6.033 Spring 2019

Lecture #9

- **Link-state Routing**
- **Distance-vector Routing**

Internet of Problems

How do we **route** (and address) scalably, while dealing with issues of policy and economy?

How do we **transport** data scalably, while dealing with varying application demands?

How do we **adapt** new applications and technologies to an inflexible architecture?

Internet of Problems

How do we **route** (and address) **scalably**, while dealing with issues of policy and economy?

How do we **transport** data scalably, while dealing with varying application demands?

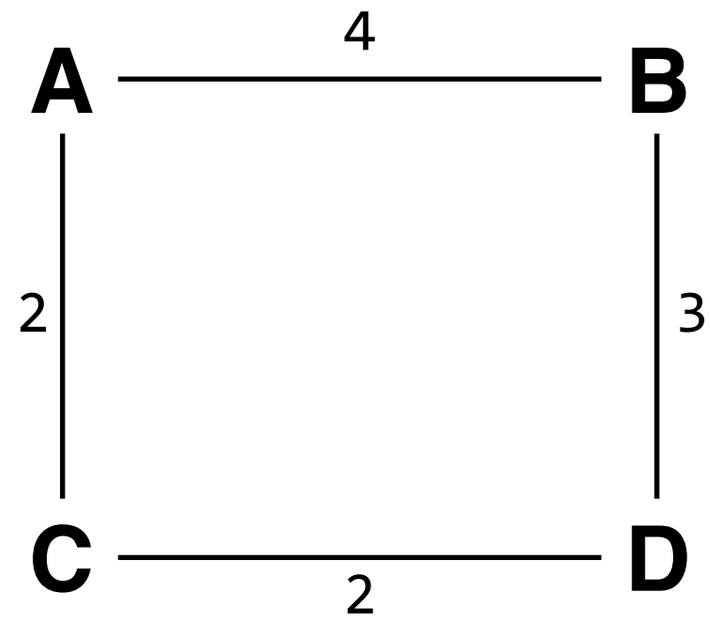
How do we **adapt** new applications and technologies to an inflexible architecture?

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

goal of a routing protocol: build a routing table at each switch, such that `routing_table[dst]` contains a **minimum-cost route** to `dst`

A's routing table

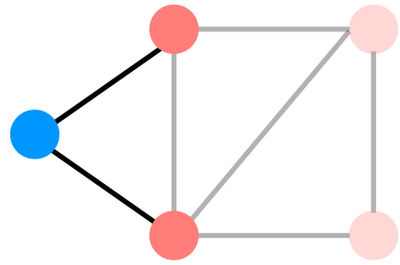
```
routing_table[A] = self ; 0
routing_table[B] = A->B ; 4
routing_table[C] = A->C ; 2
routing_table[D] = A->C ; 4
```



Distributed Routing

Distributed Routing

1. Nodes learn about their neighbors via the **HELLO** protocol



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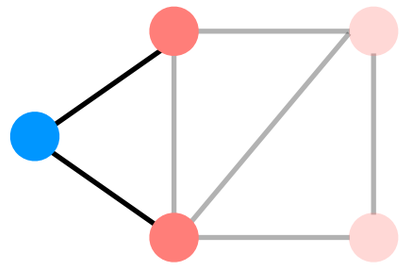
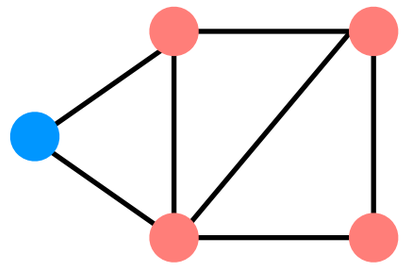


2. Nodes learn about other reachable nodes via advertisements



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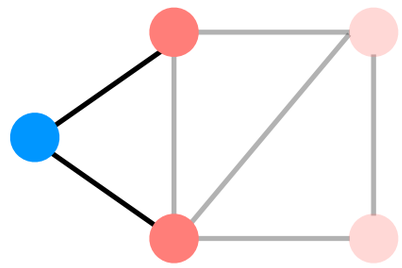

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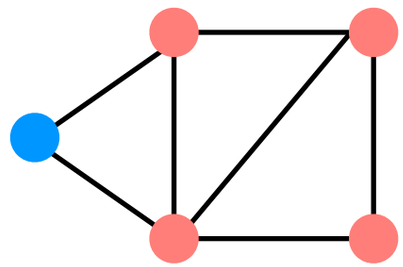
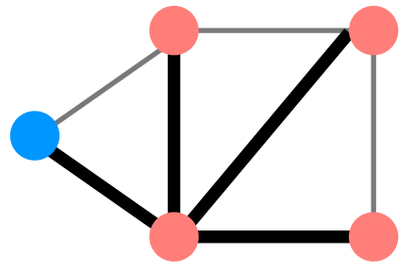


3. Nodes determine the minimum-cost routes (of the routes they know about)



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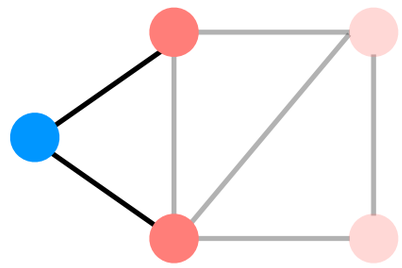

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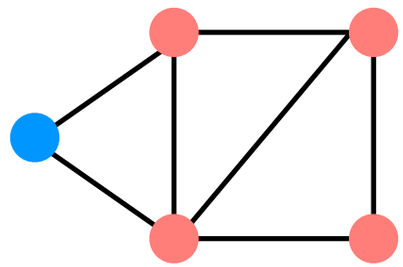

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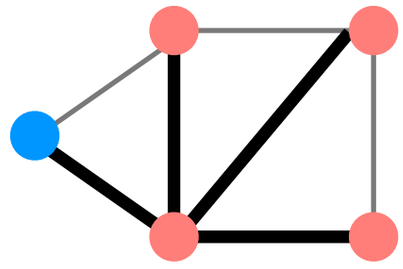

All of these steps happen periodically, which allows the routing protocol to detect and respond to failures

Link-state Routing

disseminate topology information so that nodes can run a shortest-path algorithm

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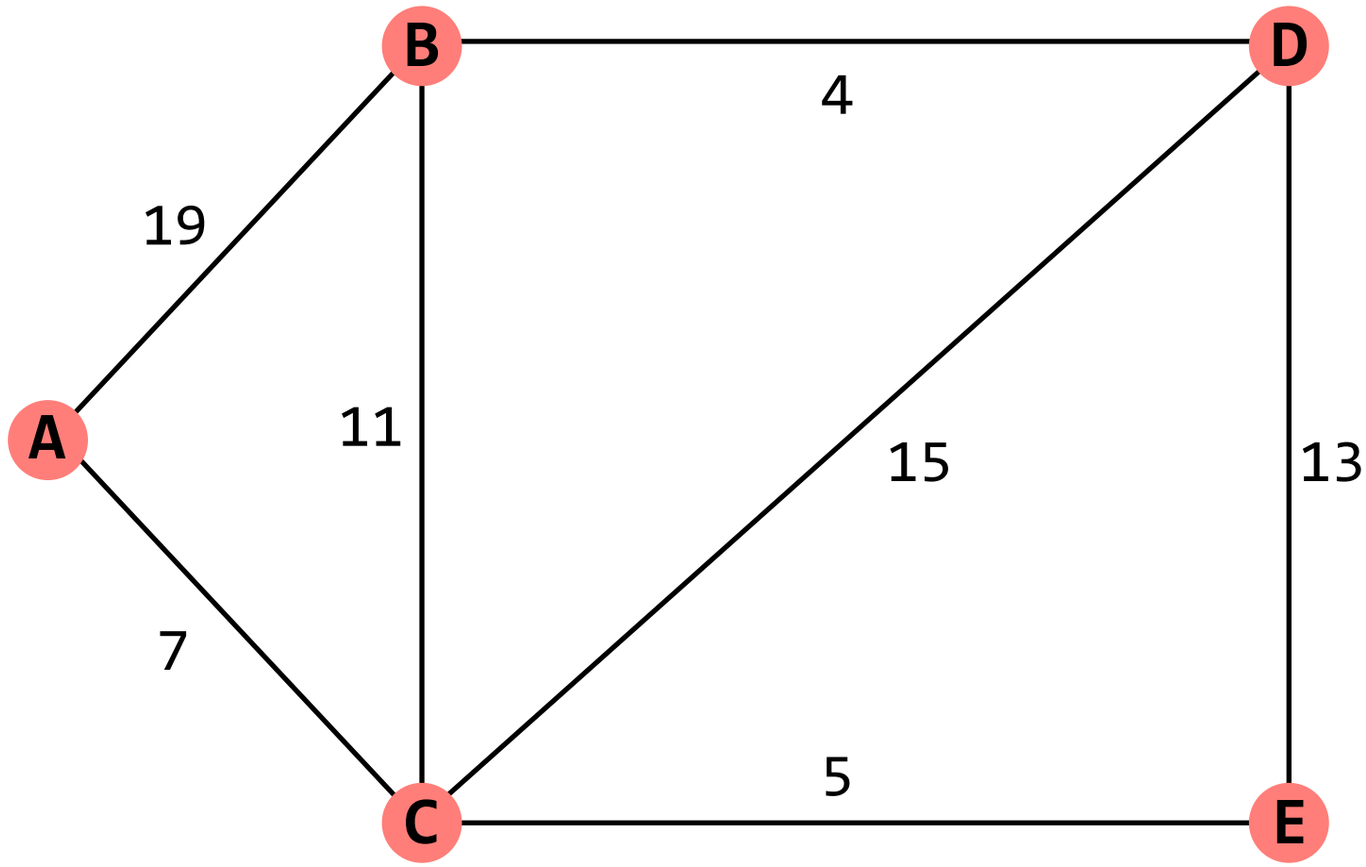

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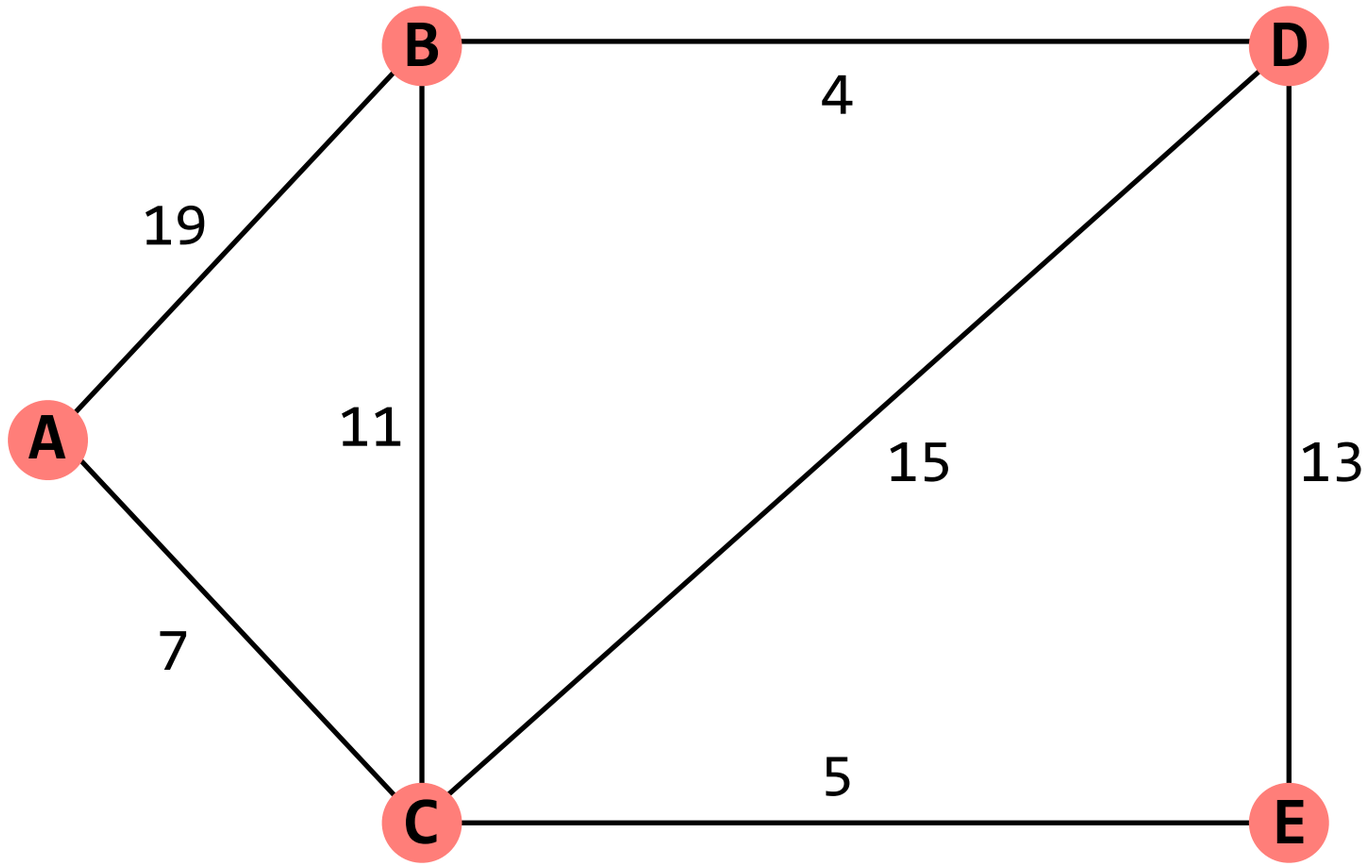
A node's advertisements contain a list of its neighbors and its **link costs** to those nodes



