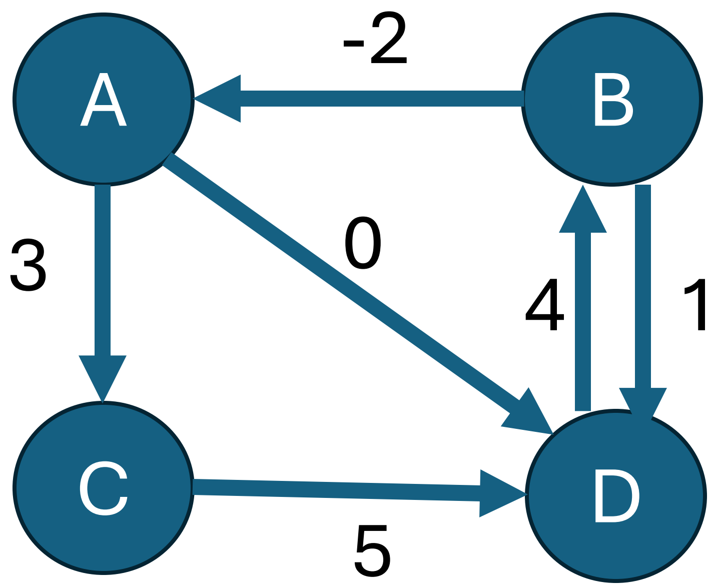
All Pairs Shortest Path

Floyd Warshall Algorithm

Floyd Warshall Algorithm

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



to

from

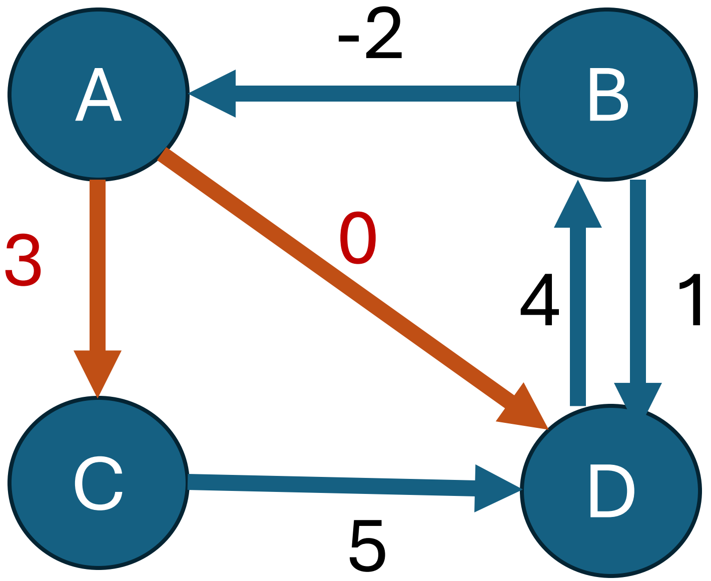
	A	B	C	D
A	∞	∞	∞	∞
B	∞	∞	∞	∞
C	∞	∞	∞	∞
D	∞	∞	∞	∞

