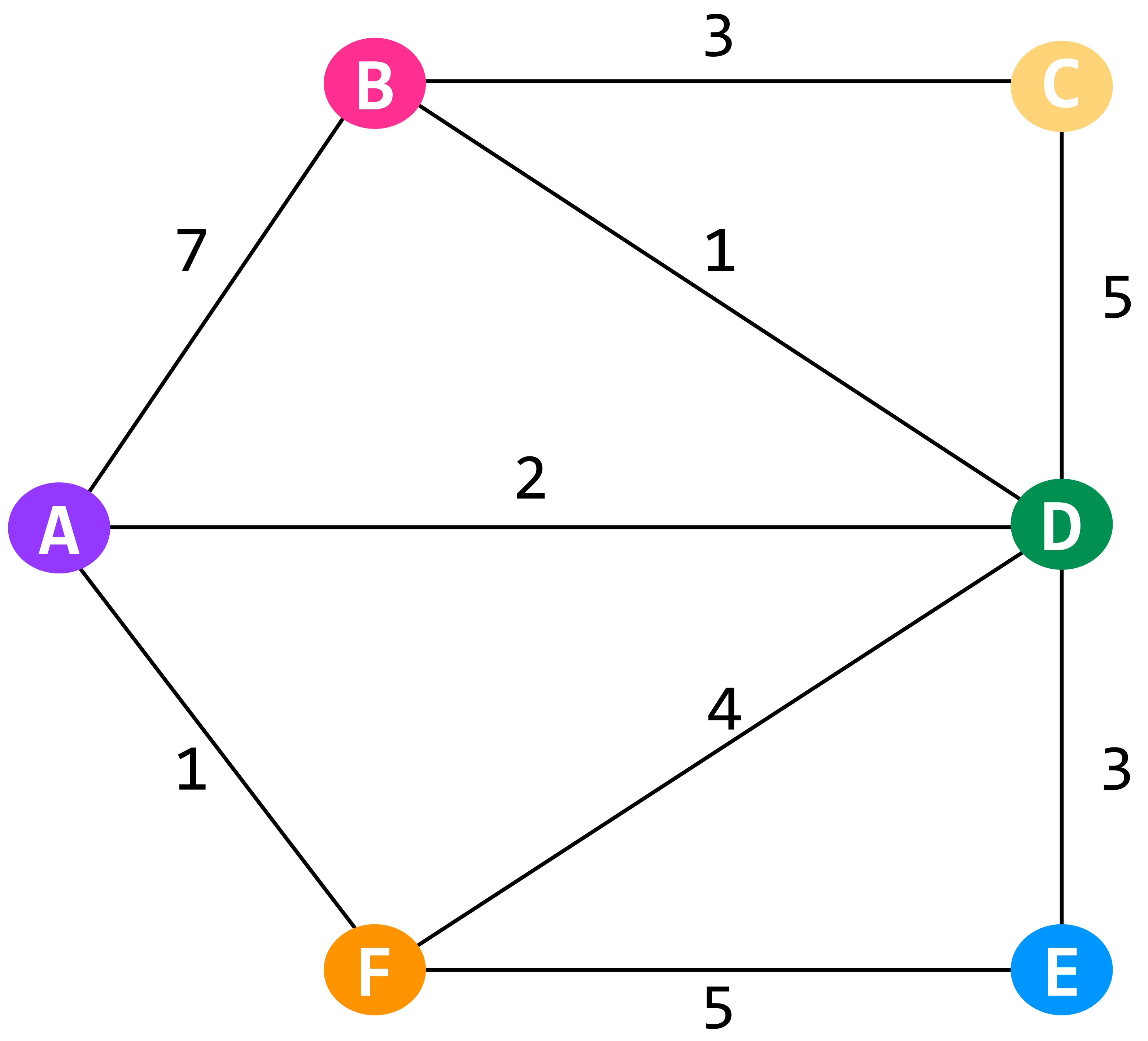
A's routing table

dst	route	cost
B	A-D	3
C	A-D	7
D	A-D	2
E	A-D	5
F	A-F	1

A's *second* adv:
[(B,3), (C,7), (D,2), (E,5), (F,1)]

link state	distance vector
what's in an advertisement	
its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	
effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	
flooding makes link-state routing very resilient to failure	
what limits scale?	
the **overhead** of flooding	