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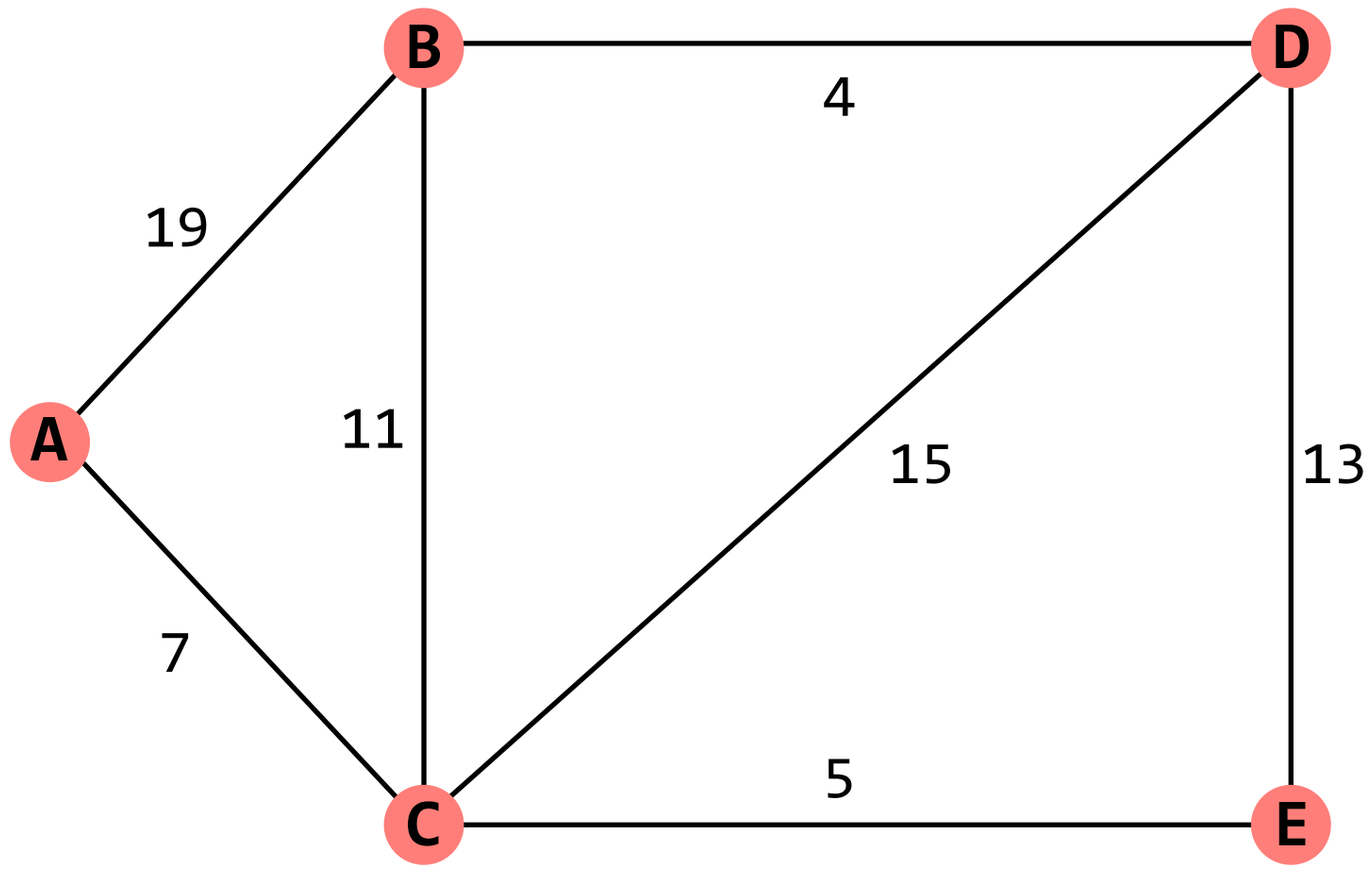


```
From A: [(B,19),(C,7)]
From B: [(A,19),(C,11),(D,4)]
From C: [(A,7),(B,11),(D,15),(E,5)]
From D: [(B,4),(C,15),(E,13)]
From E: [(C,5),(D,13)]
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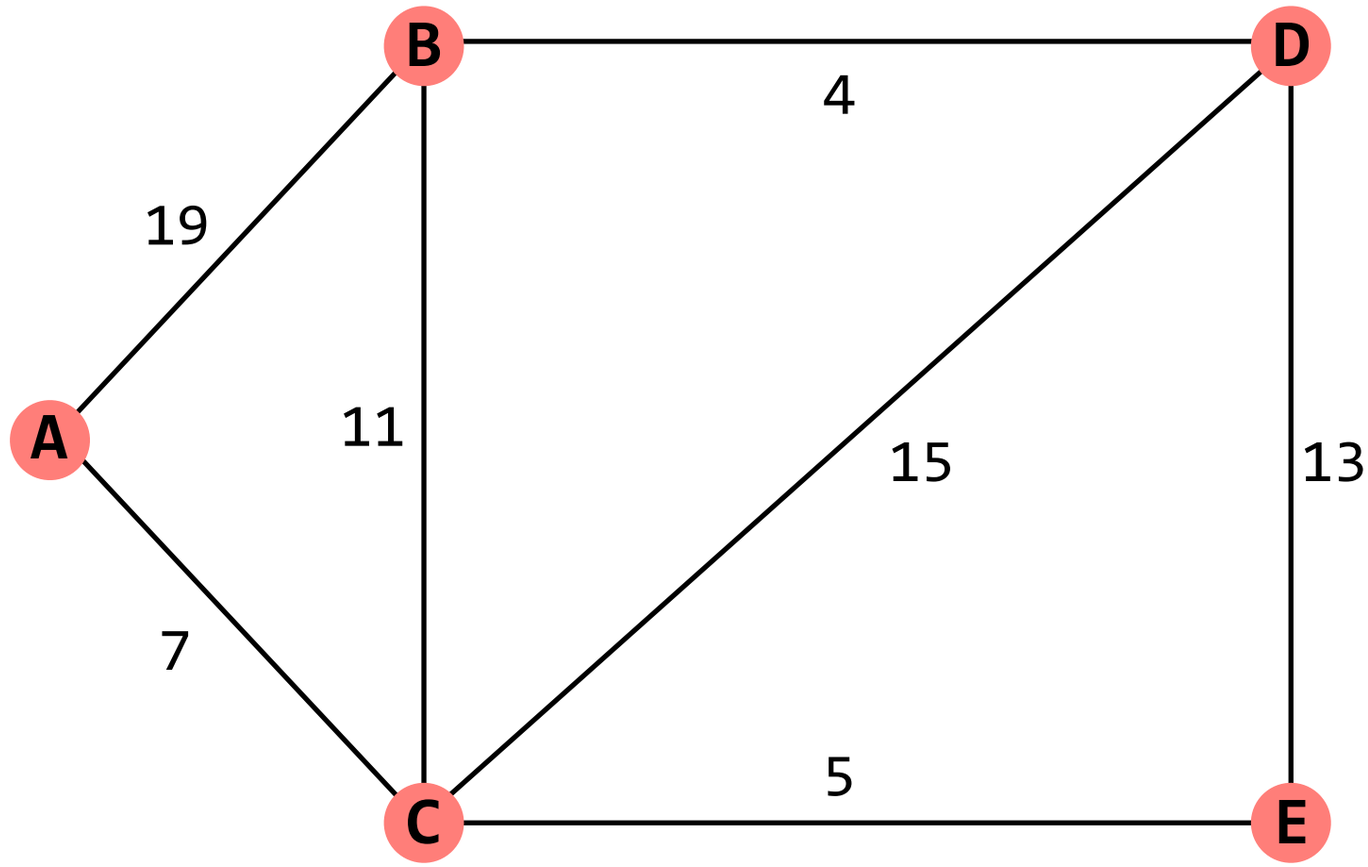

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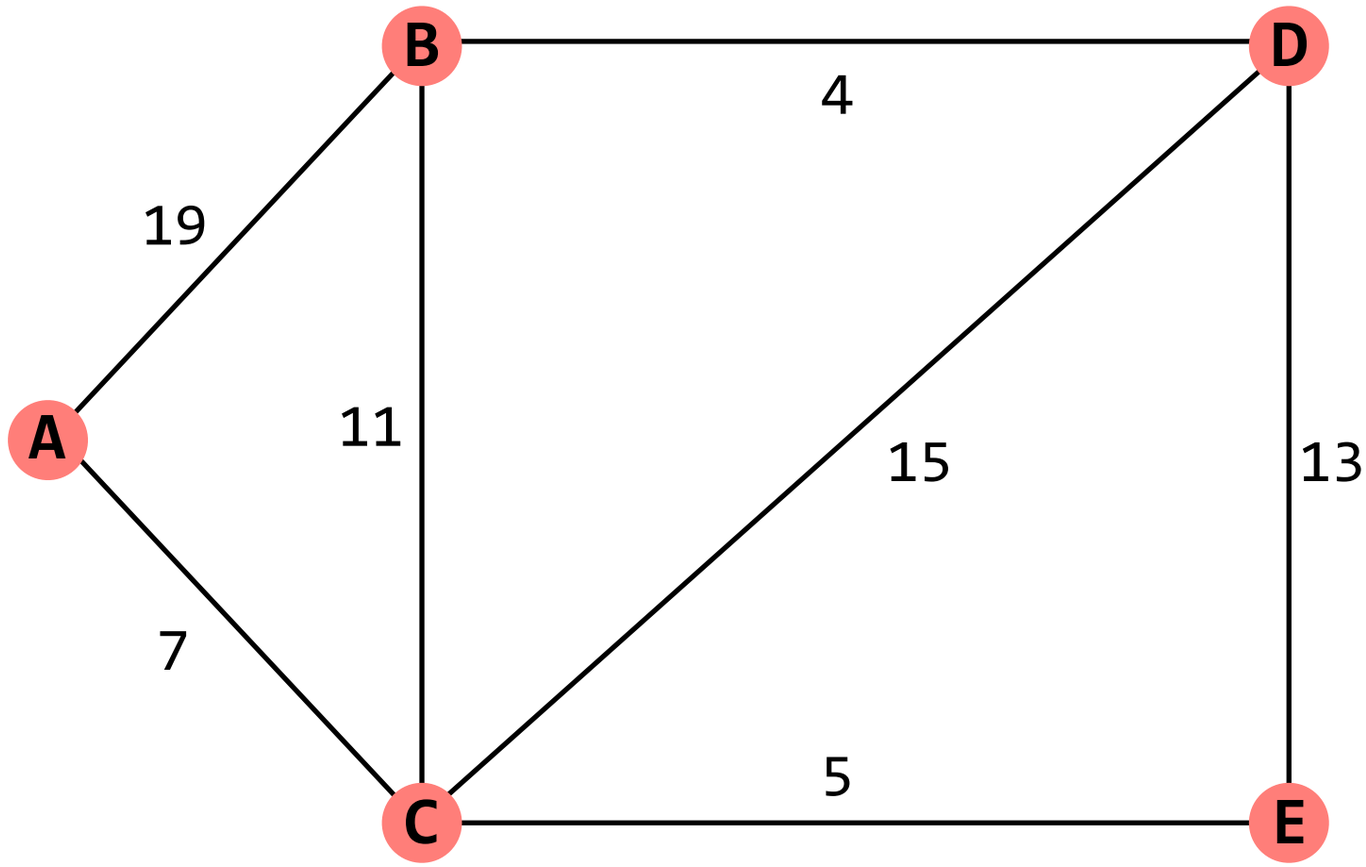

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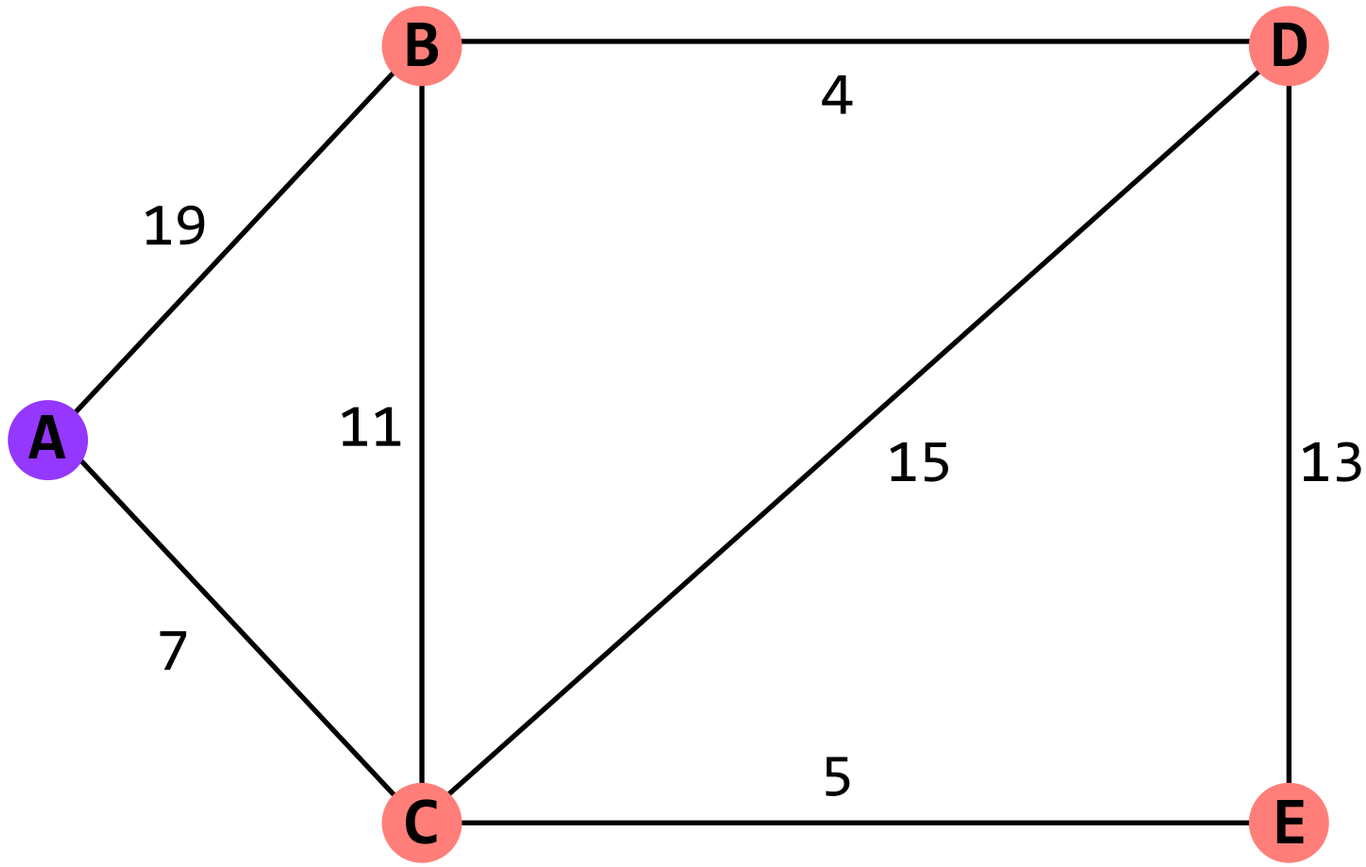

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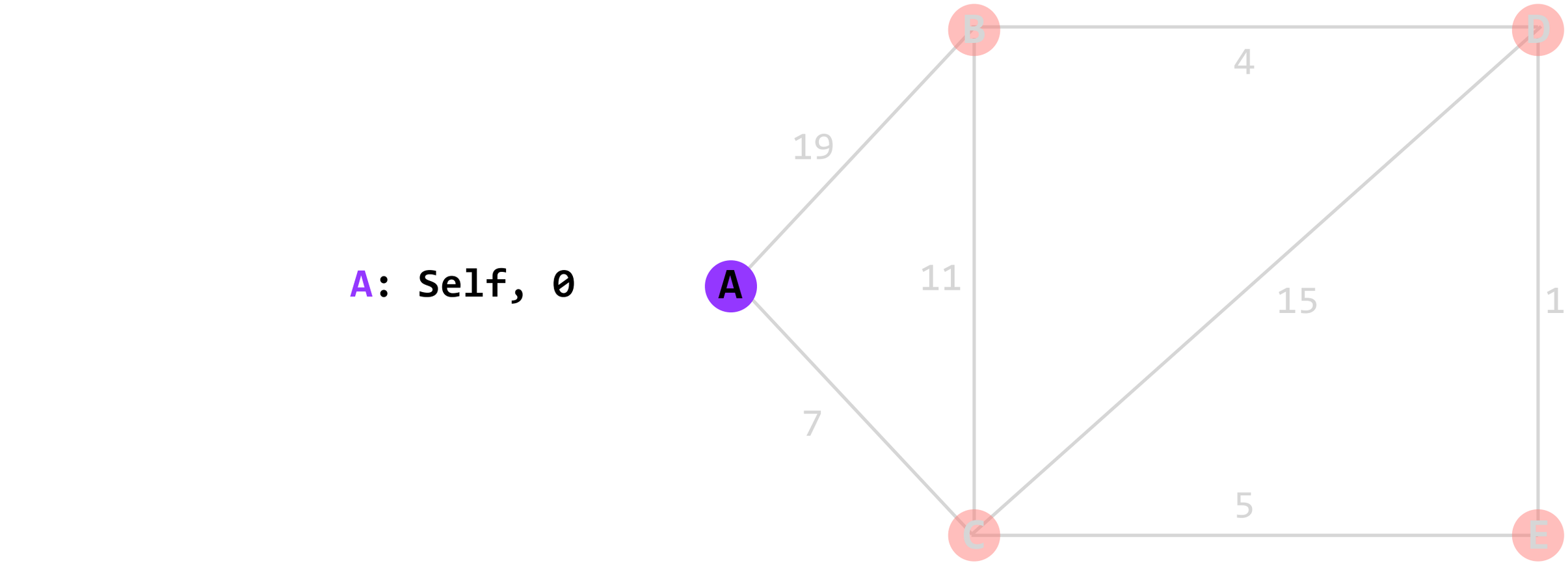

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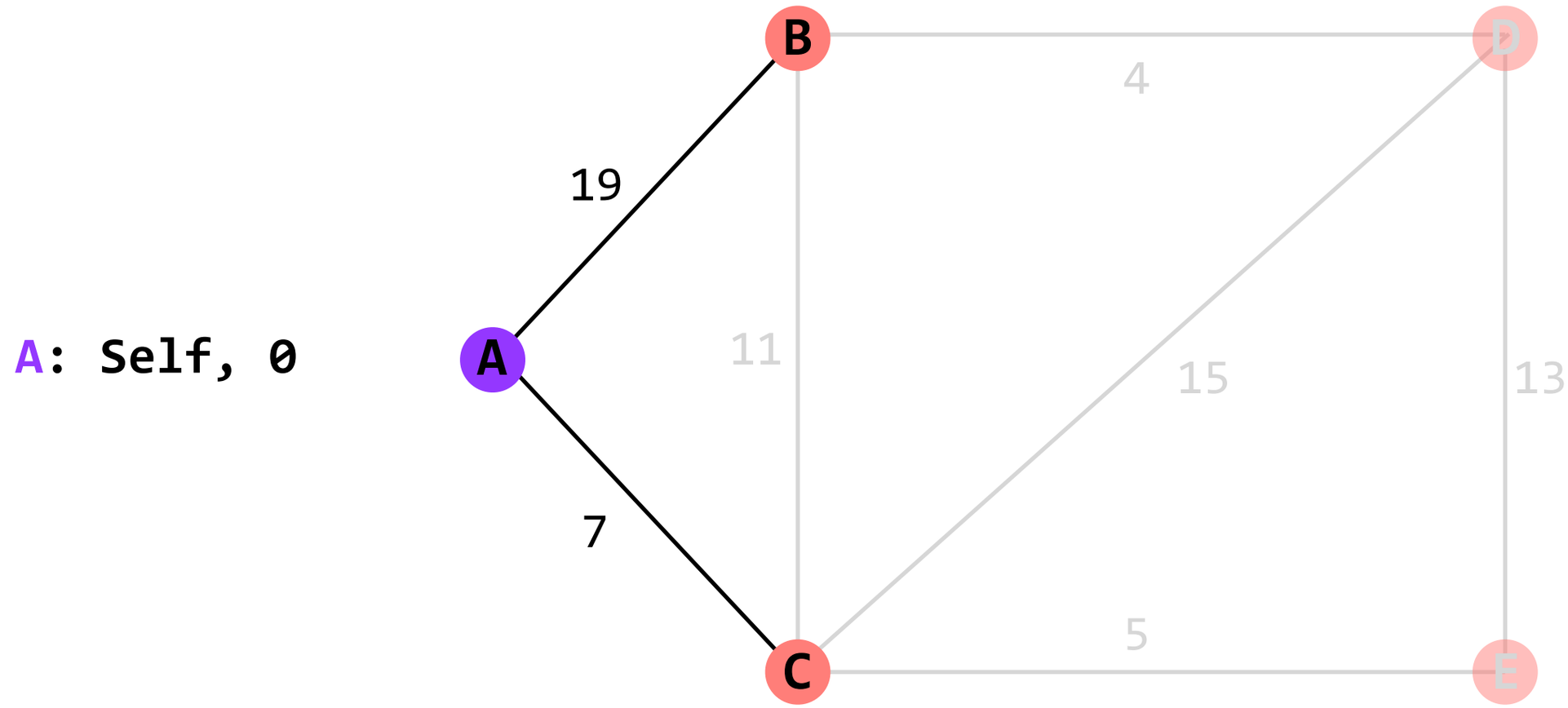

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A: Self, 0