to

from

	A	B	C	D
A				
B				
C				
D				

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge ($u$, $v$)
    do dist[$u$][$v$] = w($u$, $v$) // The weight of the edge (u, v)
for each vertex $v$ do
    dist[$v$][$v$] = 0
for $k$ from 1 to |V|
    for $i$ from 1 to |V|
        for $j$ from 1 to |V|
            if dist[$i$][$j$] > dist[$i$][$k$] + dist[$k$][$j$]
                dist[$i$][$j$] = dist[$i$][$k$] + dist[$k$][$j$]
            end if
```



to

from

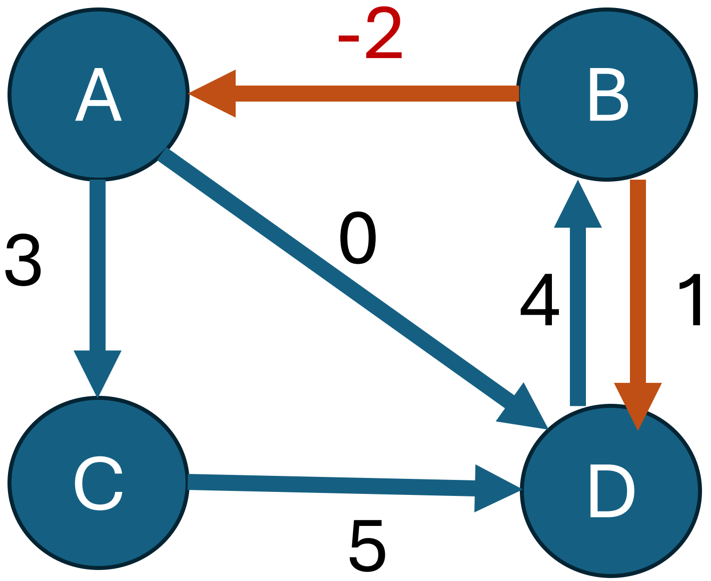
	A	B	C	D
A	∞	∞	3	0
B	∞	∞	∞	∞
C	∞	∞	∞	∞
D	∞	∞	∞	∞

to

from

	A	B	C	D
A			A	A
B				
C				
D				

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



to

from

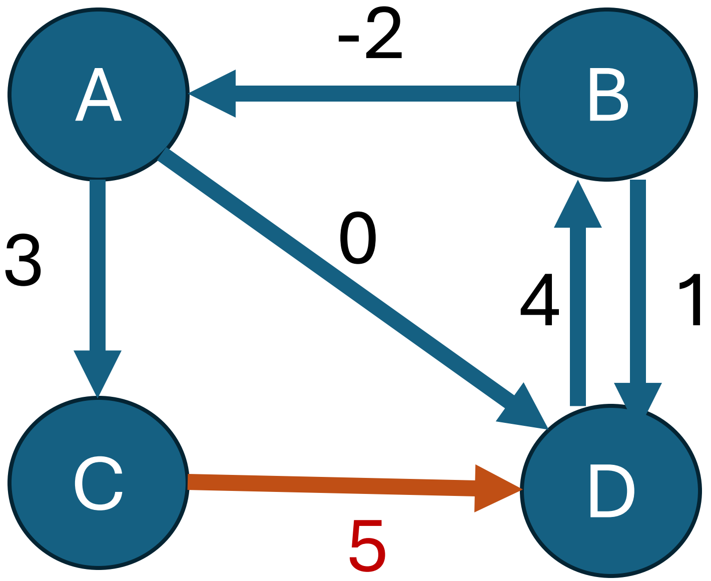
	A	B	C	D
A	∞	∞	3	0
B	-2	∞	∞	1
C	∞	∞	∞	∞
D	∞	∞	∞	∞

to

from

	A	B	C	D
A			A	A
B	B			B
C				
D				

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



to

from

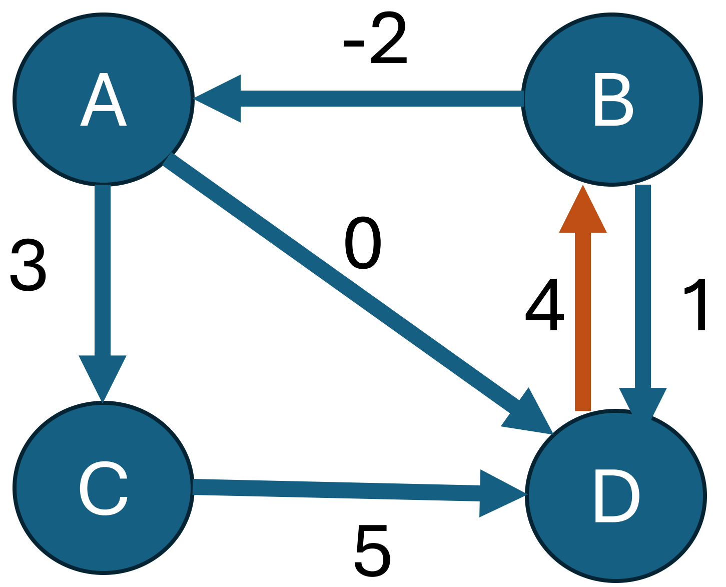
	A	B	C	D
A	∞	∞	3	0
B	-2	∞	∞	1
C	∞	∞	∞	5
D	∞	∞	∞	∞

to

from

	A	B	C	D
A			A	A