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



A's routing table

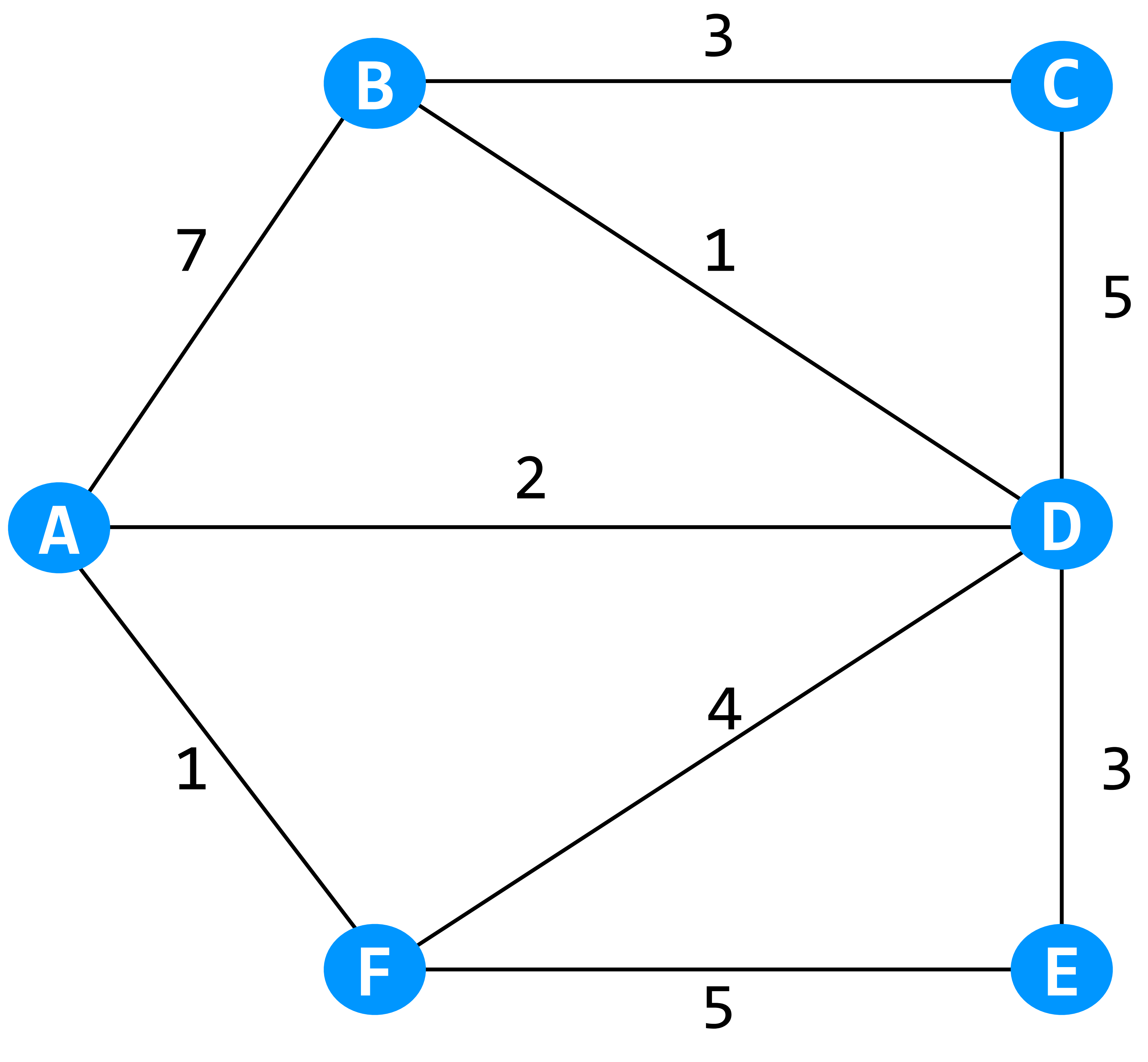
dst	route	cost
B	A-D	3
C	A-D	7
D	A-D	2
E	A-D	5
F	A-F	1

A's *second* adv:
[(B,3), (C,7), (D,2), (E,5), (F,1)]

A will learn about the correct min-cost path to C in the next round of advertisements; try that out for yourself!

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	
what limits scale?	the **overhead** of flooding	

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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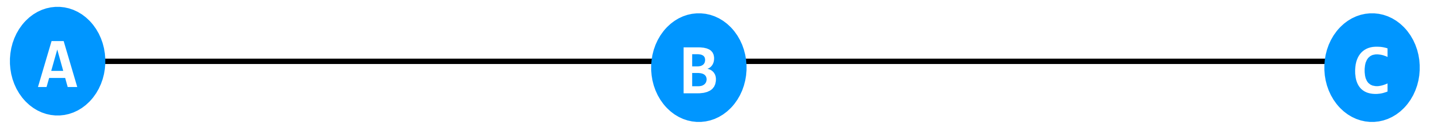
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0     A: B->A, 1
B: A->B, 1     B: Self, 0
C: A->B, 2     C: B->C, 1
```

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
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in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

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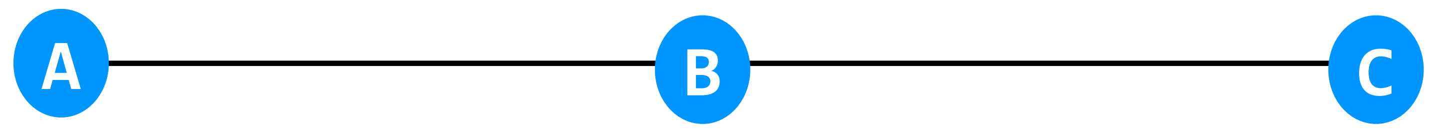


```
A: Self, 0     A: B->A, 1
B: A->B, 1     B: Self, 0
C: A->B, 2     C: B->C, 1
```

`t=9: B<->C` fails

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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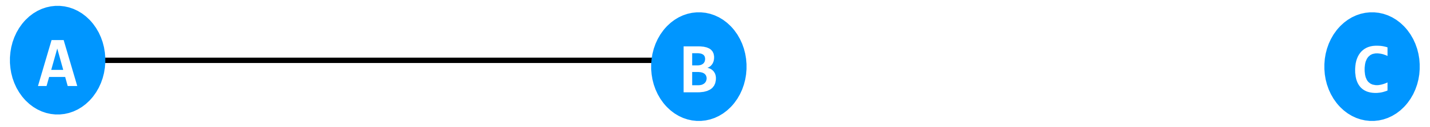


```
A: Self, 0
B: A->B, 1
C: A->B, 2
```

```
A: B->A, 1
B: Self, 0
C: None, inf
```

`t=9: B<->C` fails

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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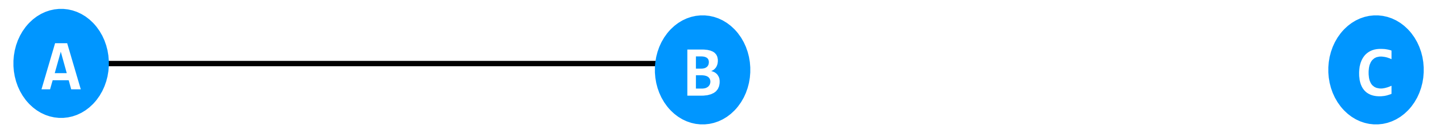
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0
B: A->B, 1
C: A->B, 2
```

```
A: B->A, 1
B: Self, 0
C: None, inf
```