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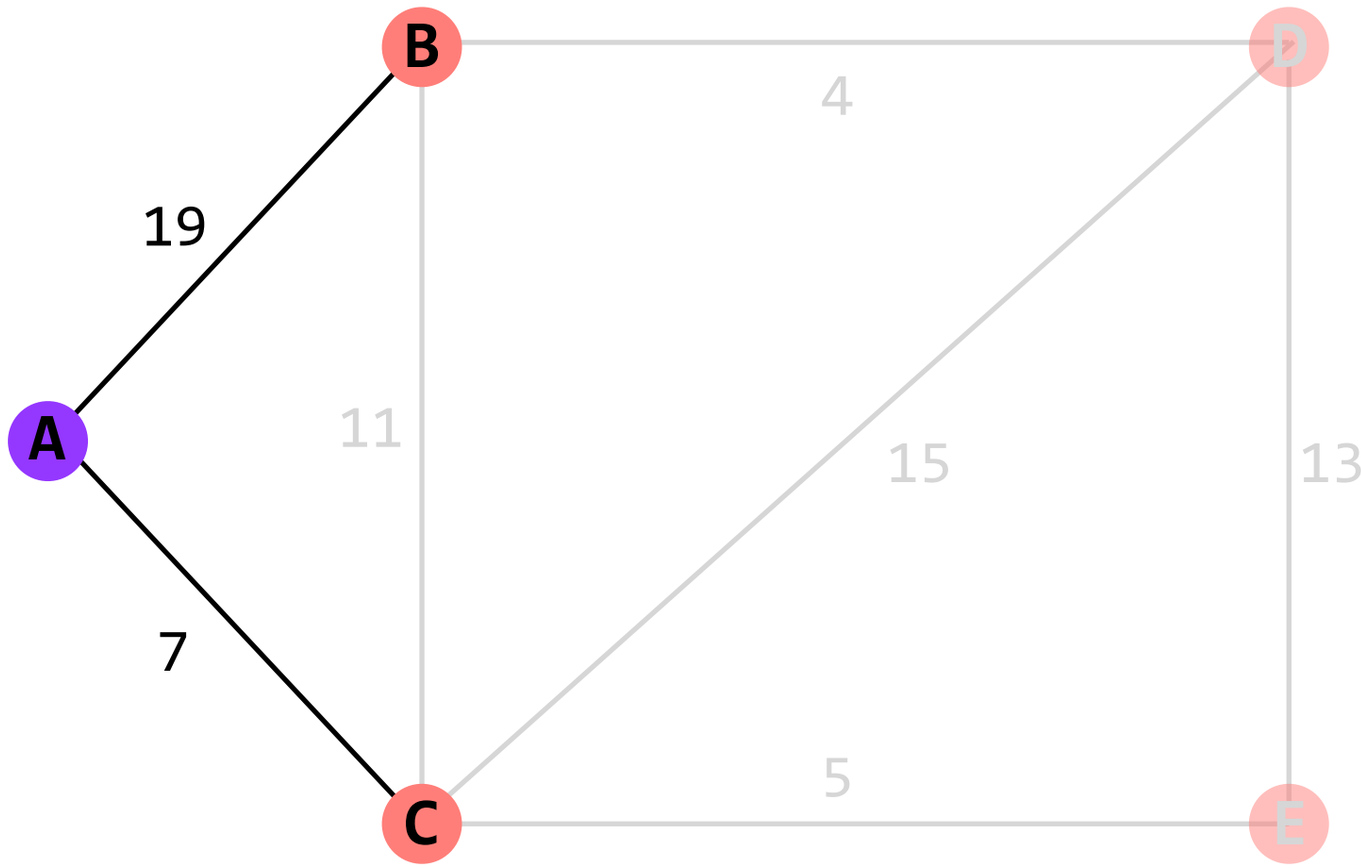

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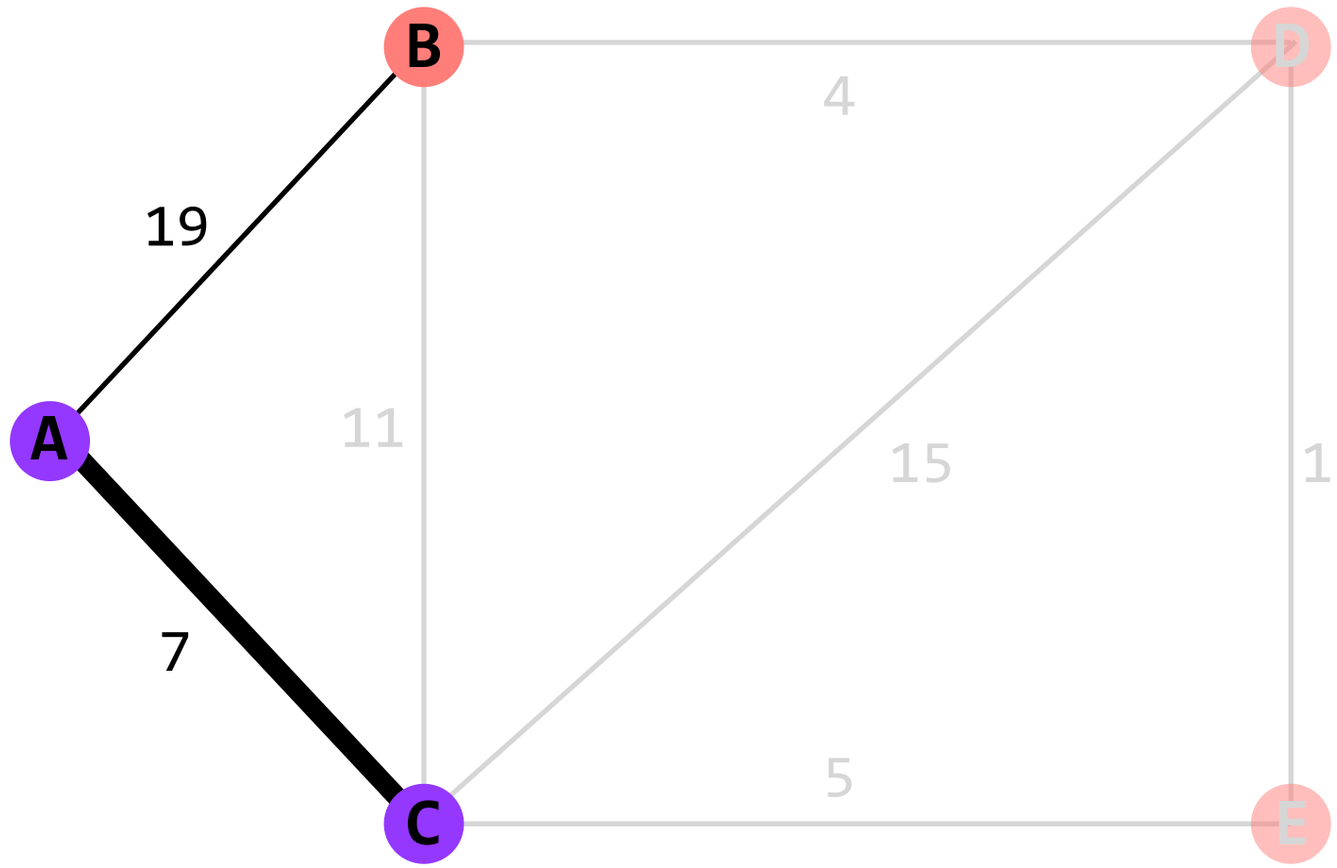

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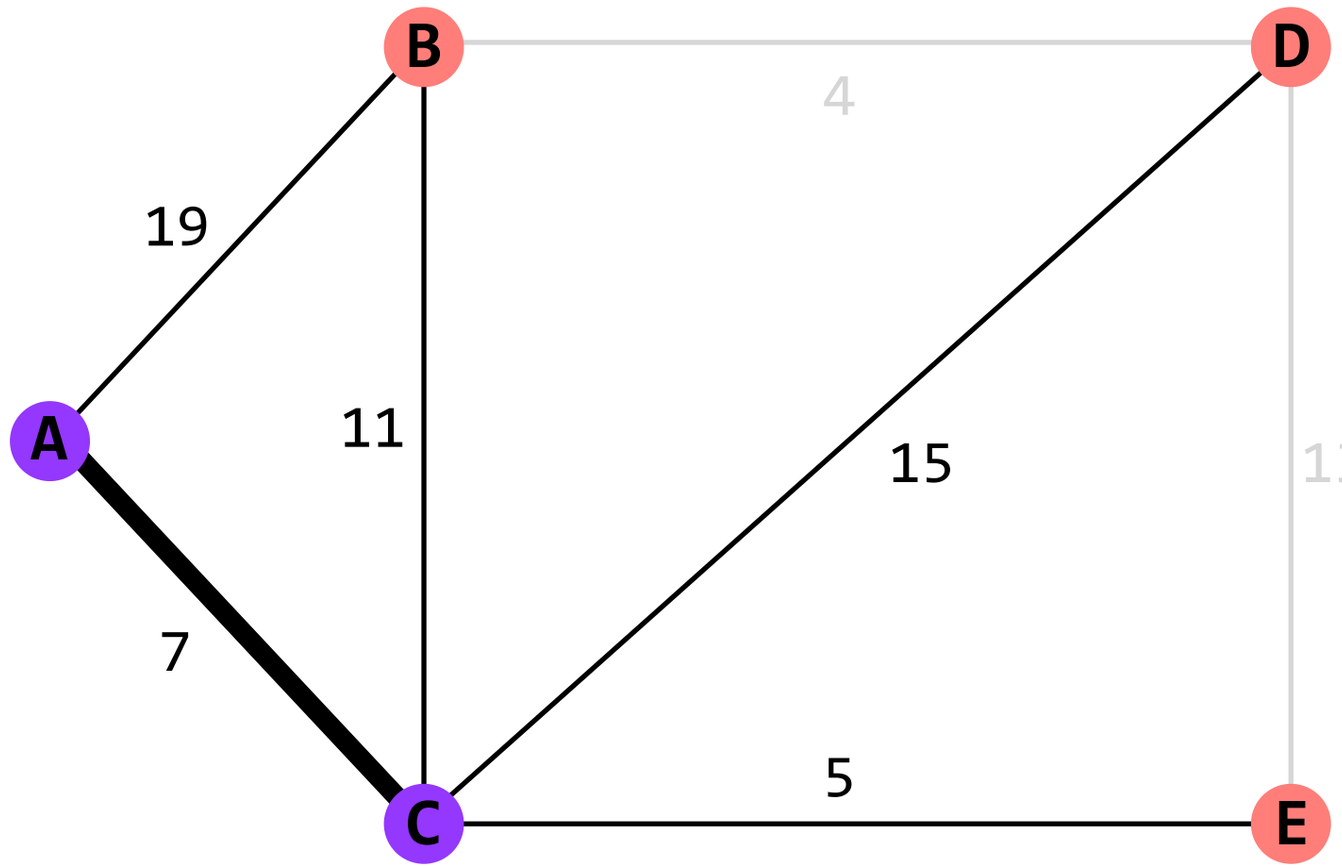

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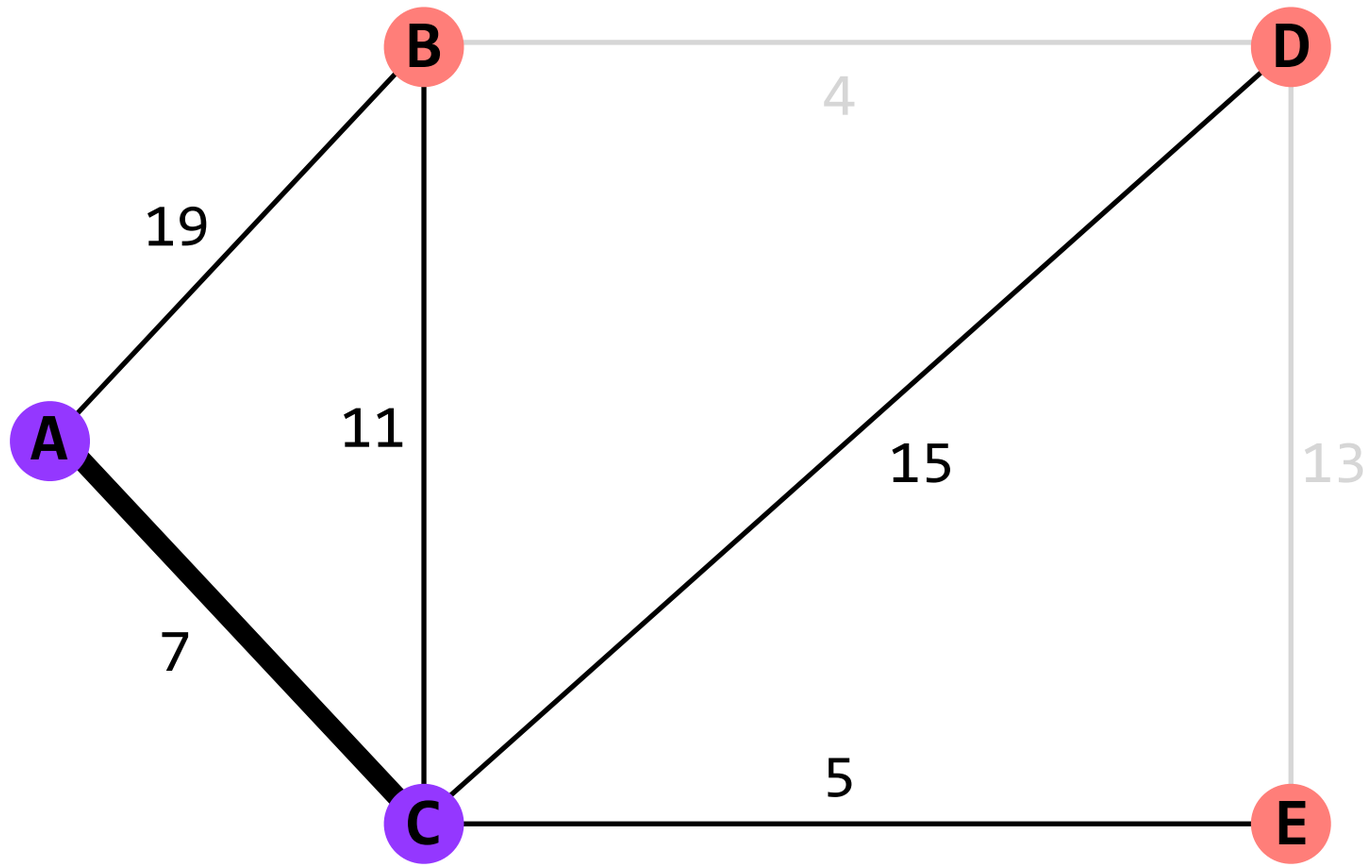

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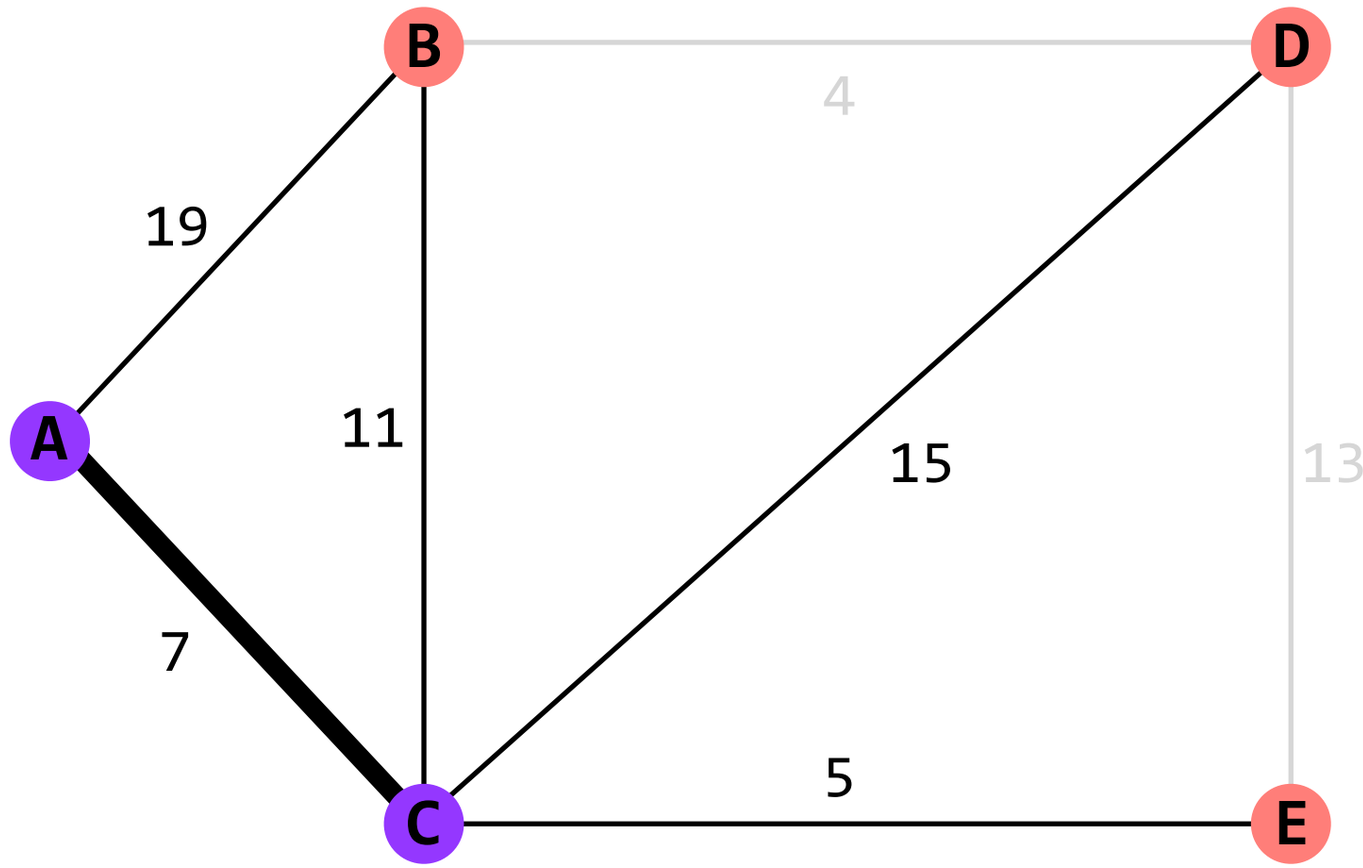

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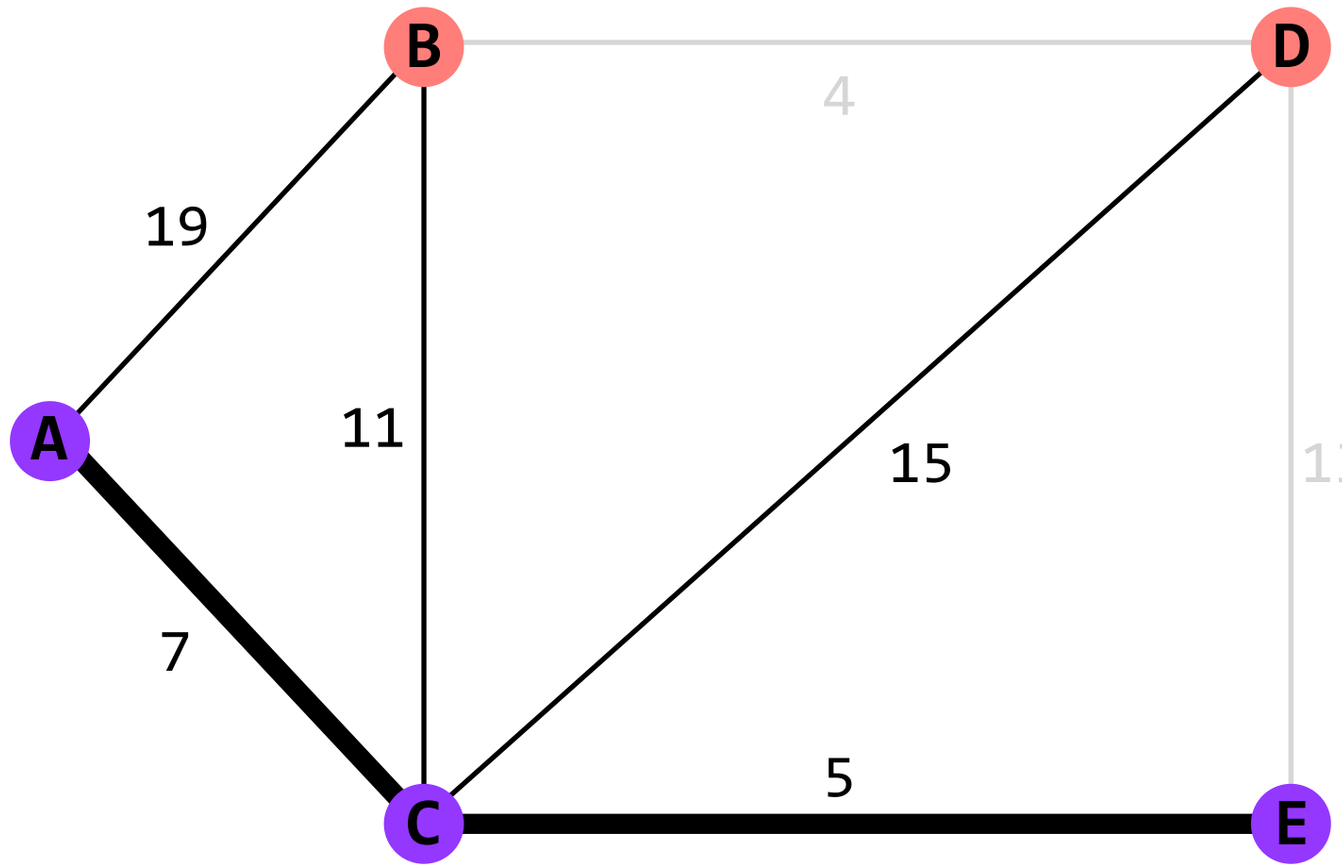

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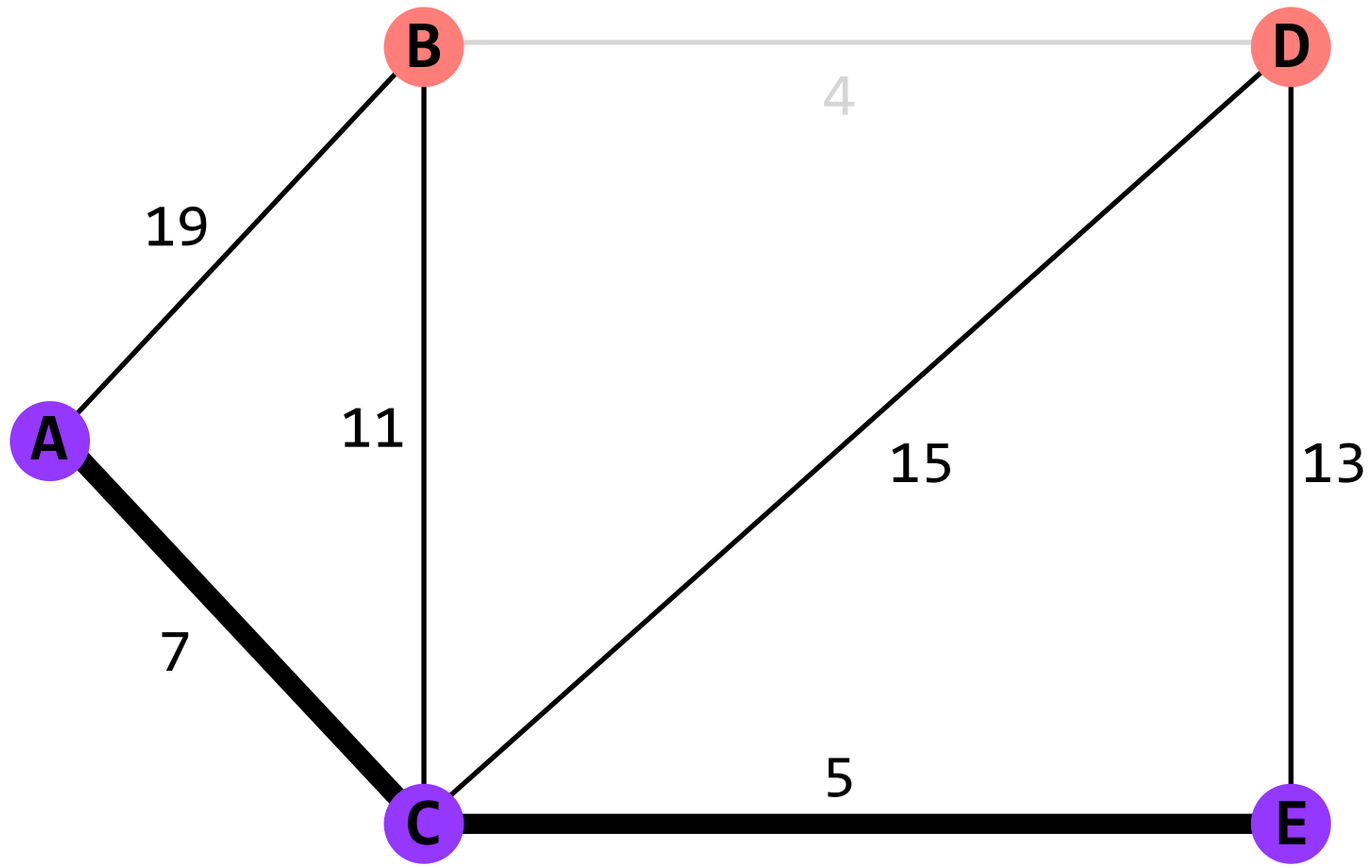

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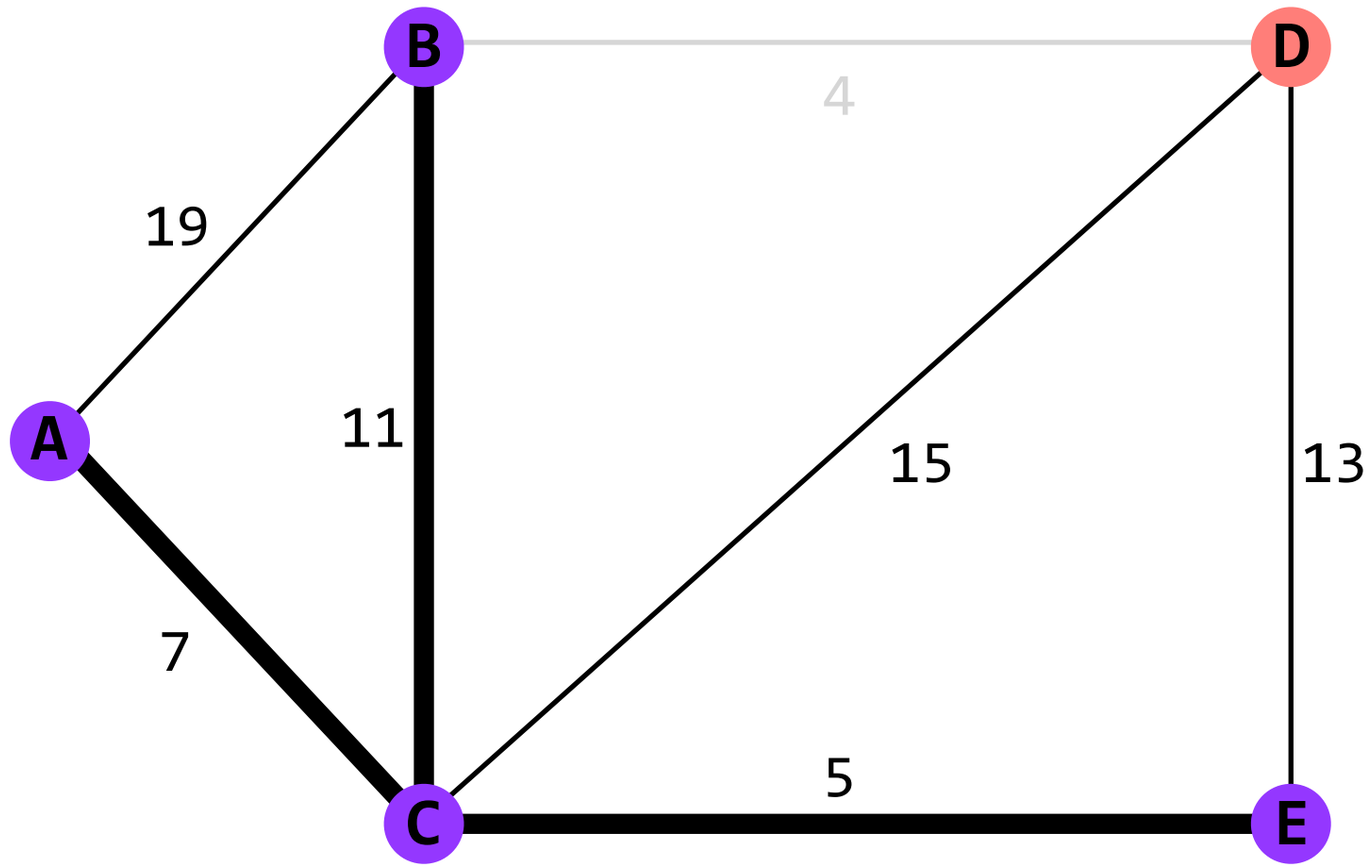

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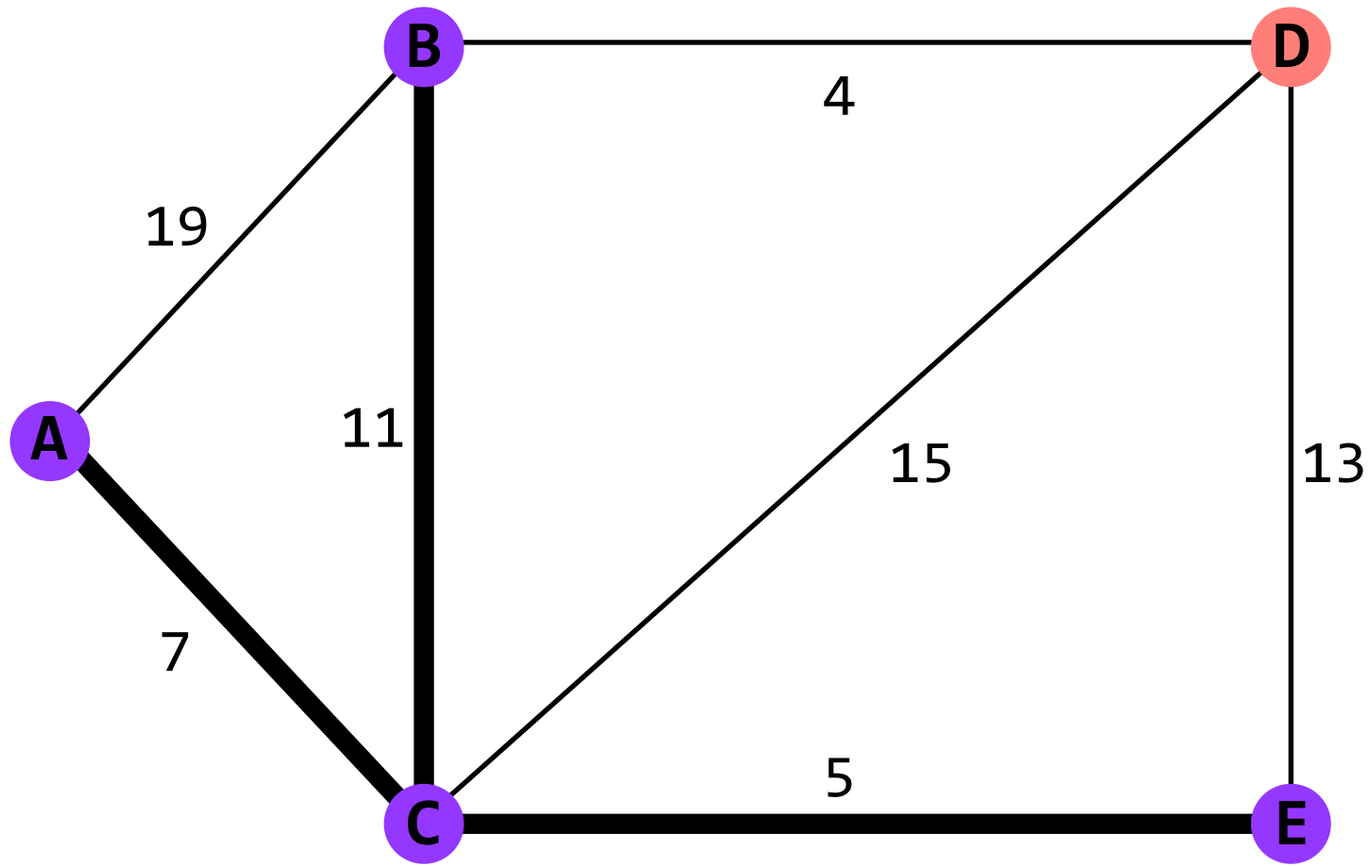