B	B			B
C				C
D				

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



to

from

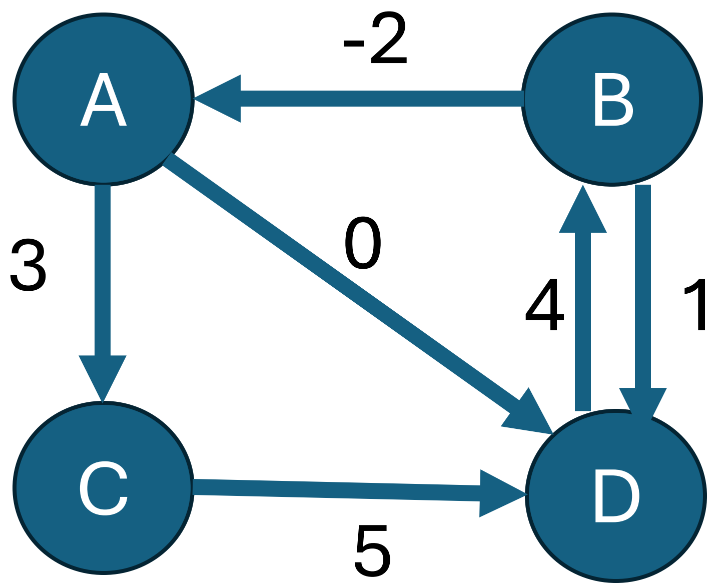
	A	B	C	D
A	∞	∞	3	0
B	-2	∞	∞	1
C	∞	∞	∞	5
D	∞	4	∞	∞

to

from

	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



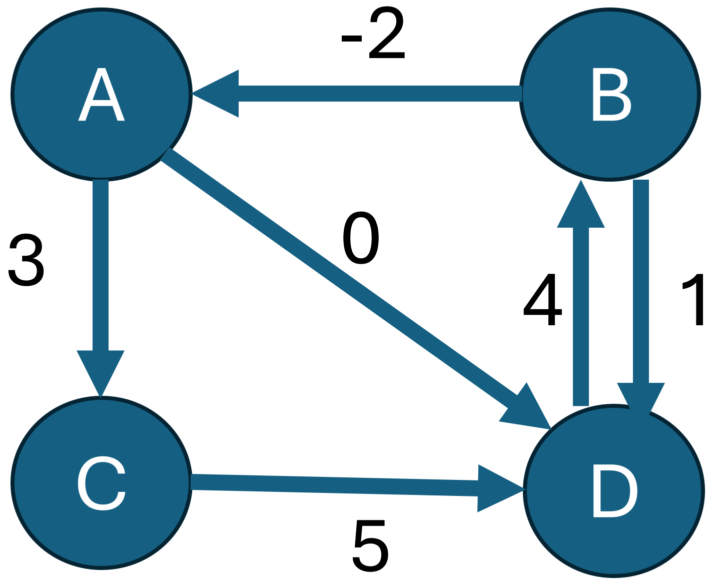
to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



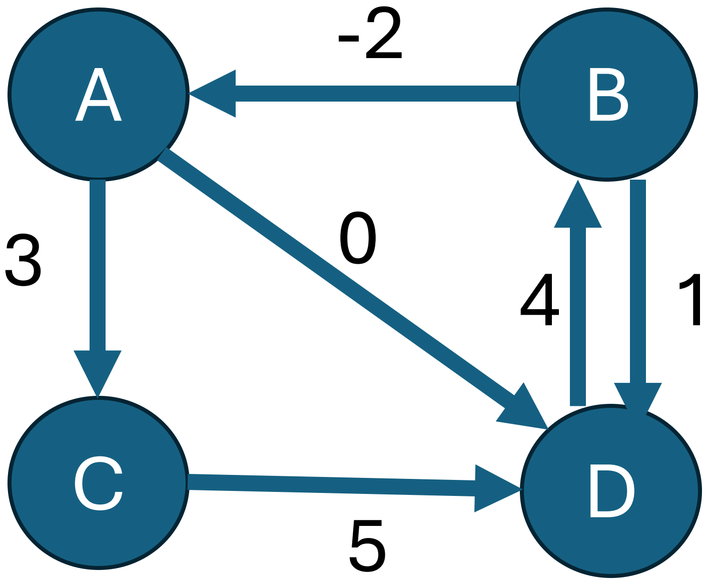
to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
let dist be a |V| × |V| array of minimum distances initialized to ∞
for each edge (u, v)
    do dist[u][v] = w(u, v) // The weight of the edge (u, v)
for each vertex v do
    dist[v][v] = 0
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

from

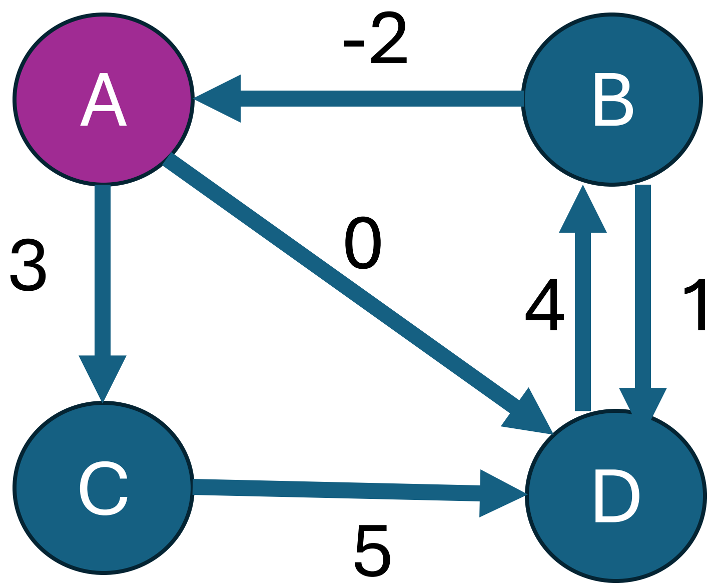
	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
for k from 1 to |V|
    for i from 1 to |V|
        for j from 1 to |V|
            if dist[i][j] > dist[i][k] + dist[k][j]
                dist[i][j] = dist[i][k] + dist[k][j]
            end if
```