`t=9: B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:
`[(A,0),(B,1),(C,2)]`

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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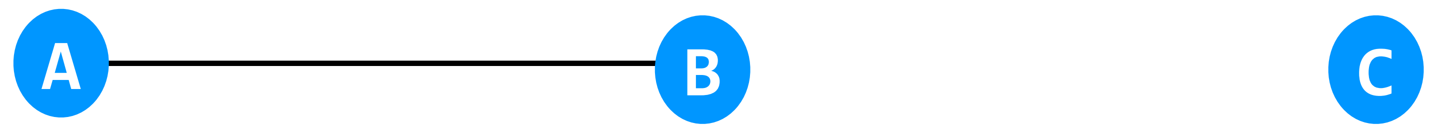
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3    (2+1)
```

`t=9: B<->C` fails

`t=10:` B receives the following advertisement from A:
`[(A,0),(B,1),(C,2)]`

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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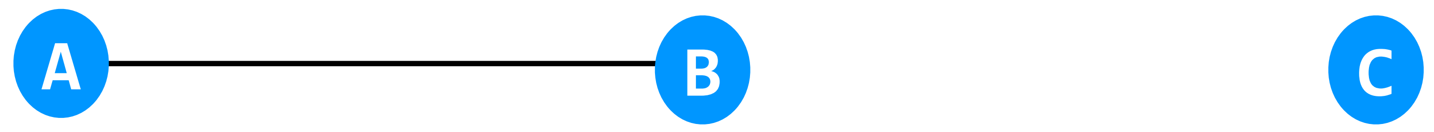
A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3   (2+1)
```

`t=9:` `B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:
`[(A,0),(B,1),(C,2)]`

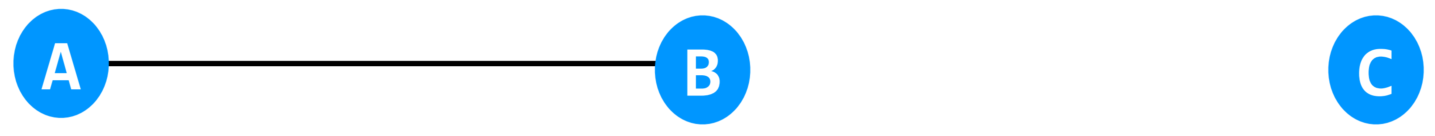
`t=15:` `A` receives the following advertisement from `B`:
`[(A,1),(B,0),(C,3)]`

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3   (2+1)

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 3
```

`t=9:` `B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:
`[(A,0),(B,1),(C,2)]`

`t=15:` `A` receives the following advertisement from `B`:
`[(A,1),(B,0),(C,3)]`

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
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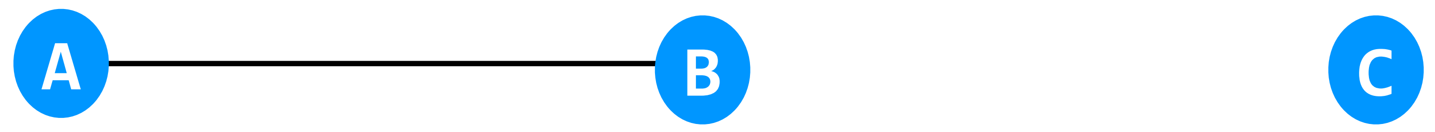
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

t=9: B<->C fails

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3    (2+1)
```

t=10: B receives the following advertisement from A:
[(A,0),(B,1),(C,2)]

t=15: A receives the following advertisement from B:
[(A,1),(B,0),(C,3)]

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 3
```

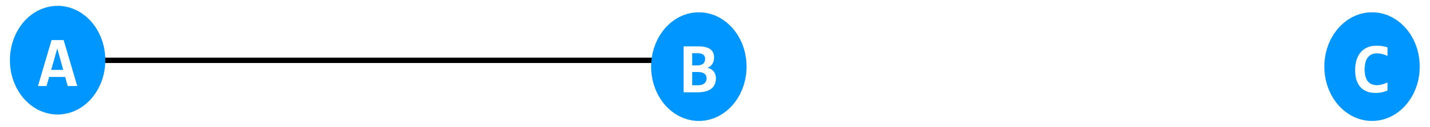
t=20: B receives the following advertisement from A:
[(A,0),(B,1),(C,4)]

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

t=9: B<->C fails

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3   (2+1)
```

t=10: B receives the following advertisement from A:
[(A,0),(B,1),(C,2)]

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 3
```

t=15: A receives the following advertisement from B:
[(A,1),(B,0),(C,3)]

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 5
```

t=20: B receives the following advertisement from A:
[(A,0),(B,1),(C,4)]

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
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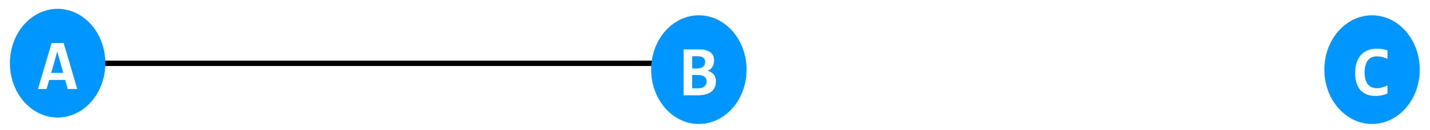
in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

t=9: B<->C fails

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->A, 3    (2+1)
```

t=10: B receives the following advertisement from A: [(A,0),(B,1),(C,2)]

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 3
```

t=15: A receives the following advertisement from B: [(A,1),(B,0),(C,3)]