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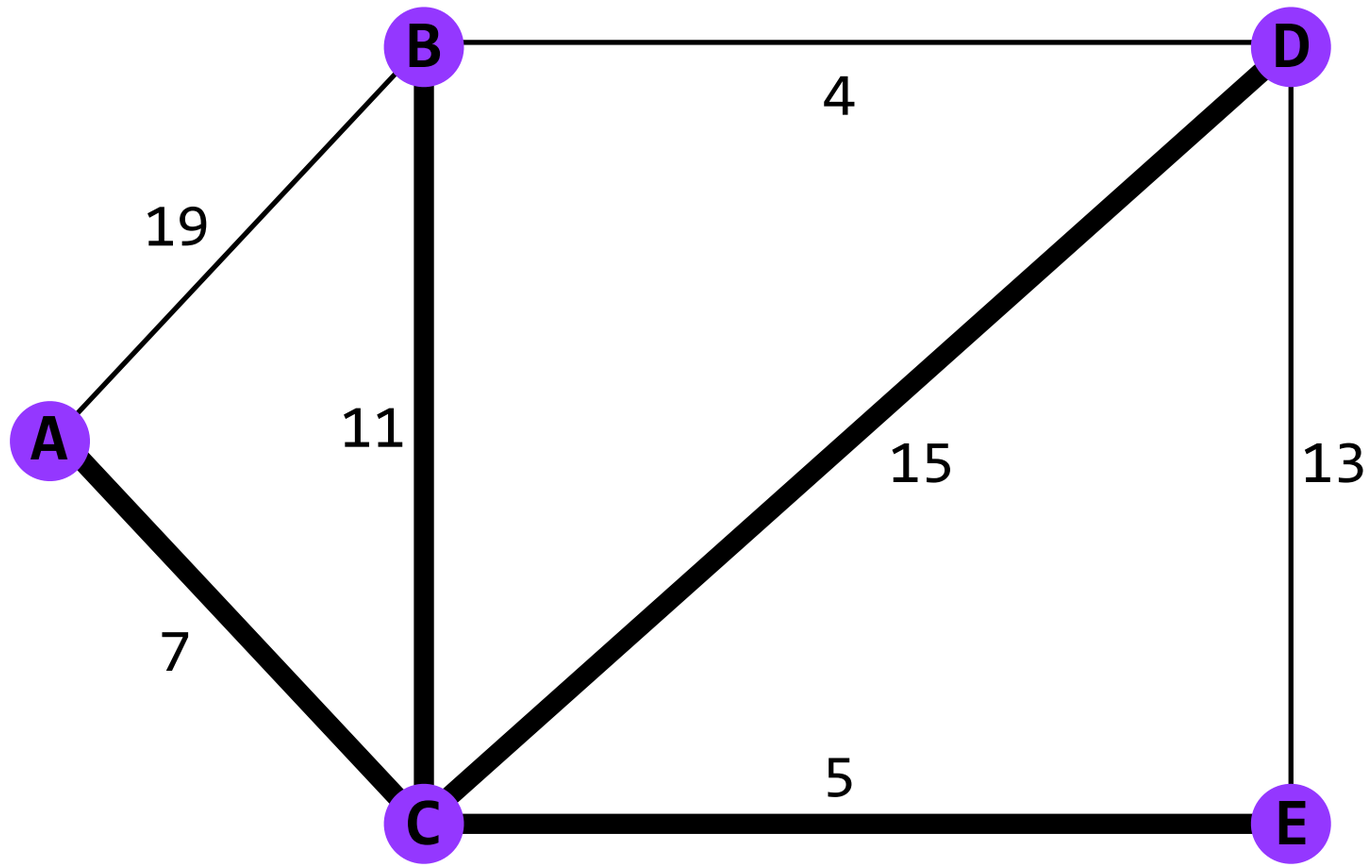

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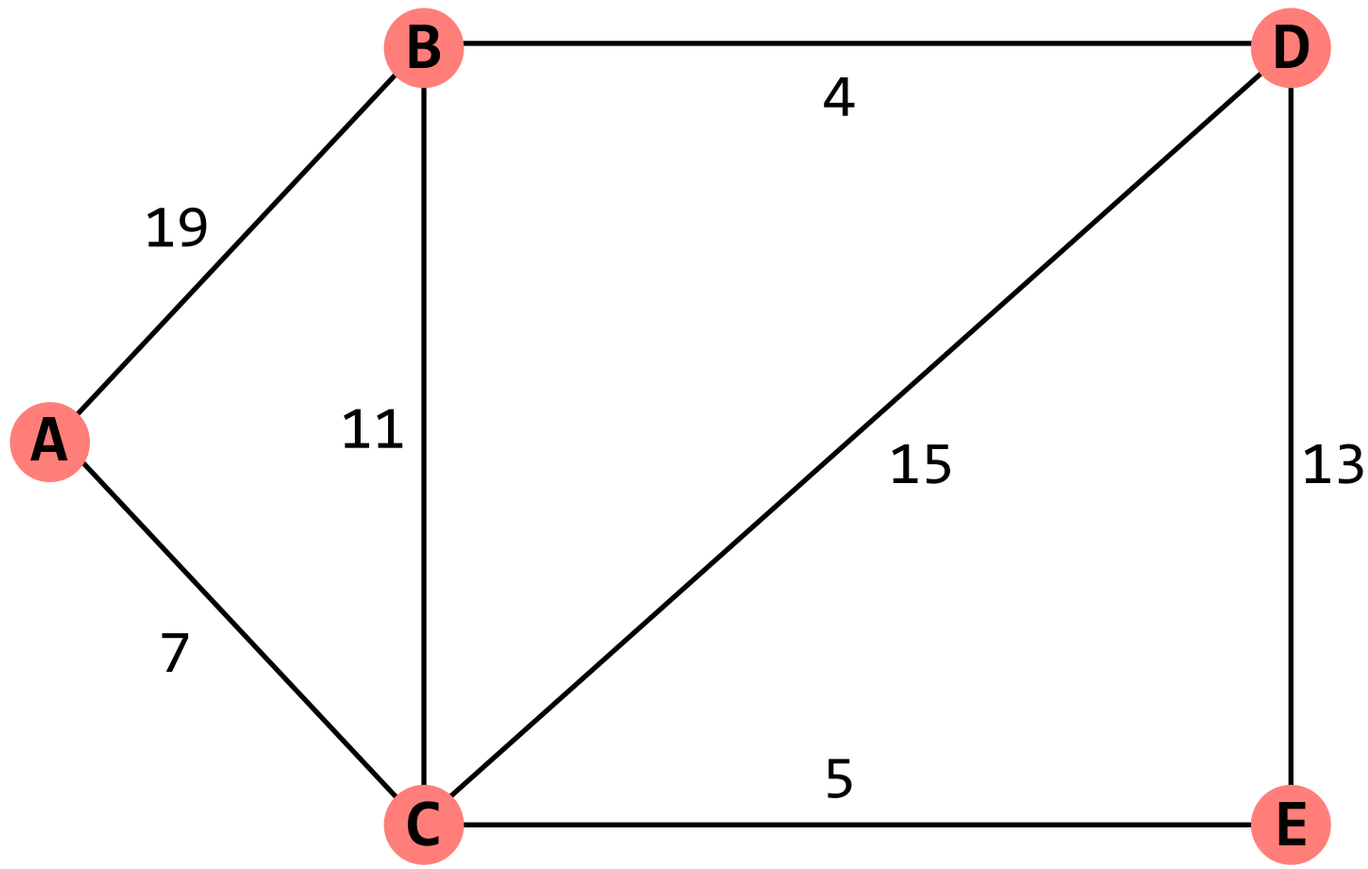

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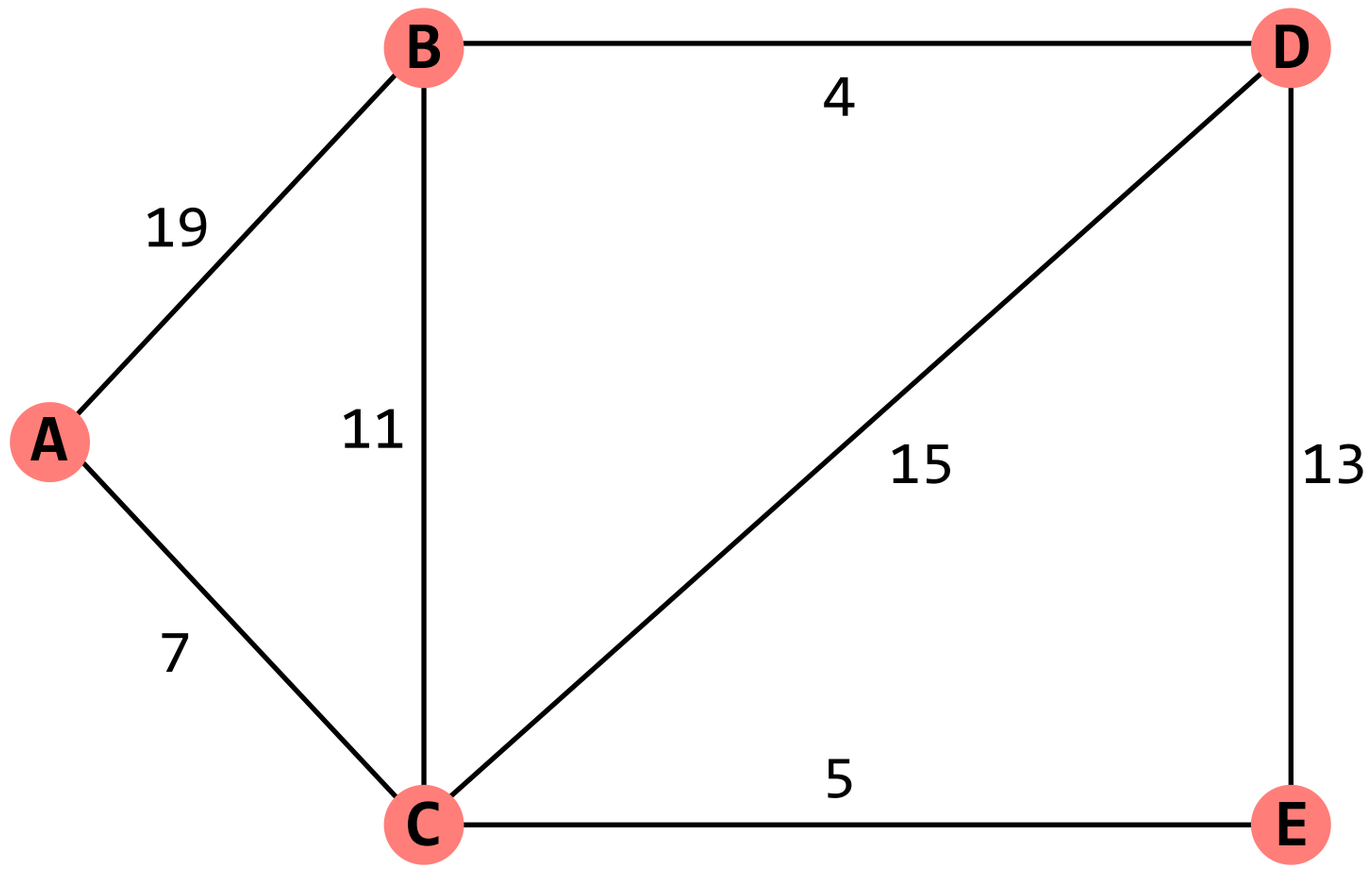

Because advertisements are **flooded**, link-state routing performs well when there are failures

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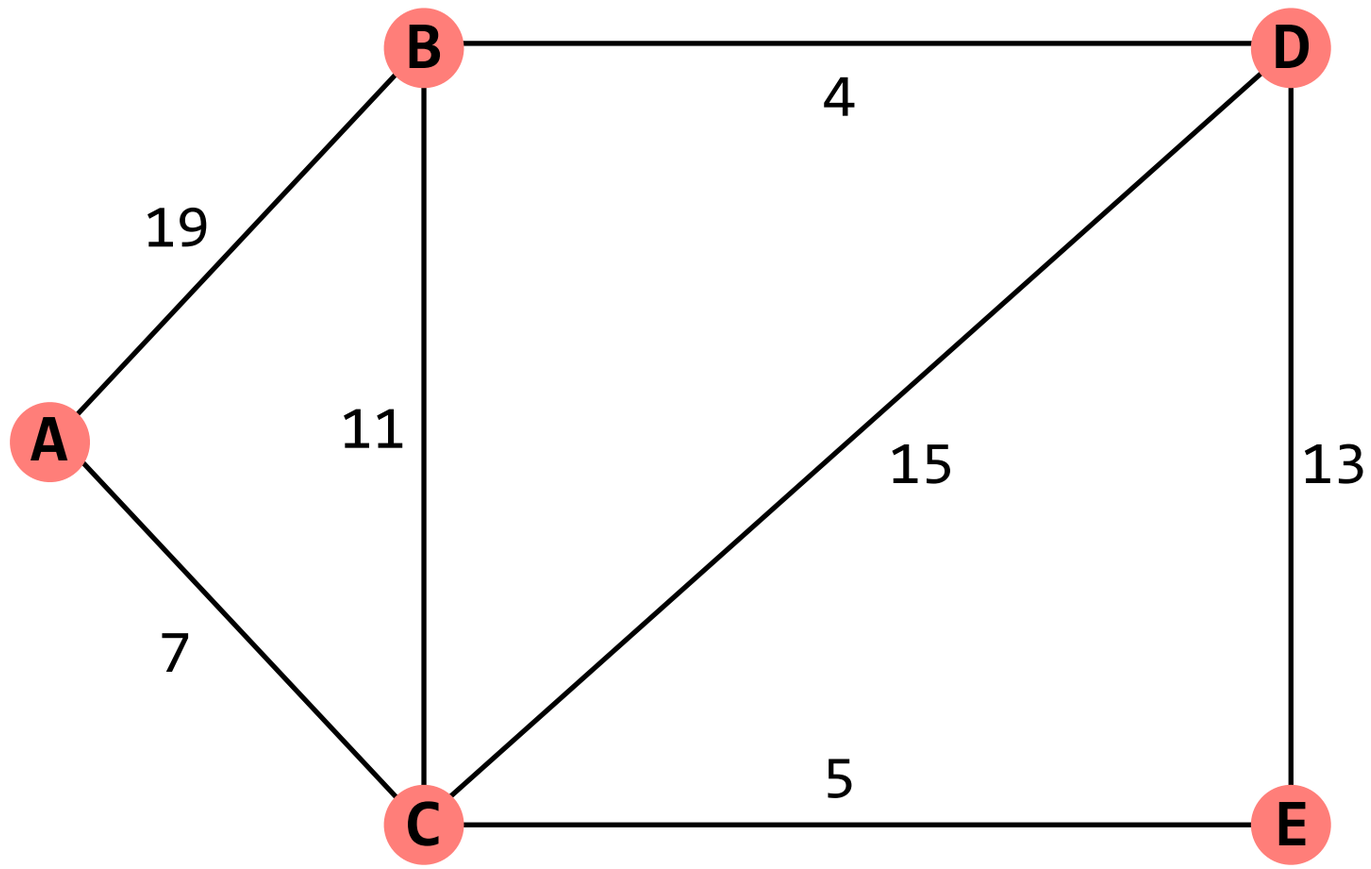
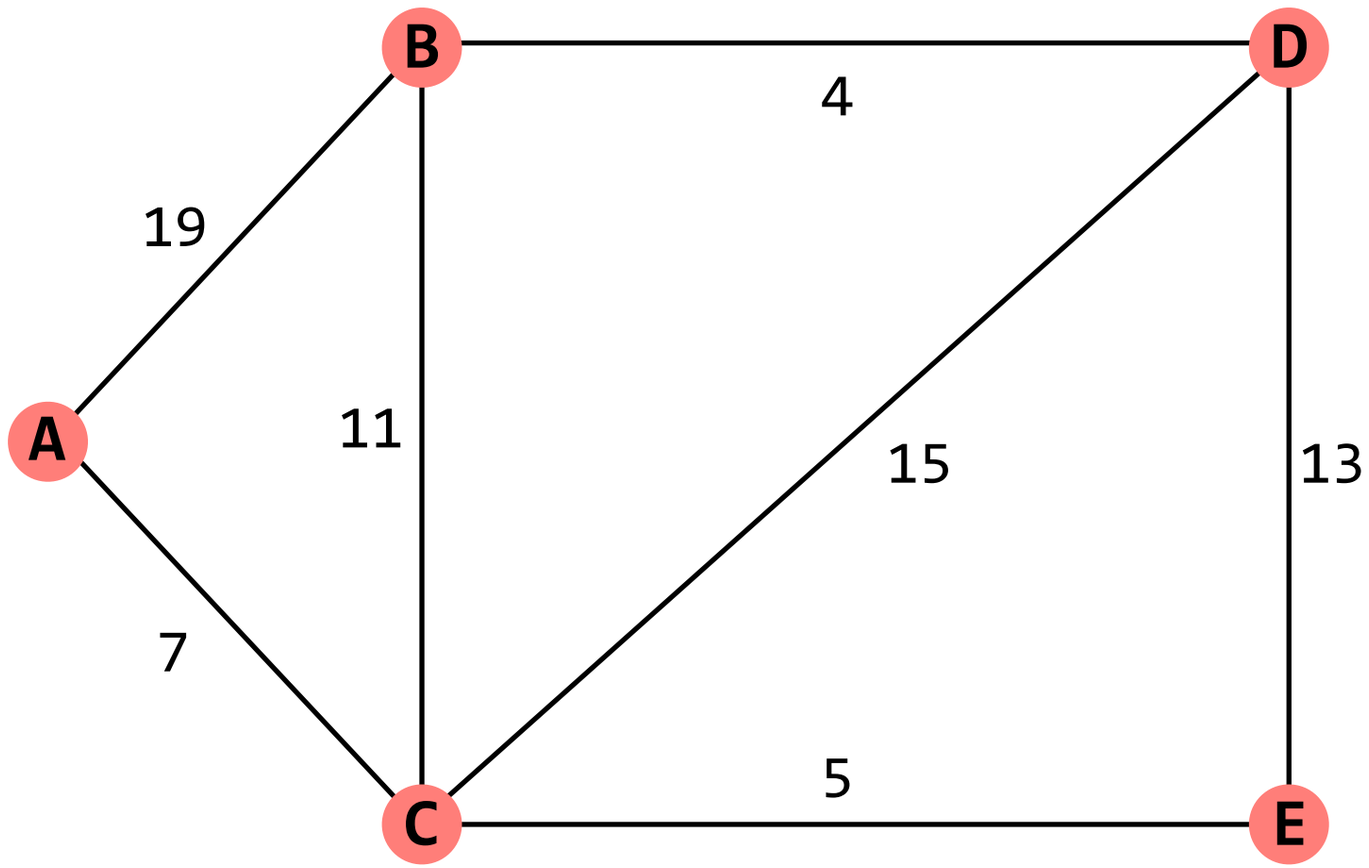


Because advertisements are **flooded**, link-state routing performs well when there are failures. However, the **overhead** of flooding limits scale

Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology



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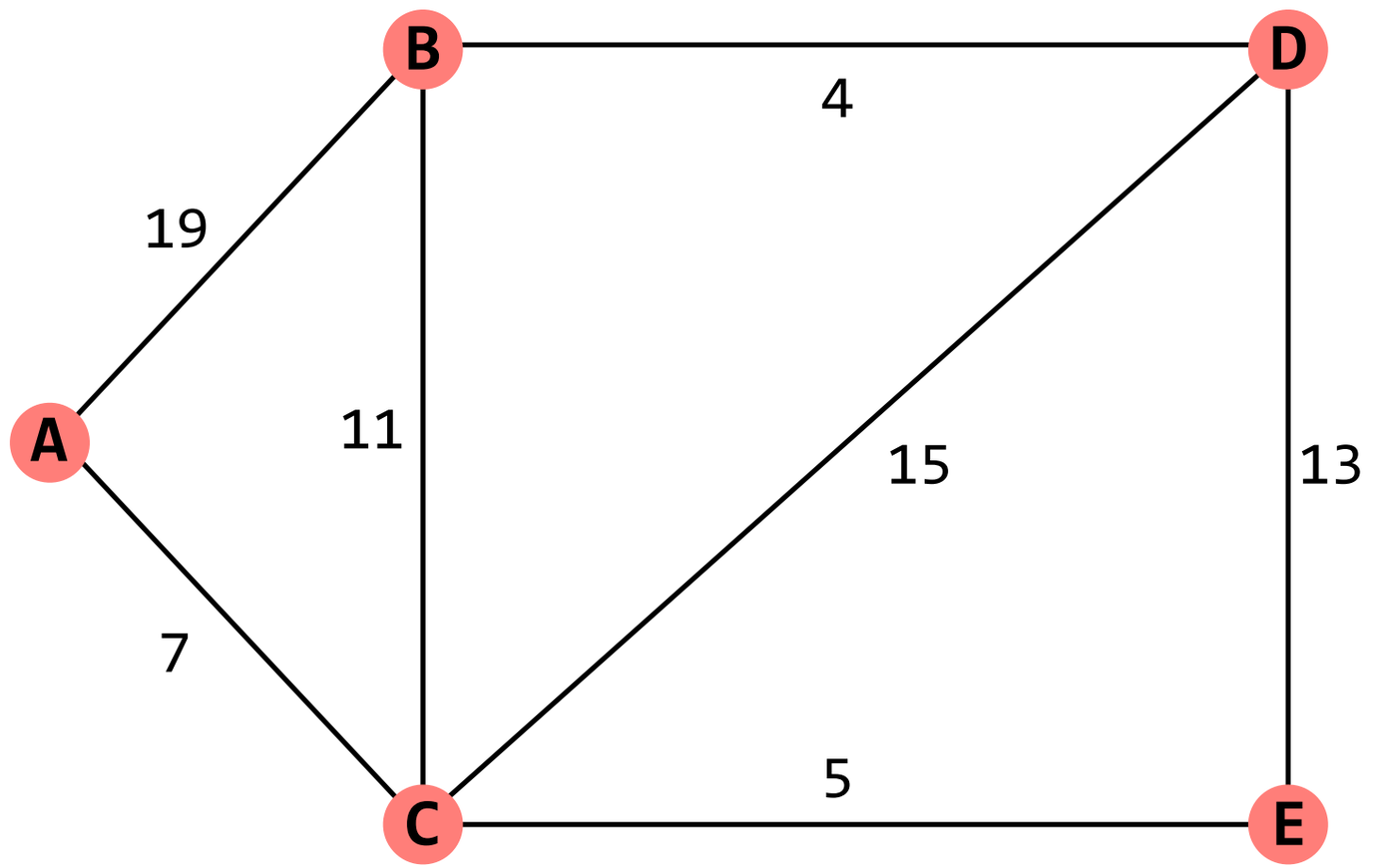