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 4      C: B->A, 5
```

t=20: B receives the following advertisement from A: [(A,0),(B,1),(C,4)]

continues until both costs to C are INFINITY

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

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A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
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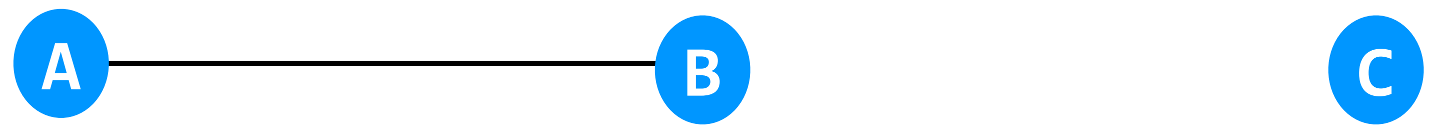

`t=9: B<->C` fails

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
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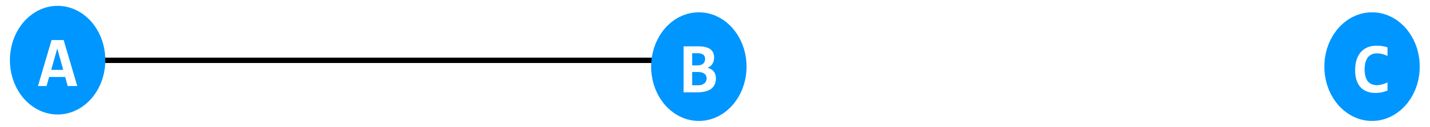


```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

`t=9: B<->C` fails

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
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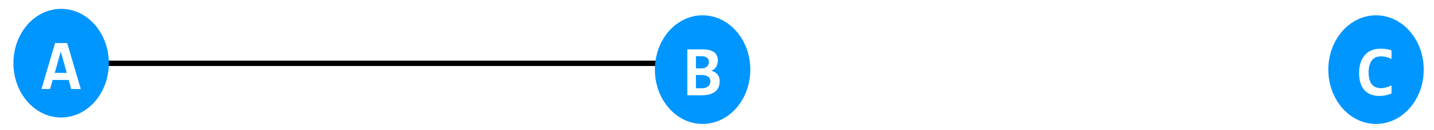


```
A: Self, 0
B: A->B, 1
C: A->B, 2
```

```
A: B->A, 1
B: Self, 0
C: None, inf
```

`t=9: B<->C` fails

`t=10:` B receives the following advertisement from `A`:
`[(A,0)]`

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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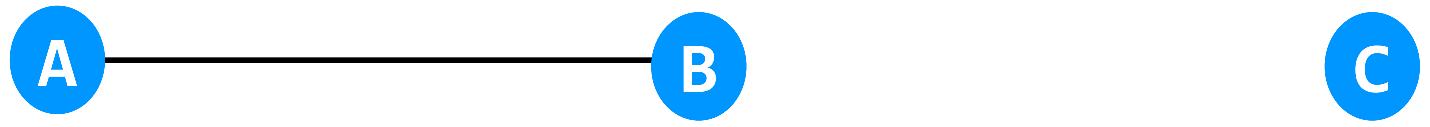
in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

t=9: B<->C fails

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

t=10: B receives the following advertisement from A:
[(A,0)]

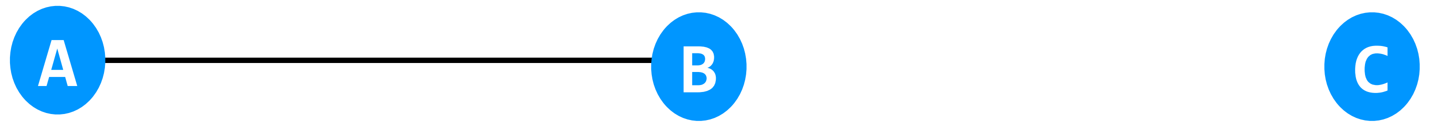
new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

link state	distance vector
what's in an advertisement	
its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	
effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	
flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	
the **overhead** of flooding	

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology

A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..
every link has cost 1




```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

`t=9: B<->C` fails

`t=10:` B receives the following advertisement from A:
`[(A,0)]`

`t=15:` A receives the following advertisement from B:
`[(B,0),(C,inf)]`

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
who gets a node's advertisement	effectively, **every other node** (via flooding)	only its **neighbors**
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	

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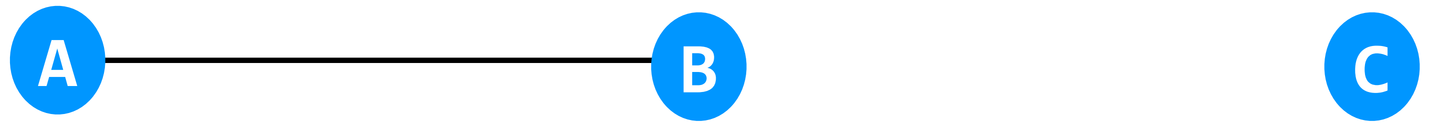


```
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B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: None, inf    C: None, inf
```

`t=9:` `B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:
`[(A,0)]`

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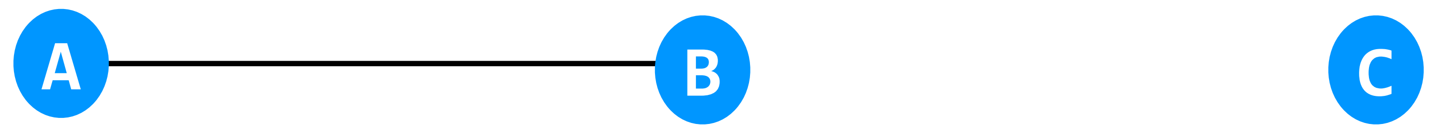


```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf

A: Self, 0      A: B->A, 1
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A: Self, 0      A: B->A, 1
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C: None, inf    C: None, inf
```

`t=9: B<->C` fails

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`t=15:` A receives the following advertisement from B: `[(B,0),(C,inf)]`

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

split horizon takes care of this particular case

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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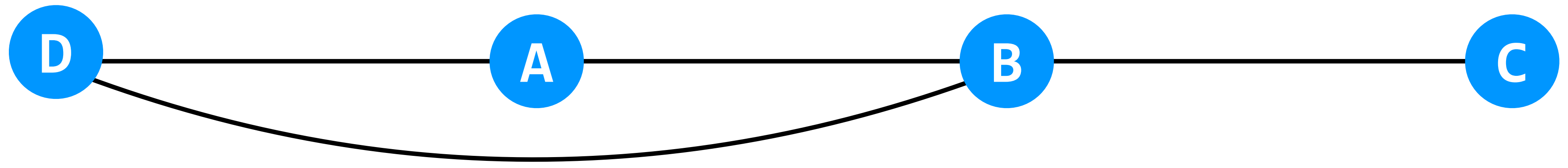
what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



C: D->B, 2 C: A->B, 2 C: B->C, 1 C: Self, 0

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

	link state	**distance vector**
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what limits scale?	the **overhead** of flooding	

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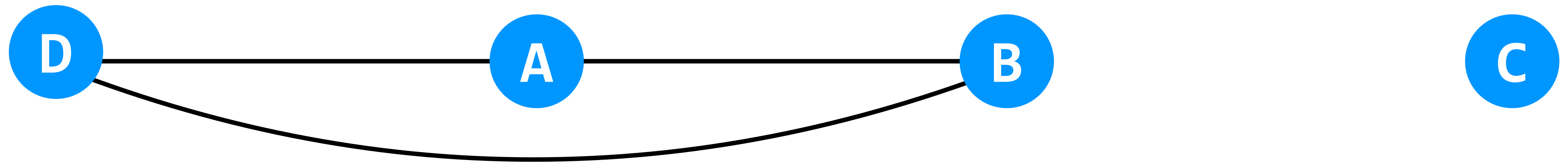
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



C: D->B, 2 C: A->B, 2 C: B->C, 1 B<->C fails

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

link state	distance vector
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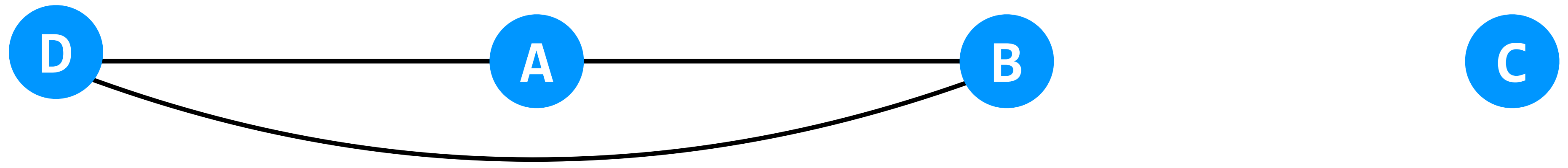
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



`C: D->B, 2`   `C: A->B, 2`   `C: None, inf`   `B<->C` fails

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
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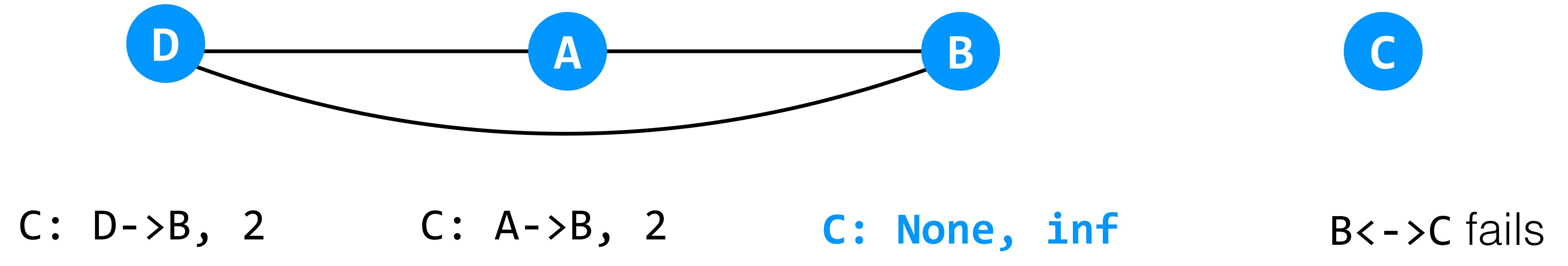
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



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	link state	**distance vector**
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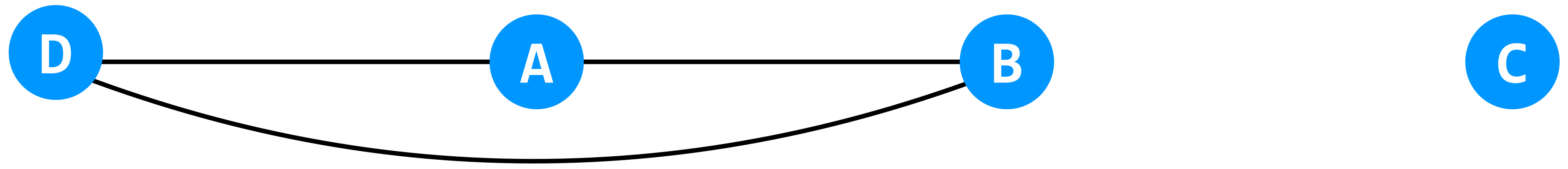

C: D->B, 2   C: A->B, 2   C: None, inf

B<->C fails

B's advertisement to A gets lost
(so A makes no changes)

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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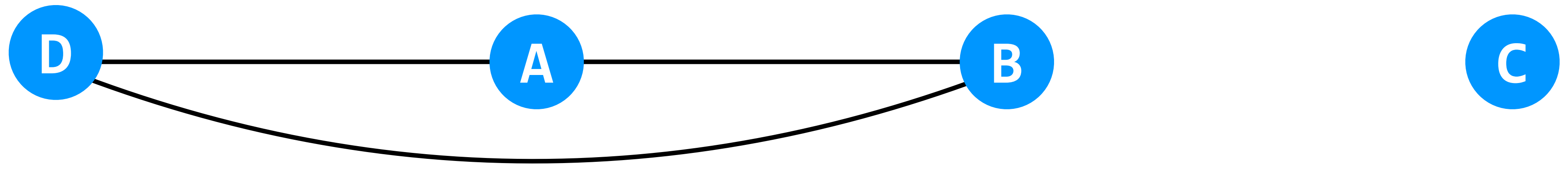
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