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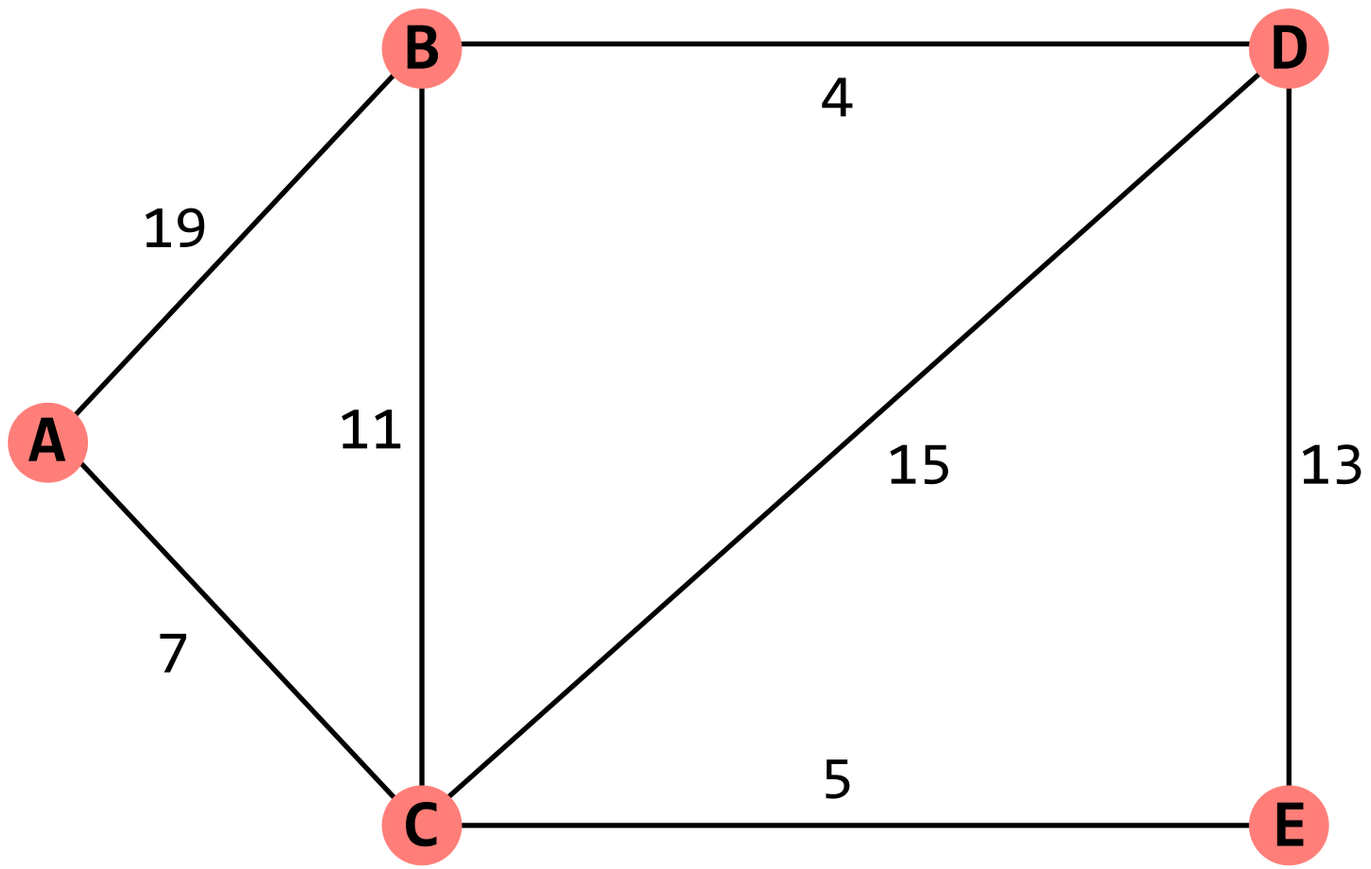

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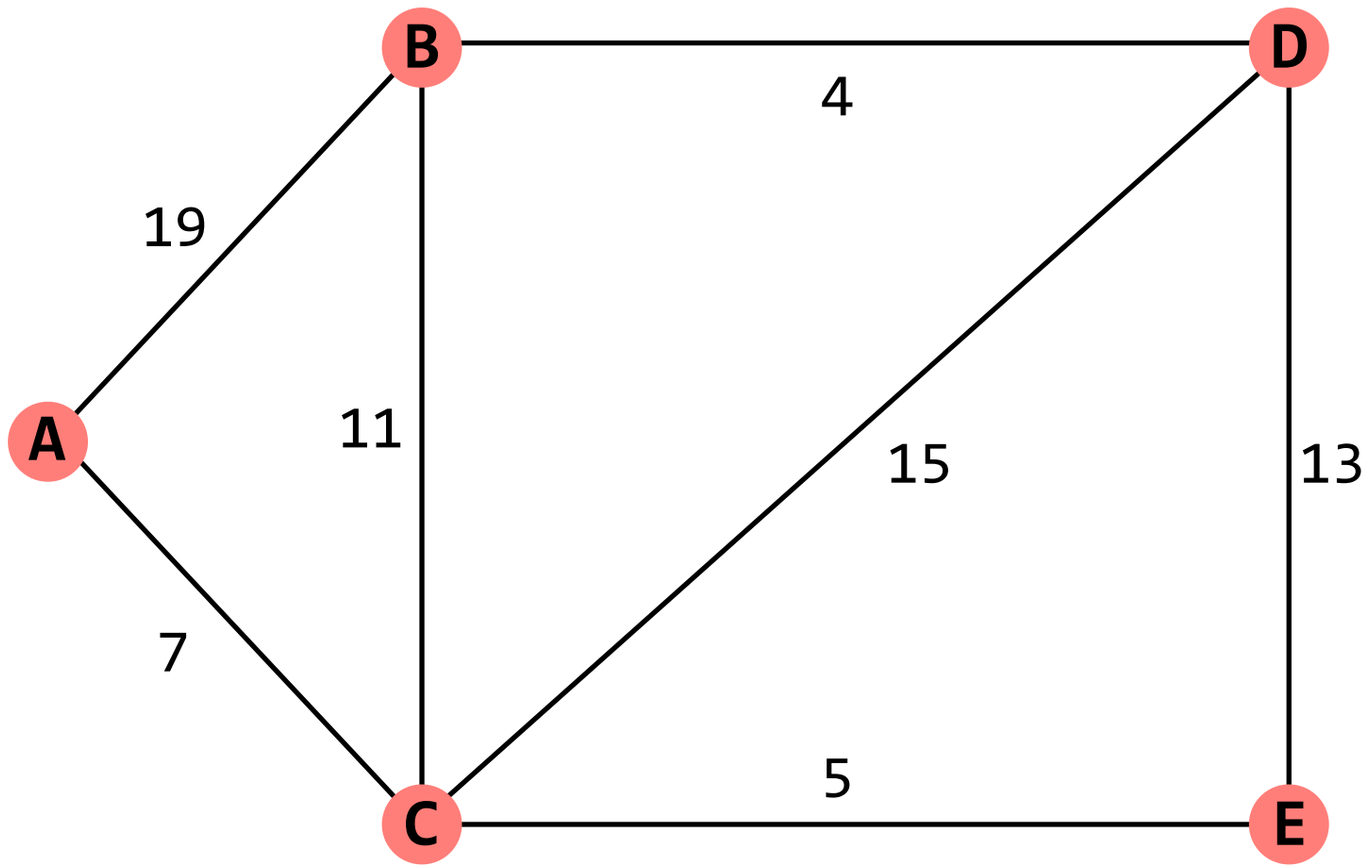

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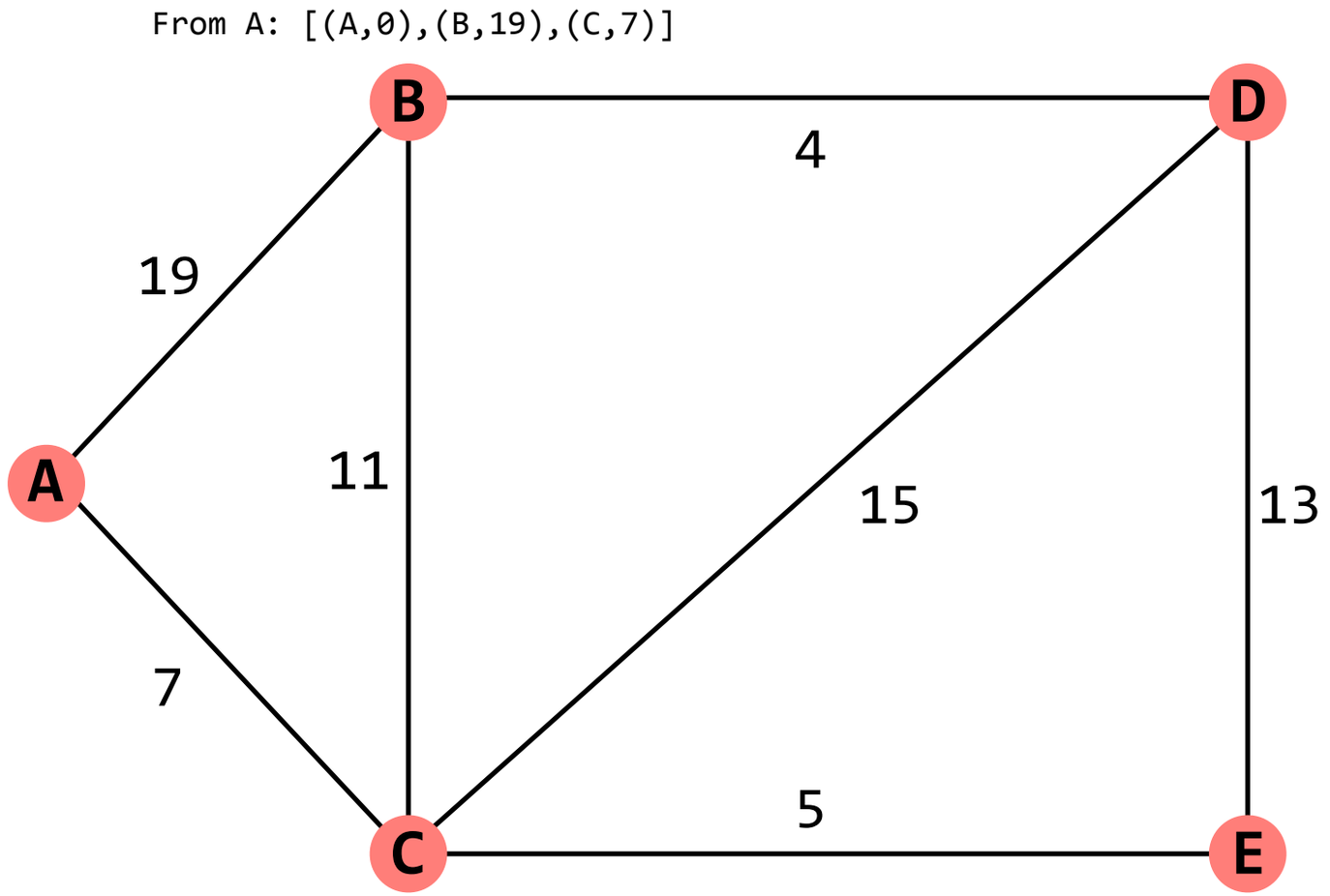

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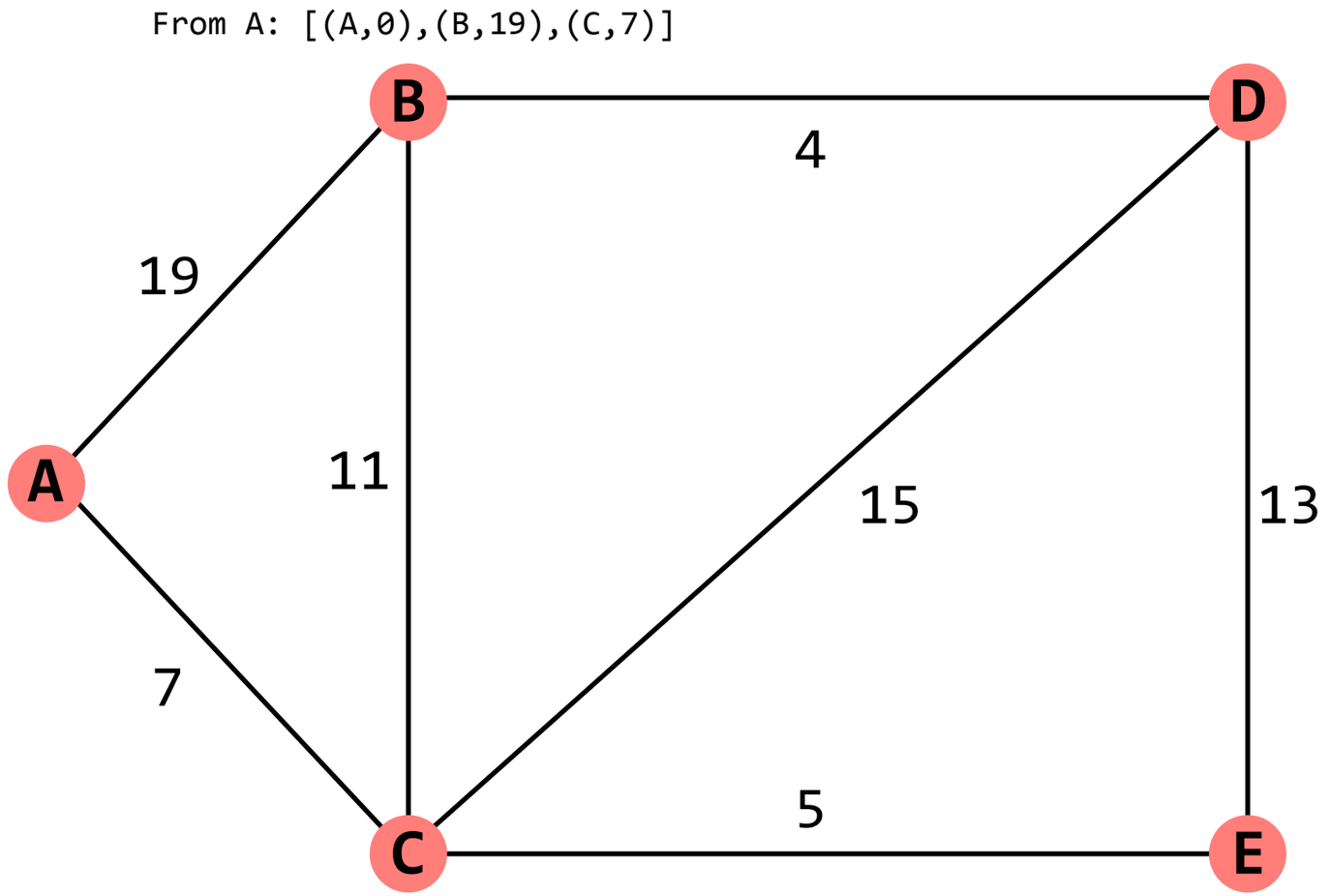
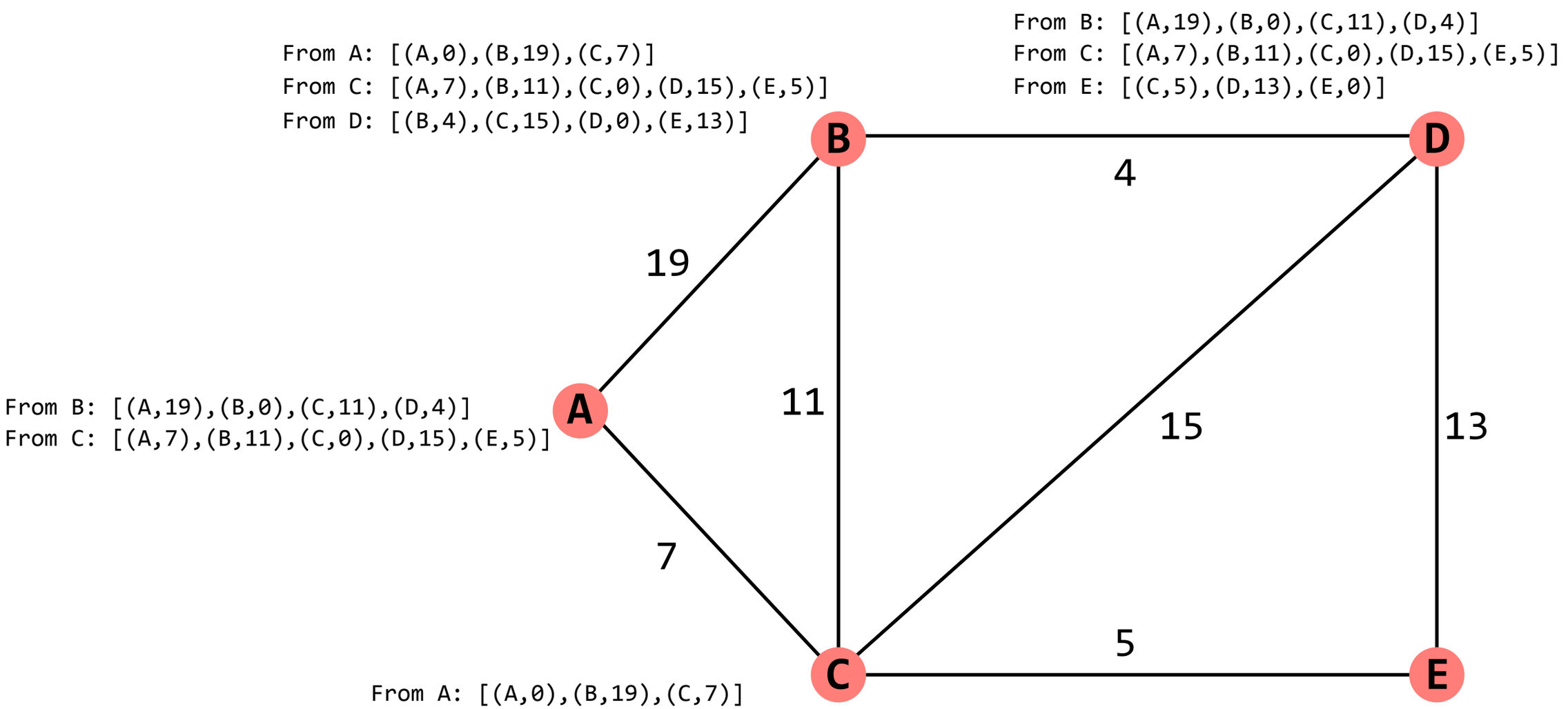
From B: [(A,19),(B,0),(C,11),(D,4)]
From C: [(A,7),(B,11),(C,0),(D,15),(E,5)]



Distance-vector Routing

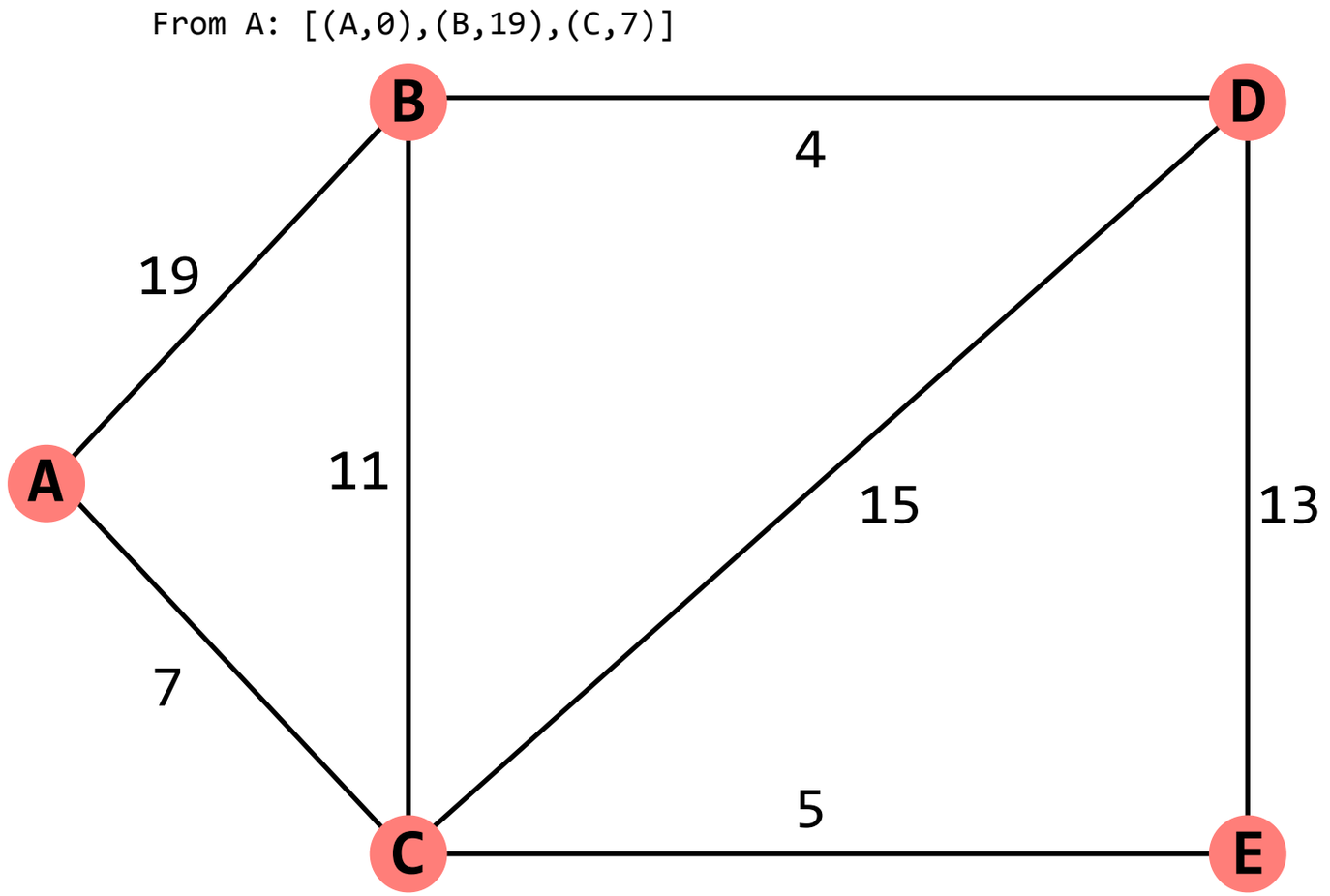
disseminate information about the current *costs* to each node, rather than the actual topology



Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology

From B: [(A,19),(B,0),(C,11),(D,4)]
From C: [(A,7),(B,11),(C,0),(D,15),(E,5)]

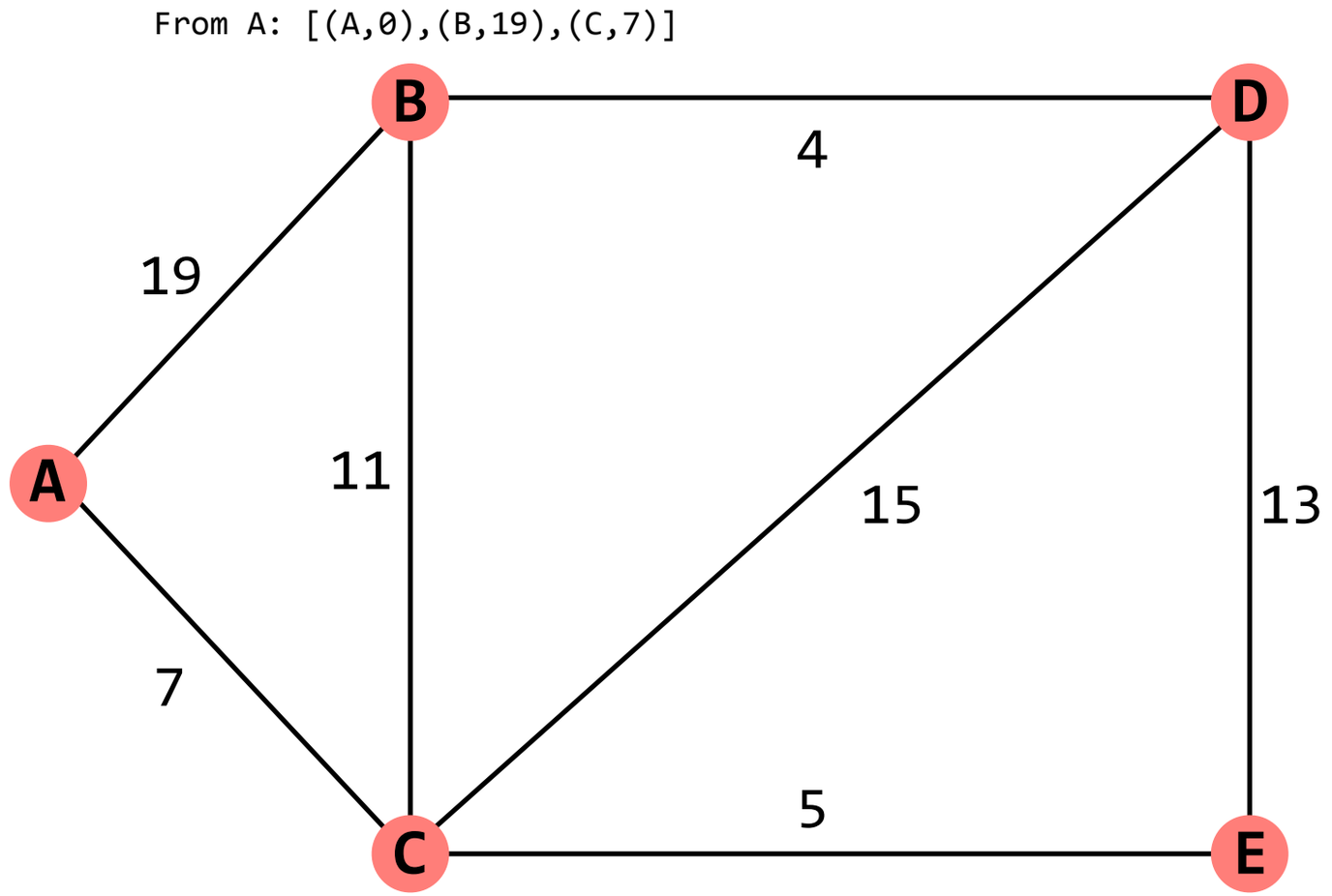


Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology

From B: [(A,19),(B,0),(C,11),(D,4)]

From C: [(A,7),(B,11),(C,0),
(D,15),(E,5)]



Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology

From B: [(A,19),(B,0),(C,11),(D,4)]

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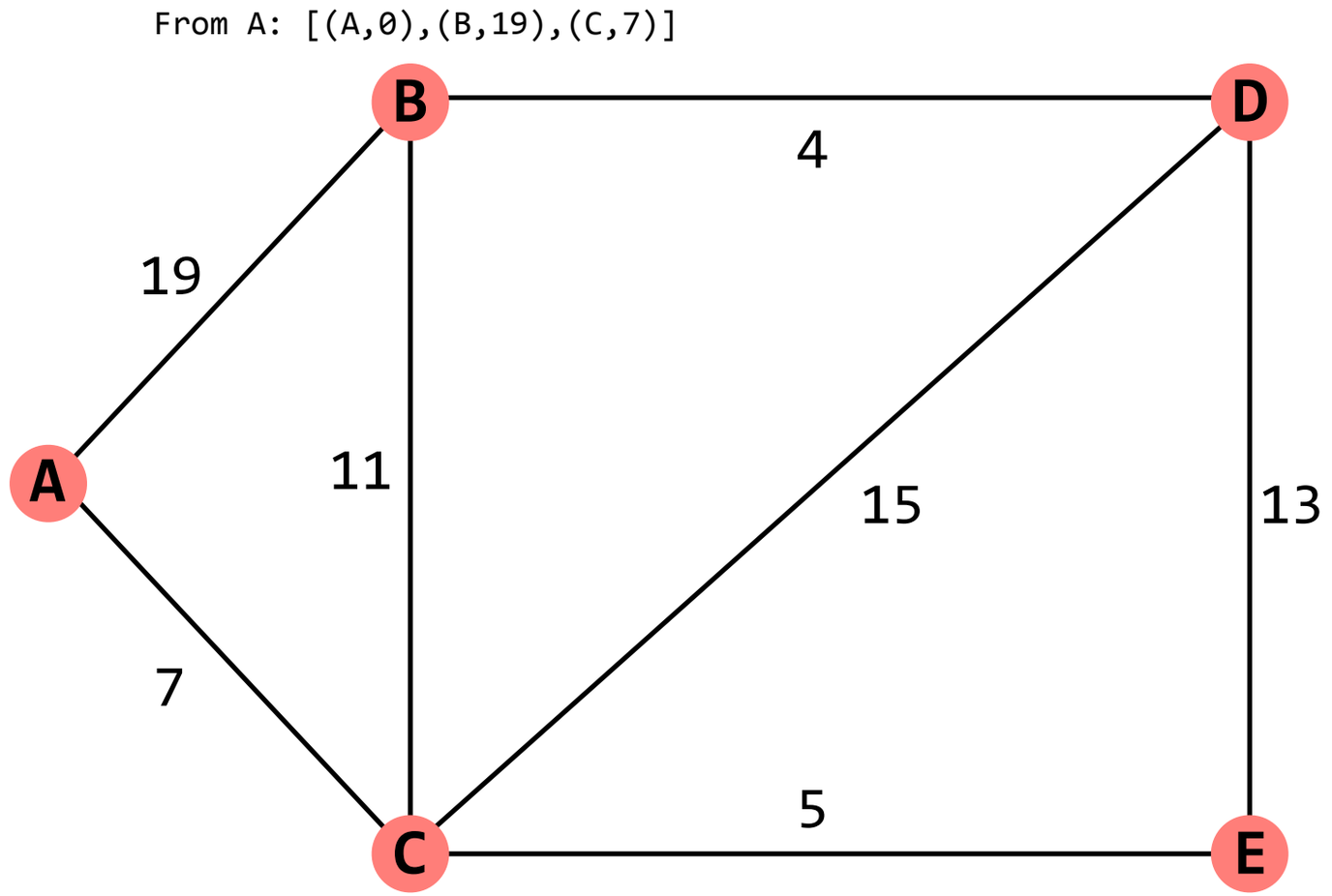

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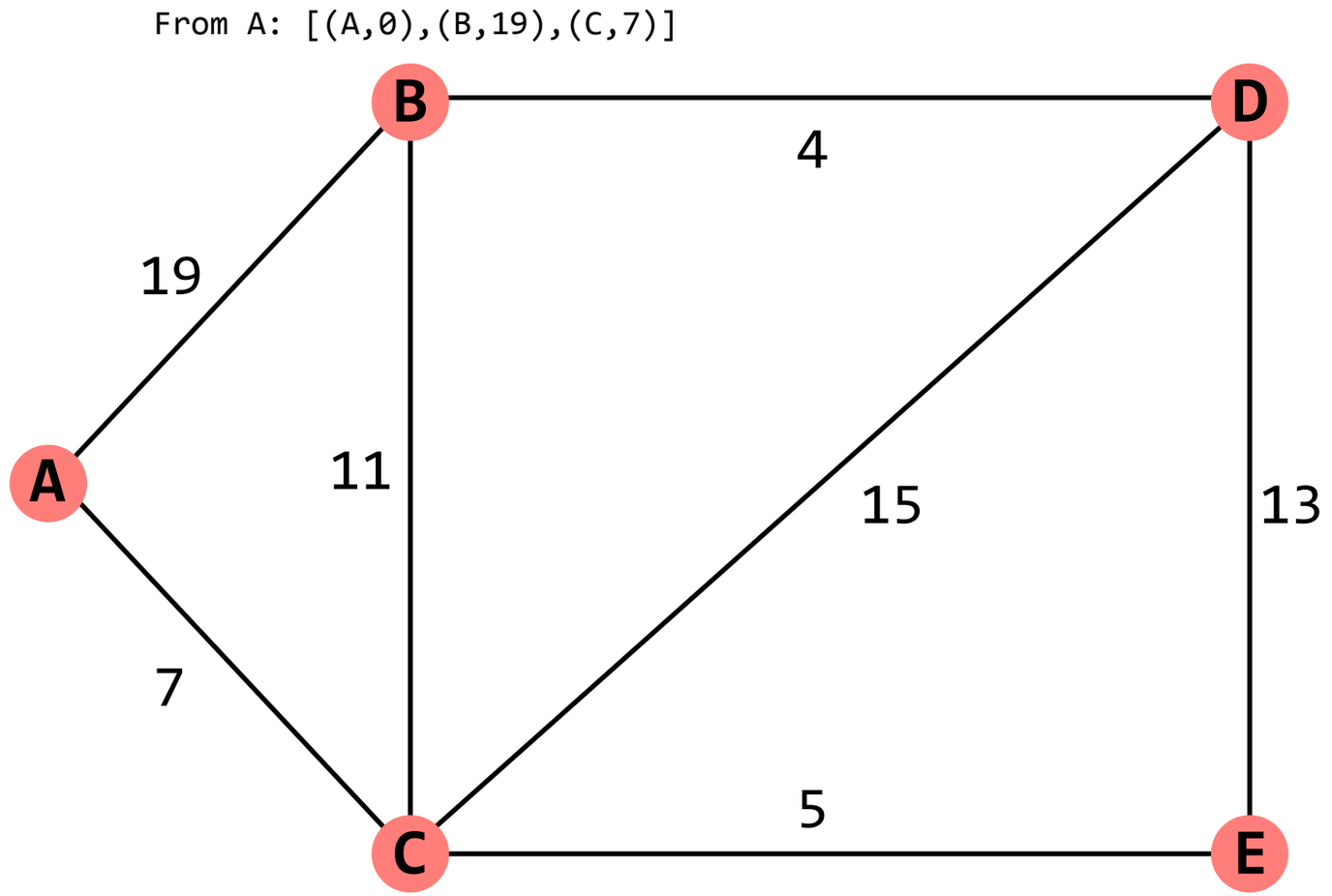

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disseminate information about the current *costs* to each node, rather than the actual topology

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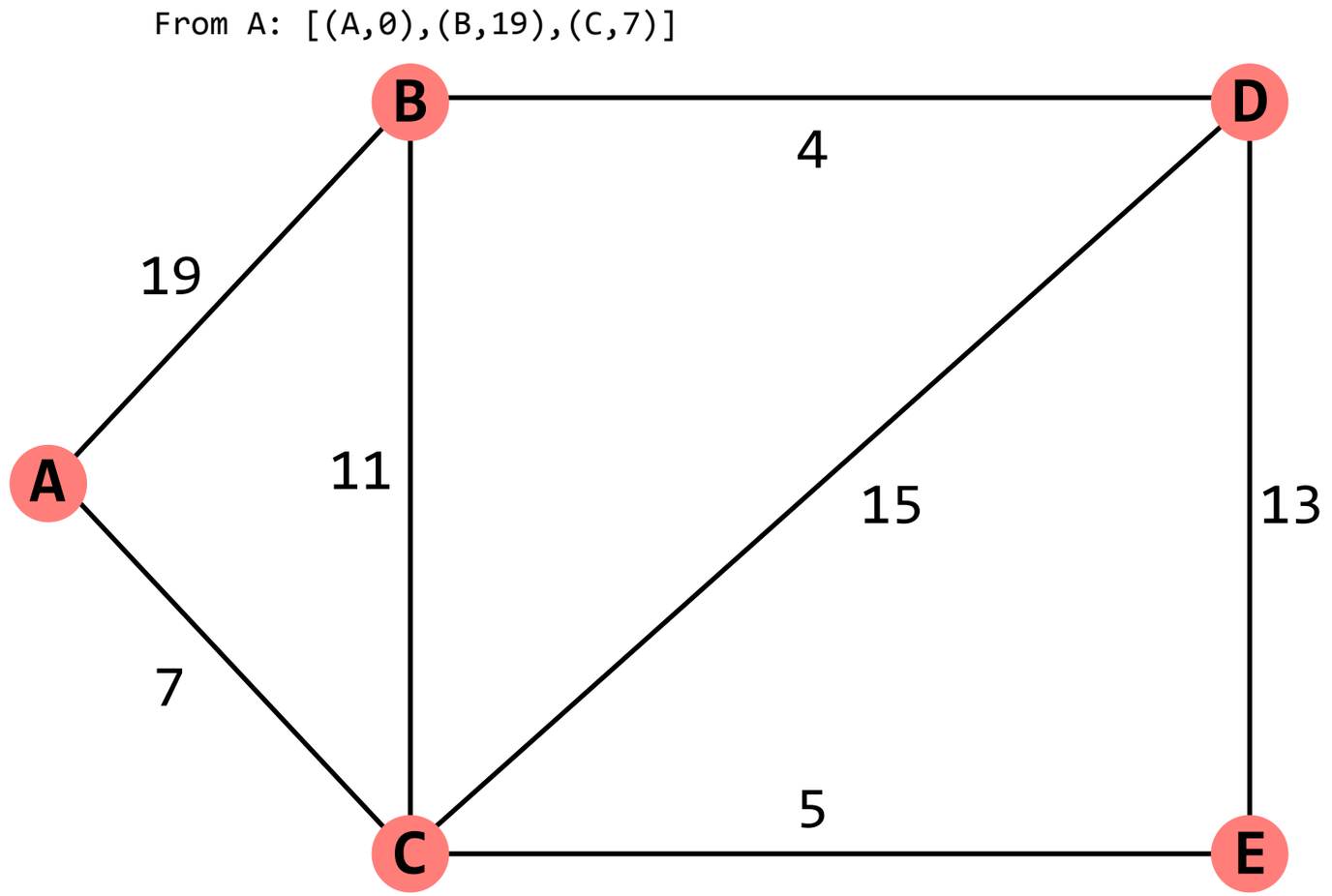
(D,15),(E,5)]

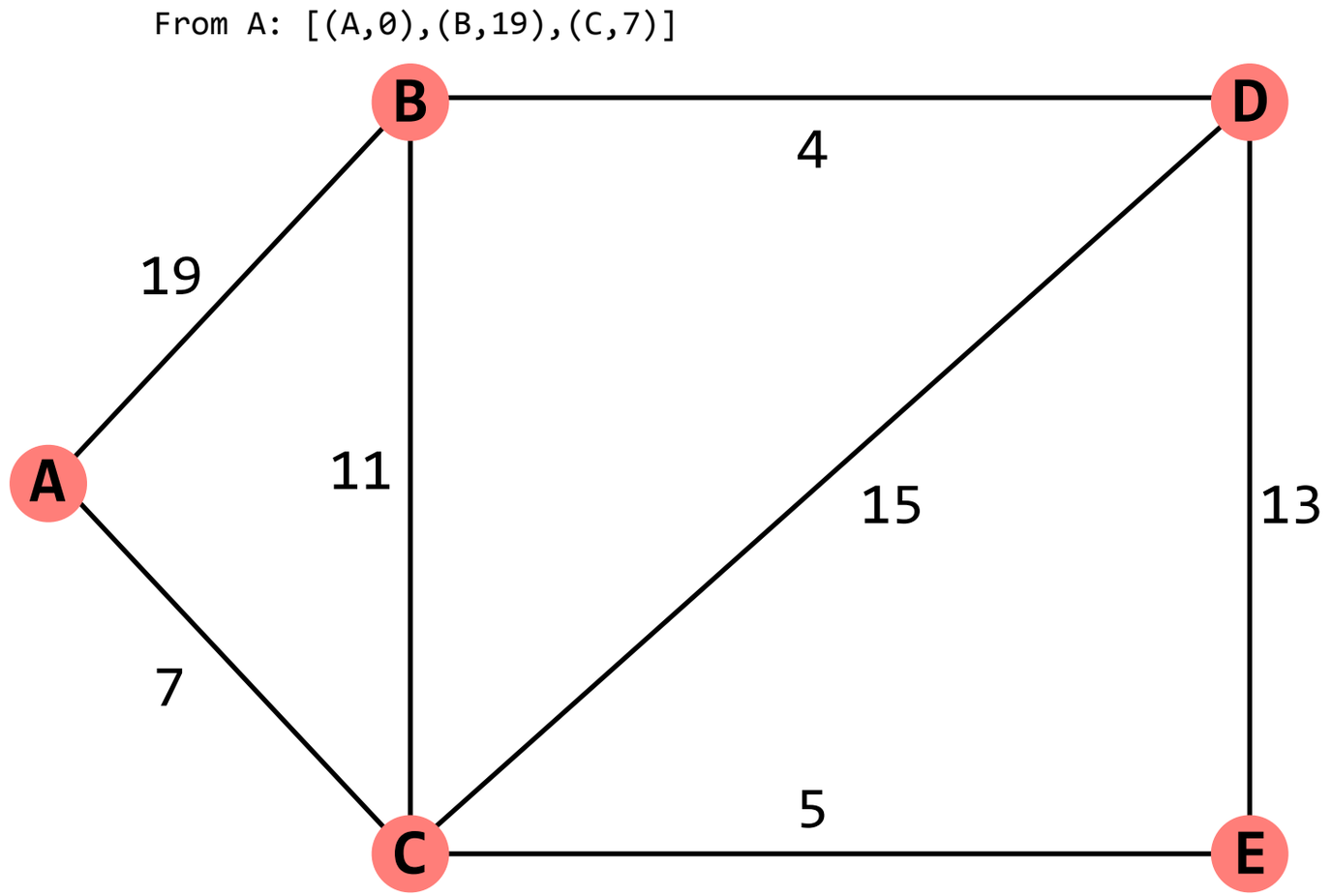


Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology

From B: [(A,19),(B,0),(C,11),(D,4)]