C: D->B, 2	C: A->B, 2	**C: None, inf**	B<->C fails
C: None, inf	C: A->B, 2	C: None, inf	B's advertisement to A gets lost (so A makes no changes)

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

link state	distance vector
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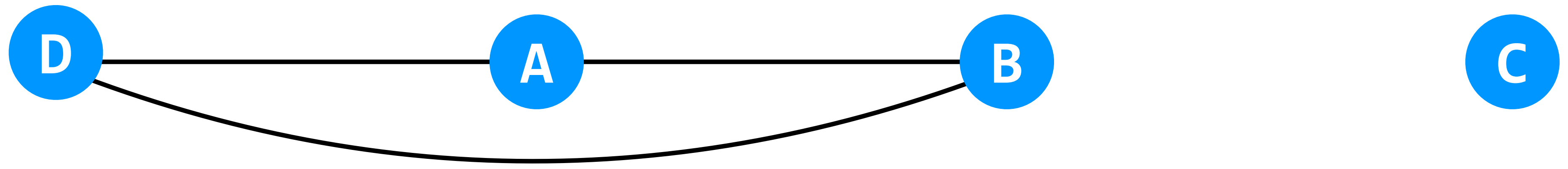
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



D	A	B
`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**
`C: None, inf`	`C: A->B, 2`	`C: None, inf`

`B<->C` fails

`B`'s advertisement to `A` gets lost
(so `A` makes no changes)

`A` advertises about `C` to `D`
(not to `B` because of split horizon)

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	distance vector
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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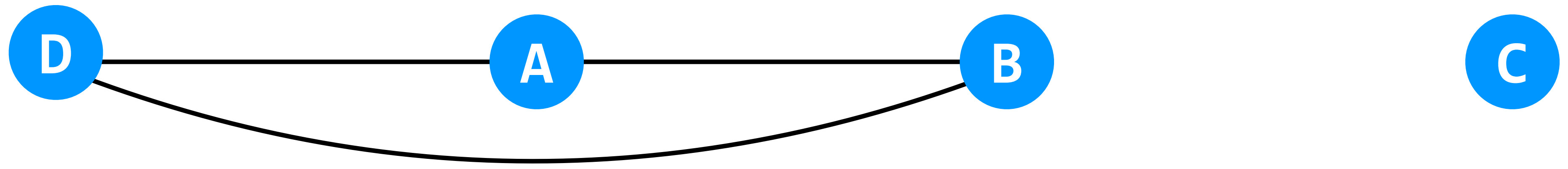
distance-vector routing: disseminate information about the current *min costs* to each node, rather than the actual topology



D	A	B	
C: D->B, 2	C: A->B, 2	**C: None, inf**	B<->C fails
C: None, inf	C: A->B, 2	C: None, inf	B's advertisement to A gets lost (so A makes no changes)
C: D->A, 3	C: A->B, 2	C: None, inf	A advertises about C to D (not to B because of split horizon)

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
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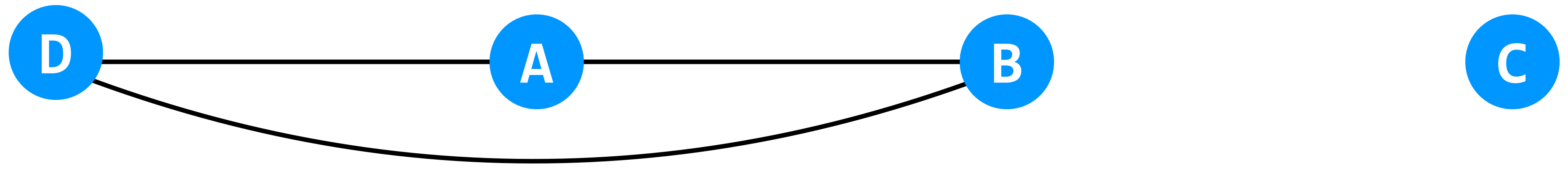

D	A	B	
`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**	B<->C fails
`C: None, inf`	`C: A->B, 2`	`C: None, inf`	B's advertisement to A gets lost (so A makes no changes)
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`	A advertises about C to D (not to B because of split horizon)
			D advertises about C to B

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

link state	distance vector
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its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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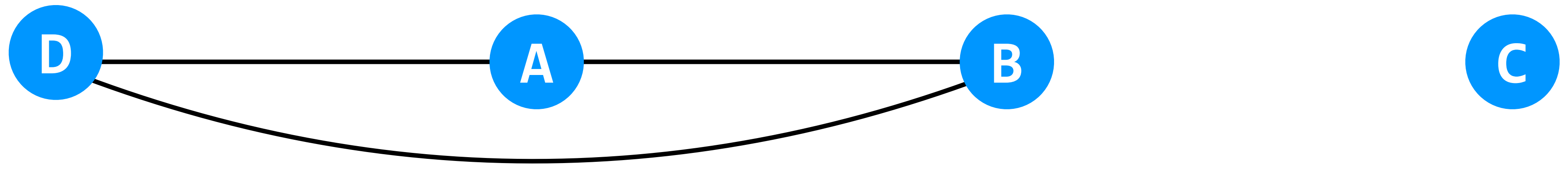

D	A	B	
`C: D->B, 2`	`C: A->B, 2`	`C: None, inf`	B<->C fails
`C: None, inf`	`C: A->B, 2`	`C: None, inf`	B's advertisement to A gets lost (so A makes no changes)
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`	A advertises about C to D (not to B because of split horizon)
`C: D->A, 3`	`C: A->B, 2`	`C: B->D, 4`	D advertises about C to B

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	distance vector
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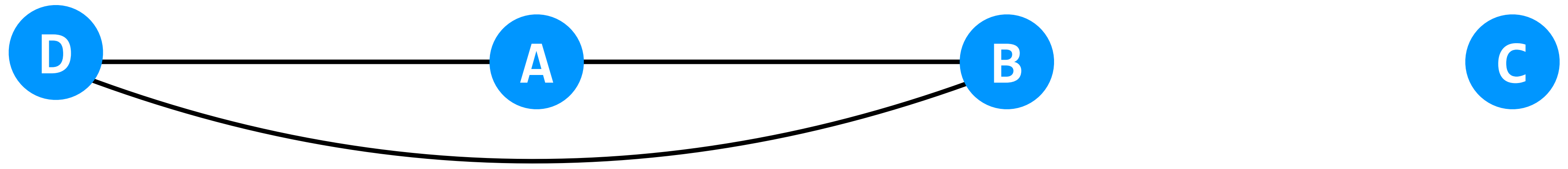

`C: D->B, 2`	`C: A->B, 2`	`C: None, inf`	`B<->C` fails
`C: None, inf`	`C: A->B, 2`	`C: None, inf`	`B`'s advertisement to `A` gets lost (so `A` makes no changes)
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`	`A` advertises about `C` to `D` (not to `B` because of split horizon)
`C: D->A, 3`	`C: A->B, 2`	`C: B->D, 4`	`D` advertises about `C` to `B`
			`B` advertises about `C` to `A`

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
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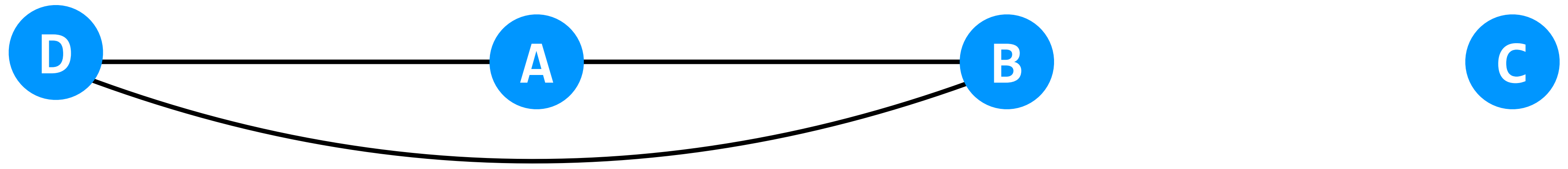

`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**	B<->C fails
`C: None, inf`	`C: A->B, 2`	`C: None, inf`	B's advertisement to A gets lost (so A makes no changes)
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`	A advertises about C to D (not to B because of split horizon)
`C: D->A, 3`	`C: A->B, 2`	**`C: B->D, 4`**	D advertises about C to B
`C: D->A, 3`	**`C: A->B, 5`**	`C: B->D, 4`	B advertises about C to A

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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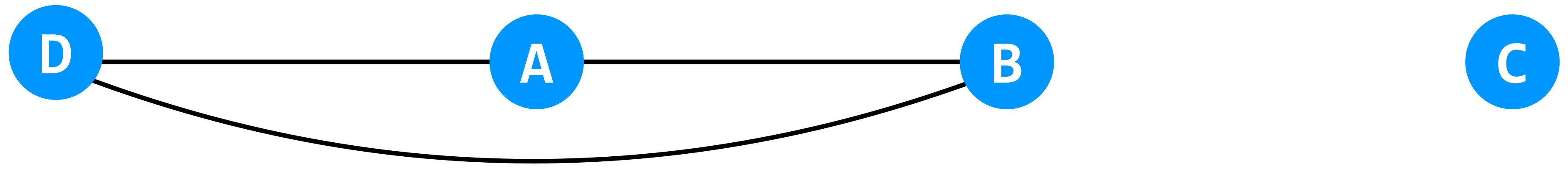

D	A	B	event
`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**	`B<->C` fails
`C: None, inf`	`C: A->B, 2`	`C: None, inf`	`B`'s advertisement to `A` gets lost (so `A` makes no changes)
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`	`A` advertises about `C` to `D` (not to `B` because of split horizon)
`C: D->A, 3`	`C: A->B, 2`	**`C: B->D, 4`**	`D` advertises about `C` to `B`
`C: D->A, 3`	**`C: A->B, 5`**	`C: B->D, 4`	`B` advertises about `C` to `A`

continues until all costs to C are INFINITY

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

link state	**distance vector**
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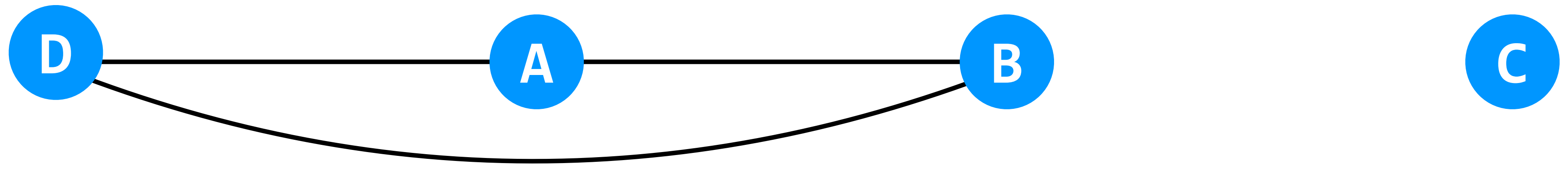

D	A	B	