From C: [(A,7),(B,11),(C,0),
(D,15),(E,5)]

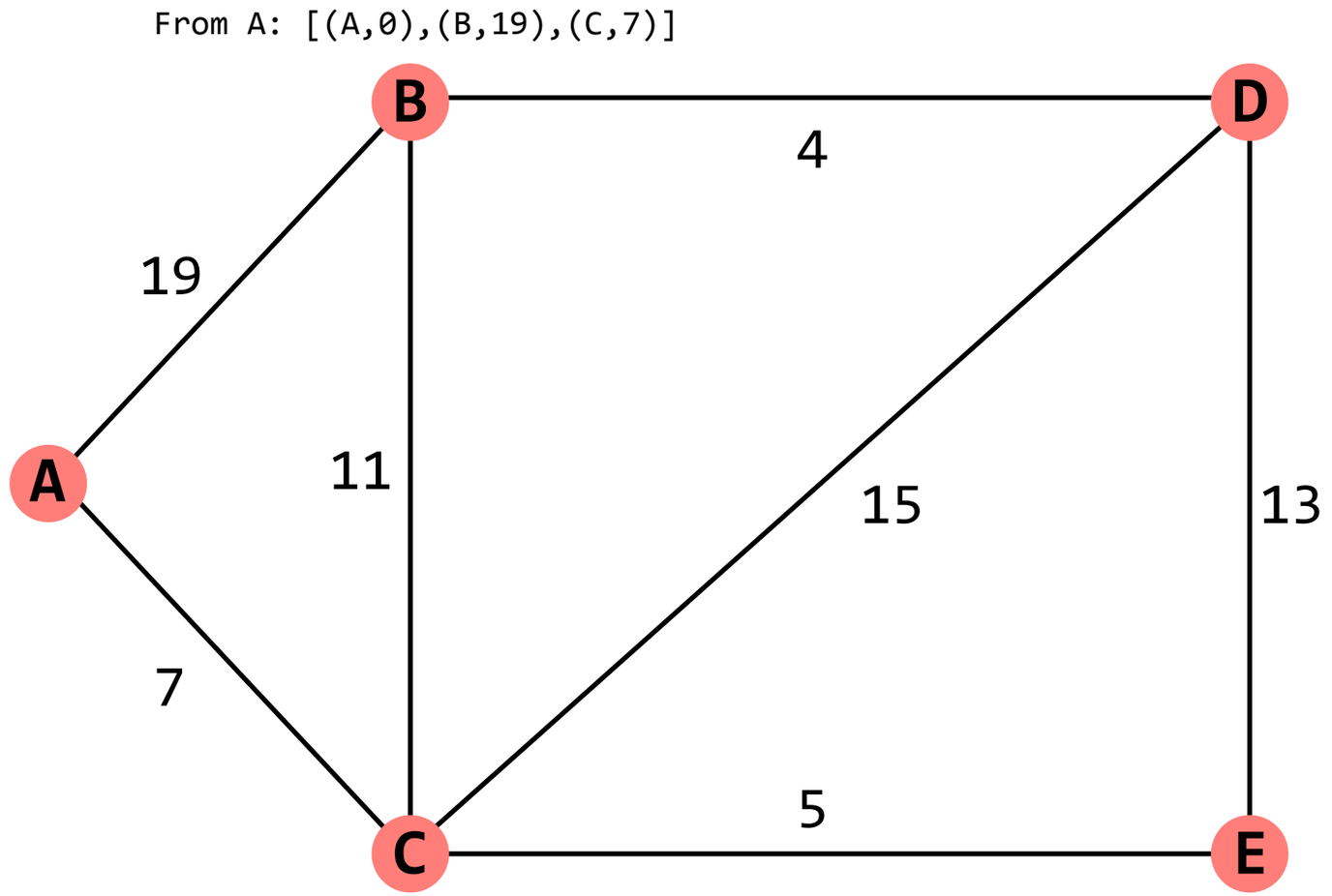


Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology

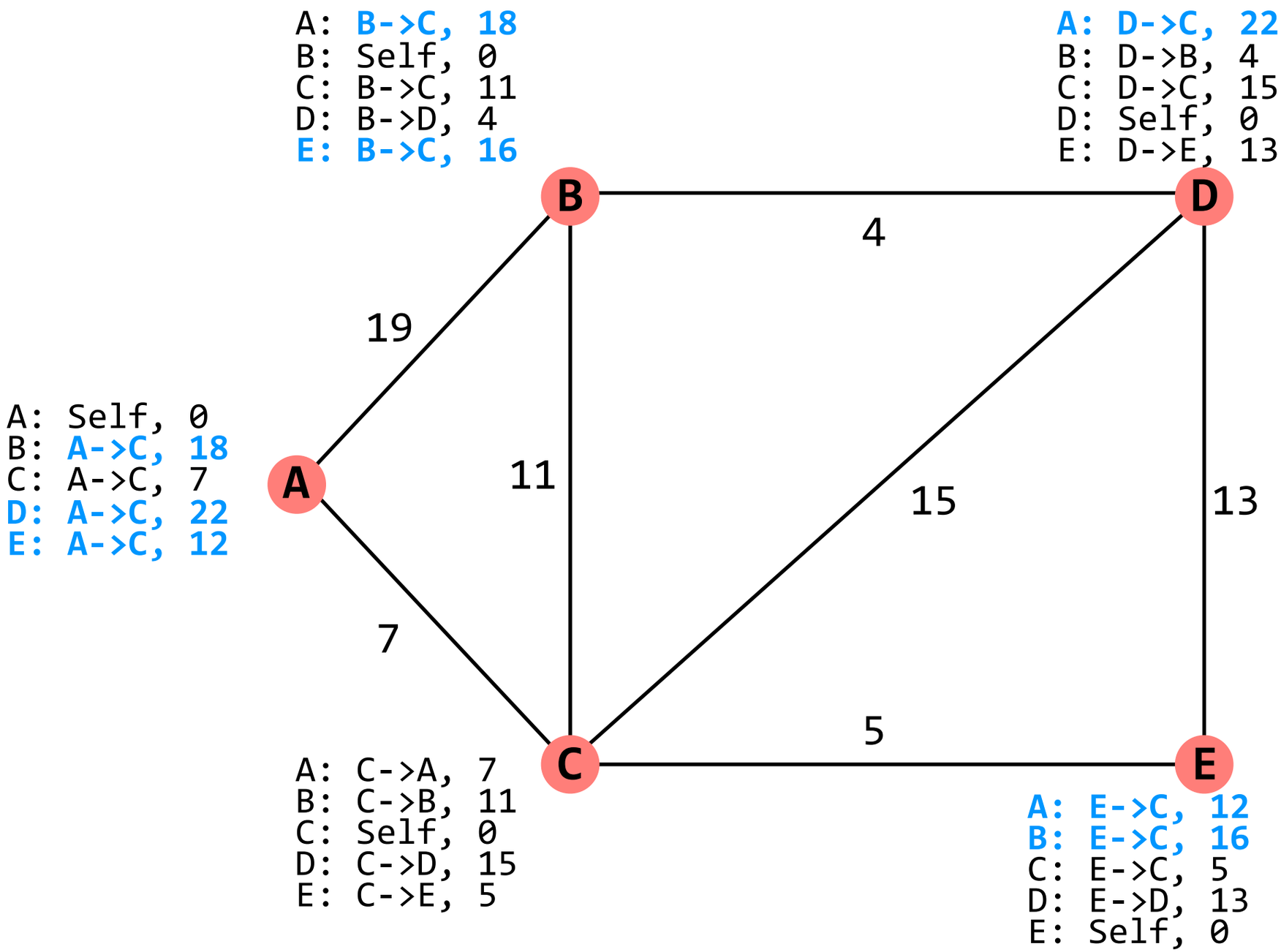
From B: [(A,19),(B,0),(C,11),(D,4)]

From C: [(A,7),(B,11),(C,0),
(D,15),(E,5)]



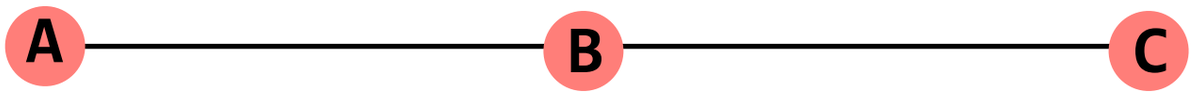
Distance-vector Routing

disseminate information about the current *costs* to each node, rather than the actual topology



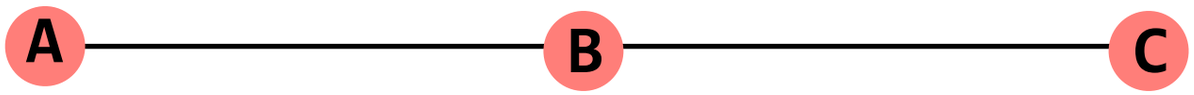
INFINITY

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



INFINITY

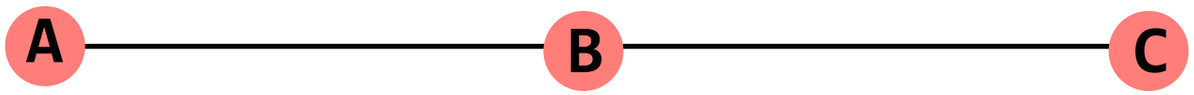
A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..




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

INFINITY

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

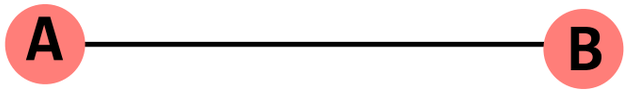