C: D->B, 2	C: A->B, 2	**C: None, inf**	B<->C fails
C: None, inf	C: A->B, 2	C: None, inf	B's advertisement to A gets lost (so A makes no changes)
C: D->A, 3	C: A->B, 2	C: None, inf	A advertises about C to D (not to B because of split horizon)
C: D->A, 3	C: A->B, 2	**C: B->D, 4**	D advertises about C to B
C: D->A, 3	**C: A->B, 5**	C: B->D, 4	B advertises about C to A

continues until all costs to C are INFINITY

new strategy ("split horizon"): don't send advertisements about a route to the node providing the route

	link state	**distance vector**
what's in an advertisement	its **link costs** to each of its **neighbors**	its **current costs** to **every node it's aware of**
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what happens when things fail?	flooding makes link-state routing very resilient to failure	failures can be complicated because of timing
what limits scale?	the **overhead** of flooding	failure handling

in this example, nodes will explicitly include their route/cost to themselves in their advertisements; you can make distance-vector work either way

	link state	**distance vector**
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neither one of these algorithms will scale to the size of the internet, nor do either of them allow for *policy routing*

	link state	**distance vector**
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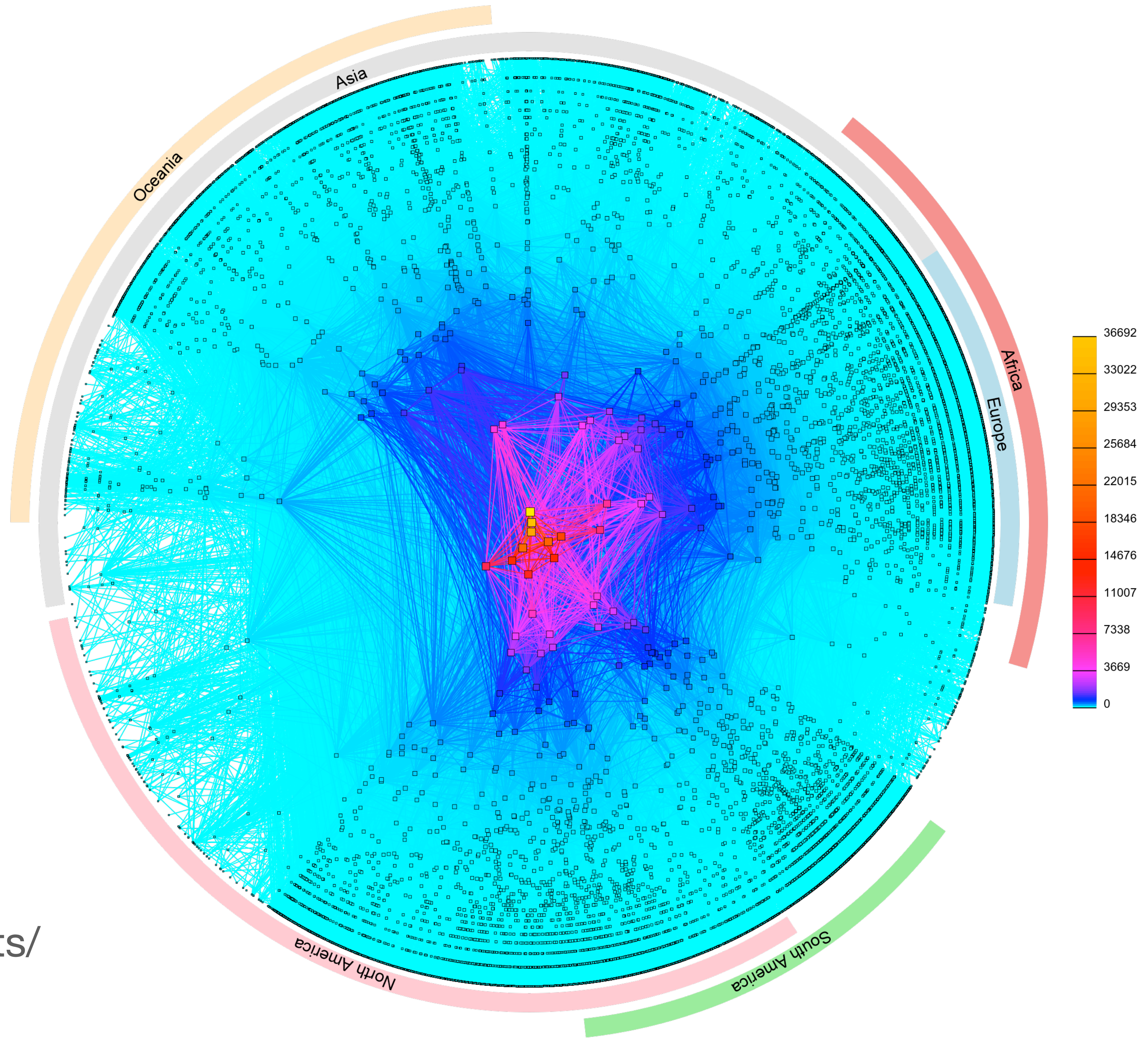
1970s: ARPAnet — hosts.txt

1978: flexibility and layering — **distance-vector routing**

early 80s: growth → change — TCP, UDP; **OSPF**, EGP, DNS (a link-state routing protocol)

late 80s: growth → problems — congestion collapse; policy routing; CIDR

1993: commercialization



CAIDA's IPv4 AS Core, January 2020 (https://www.caida.org/projects/cartography/as-core/2020/)

application	the things that actually generate traffic
transport	sharing the network, reliability (or not) *examples: TCP, UDP*
network	naming, addressing, routing *examples: IP*
link	communication between two directly-connected nodes *examples: ethernet, bluetooth, 802.11 (wifi)*

IP networks can route using either distance-vector routing (RIP) or link-state routing (OSPF)