```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: B->C, 1
```

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

INFINITY

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

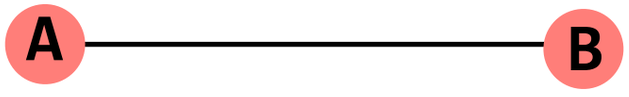



```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

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

INFINITY

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



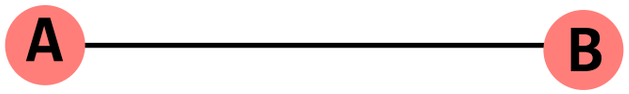

```
A: Self, 0      A: B->A, 1
B: A->B, 1      B: Self, 0
C: A->B, 2      C: None, inf
```

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

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

INFINITY

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




```
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)
```

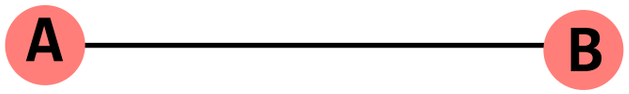
`t=9: B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:

`[(A,0),(B,1),(C,2)]`

INFINITY

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




```
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)
```

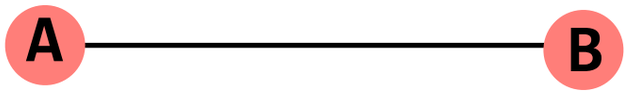
`t=9:` `B<->C` fails

`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)]`

INFINITY

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




```
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
```

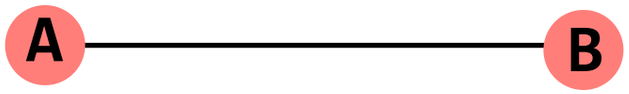
`t=9:` `B<->C` fails

`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)]`

INFINITY

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




```
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

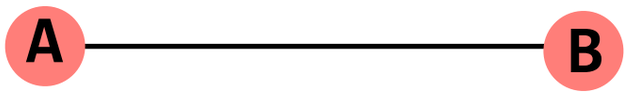
`t=10:` `B` receives the following advertisement from `A`:
`[(A,0),(B,1),(C,2)]`

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

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

INFINITY

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




```
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

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

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

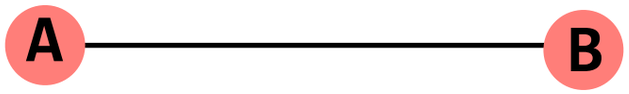
`t=10:` `B` receives the following advertisement from `A`:
`[(A,0),(B,1),(C,2)]`

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

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

INFINITY

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




```
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

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

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

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

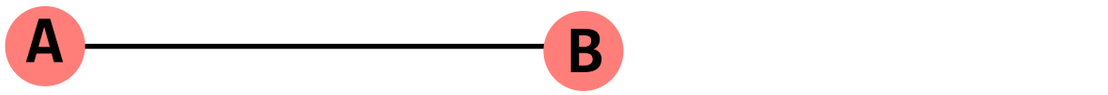
`t=15:` `A` receives the following advertisement from `B`:
`[(A,1),(B,0),(C,3)]`

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

continues until both costs to C are INFINITY

Split Horizon

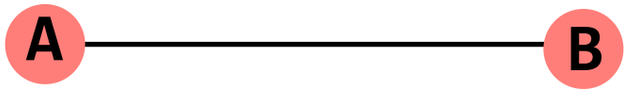
A sends advertisements at t=0, 10, 20,..; B sends advertisements at t=5, 15, 25,..



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

Split Horizon

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



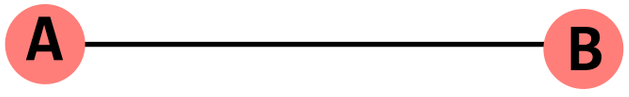

```
A: Self, 0
B: A->B, 1
C: A->B, 2
```

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

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

Split Horizon

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




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

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

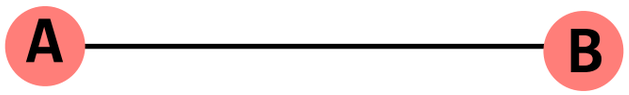
C

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

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

Split Horizon

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




```
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
```

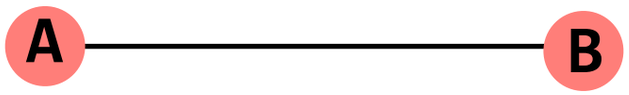
`t=9: B<->C` fails

`t=10:` `B` receives the following advertisement from `A`:

`[(A,0)]`

Split Horizon

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




```
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
```

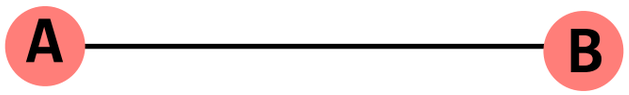
`t=9:` `B<->C` fails

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

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

Split Horizon

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




```
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
```

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

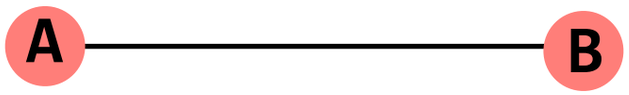
`t=9:` `B<->C` fails

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

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

Split Horizon

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




```
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

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)]`

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

split horizon takes care of this particular case

Split-horizon

Don’t send advertisements about a route to the node providing the route


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

Split-horizon

Don’t send advertisements about a route to the node providing the route

`C: D->B, 2`

`C: A->B, 2`

`C: B->C, 1`

`B<->C` fails

Split-horizon

Don’t send advertisements about a route to the node providing the route

`C: D->B, 2`

`C: A->B, 2`

`C: None, inf`

`B<->C` fails

Split-horizon

Don’t send advertisements about a route to the node providing the route

`C: D->B, 2`

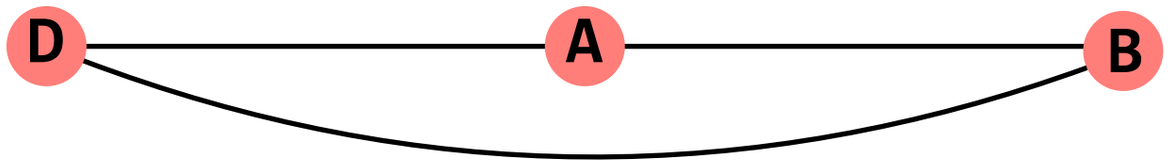
`C: A->B, 2`

`C: None, inf`

`B<->C` fails

Split-horizon

Don’t send advertisements about a route to the node providing the route



`C: D->B, 2`

`C: A->B, 2`

`C: None, inf`

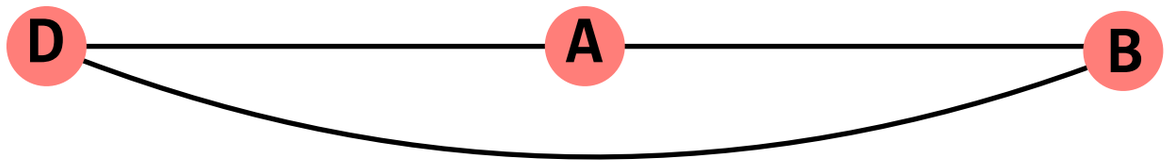
`B<->C` fails

`B`’s advertisement to `A` gets lost

(so **A** makes no changes)

Split-horizon

Don’t send advertisements about a route to the node providing the route



`C: D->B, 2`

`C: None, inf`

`C: None, inf`

`C: A->B, 2`

`C: A->B, 2`

`C: A->B, 2`

`C: None, inf`

`C: None, inf`

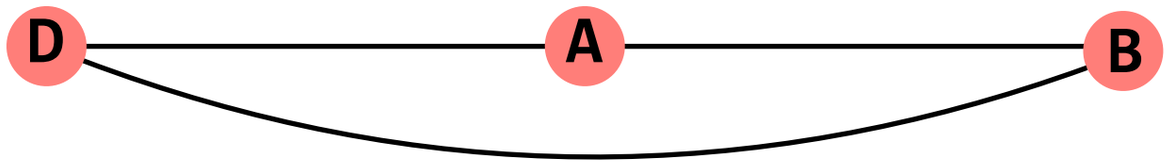
`B<->C` fails

`B`’s advertisement to `A` gets lost

(so **A** makes no changes)

Split-horizon

Don't send advertisements about a route to the node providing the route



`C: D->B, 2`

`C: None, inf`

`C: None, inf`

`C: A->B, 2`

`C: A->B, 2`

`C: A->B, 2`

`C: None, inf`

`C: None, inf`

`B<->C` fails

`B`'s advertisement to `A` gets lost

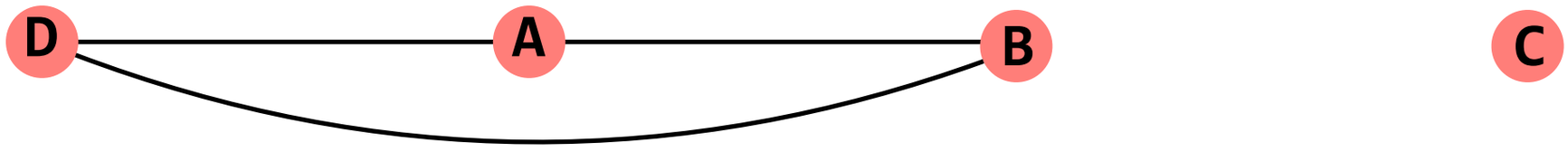
(so `A` makes no changes)

`A` advertises about `C` to `D`

(not to `B` because of split horizon)

Split-horizon

Don't send advertisements about a route to the node providing the route



`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**
`C: None, inf`	`C: A->B, 2`	`C: None, inf`
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`

`B<->C` fails

`B`'s advertisement to `A` gets lost

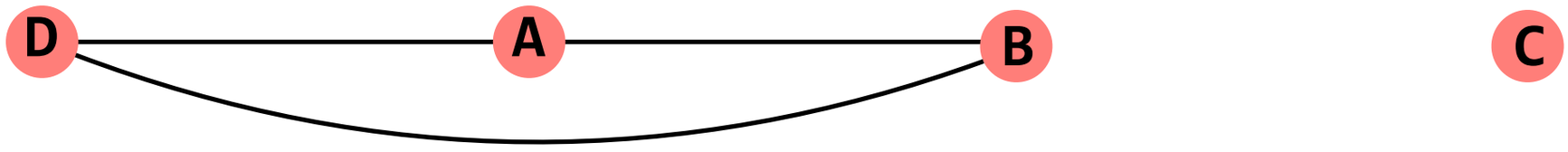
(so `A` makes no changes)

`A` advertises about `C` to `D`

(not to `B` because of split horizon)

Split-horizon

Don't send advertisements about a route to the node providing the route



`C: D->B, 2`	`C: A->B, 2`	**`C: None, inf`**
`C: None, inf`	`C: A->B, 2`	`C: None, inf`
`C: D->A, 3`	`C: A->B, 2`	`C: None, inf`

`B<->C` fails

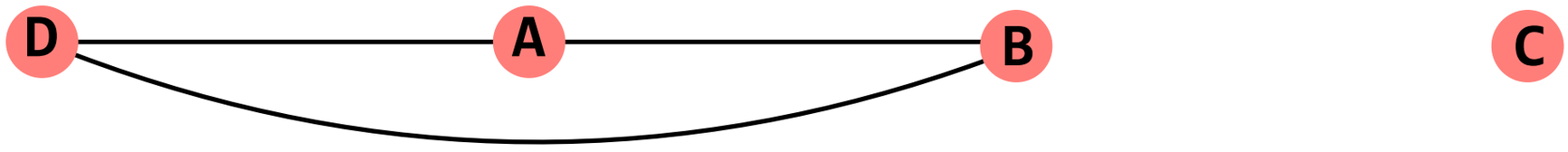
`B`'s advertisement to `A` gets lost (so `A` makes no changes)

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

`D` advertises about `C` to `B`

Split-horizon

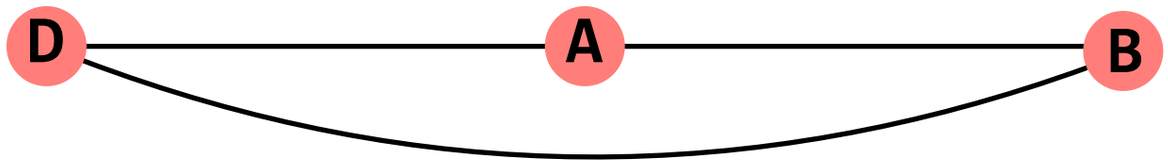
Don't send advertisements about a route to the node providing the route



`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`

Split-horizon

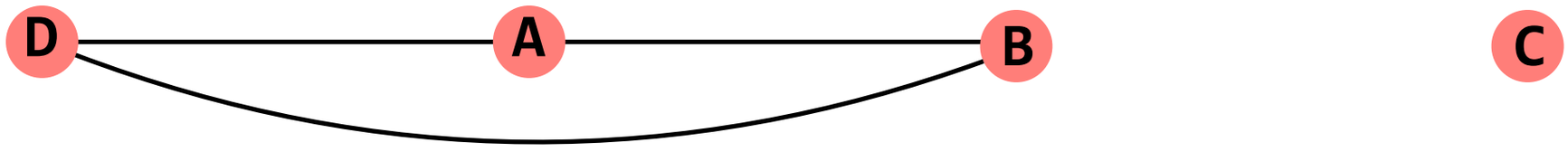
Don't send advertisements about a route to the node providing the route



`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`

Split-horizon

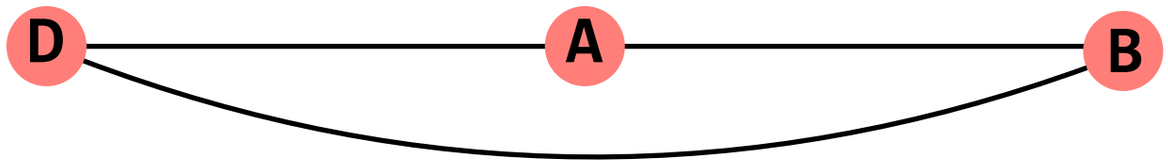
Don't send advertisements about a route to the node providing the route



`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`

Split-horizon

Don't send advertisements about a route to the node providing the route



`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

problem: neither distance-vector nor link-state routing will scale to the size of the Internet

- **Link-state routing** works by disseminating full topology information to all nodes. It's quite robust to failures, but the **overhead** of flooding limits its scale.

- **Distance-vector routing** works by disseminating information about the cost of the actual routes. It has less overhead, but is not as robust to failures; the way in which it handles **failures** limits its scale.

- Neither of these protocols is appropriate for routing across the entire Internet. Link-state routing works well for MIT-sized networks, but we still need a means to route outside of MIT.