k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

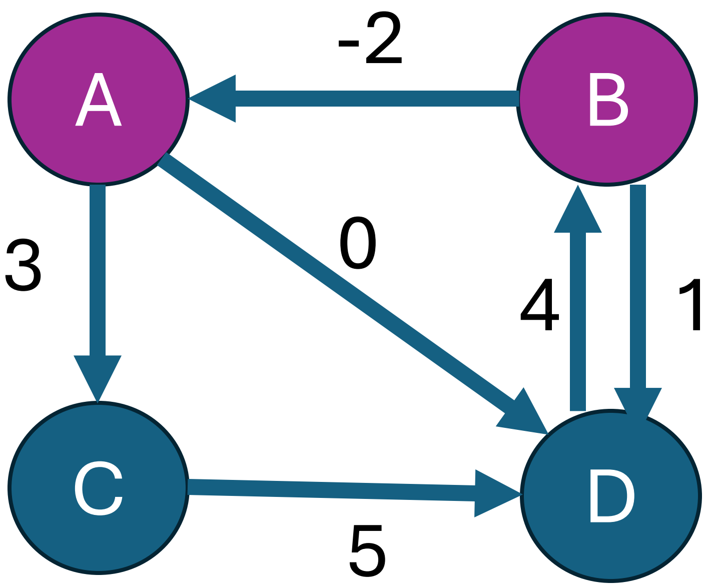
from

	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

```
       AA             AA              AA
if dist[1][1] > dist[1][1] + dist[1][1]
     dist[1][1] = dist[1][1] + dist[1][1]
         AA            AA             AA
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

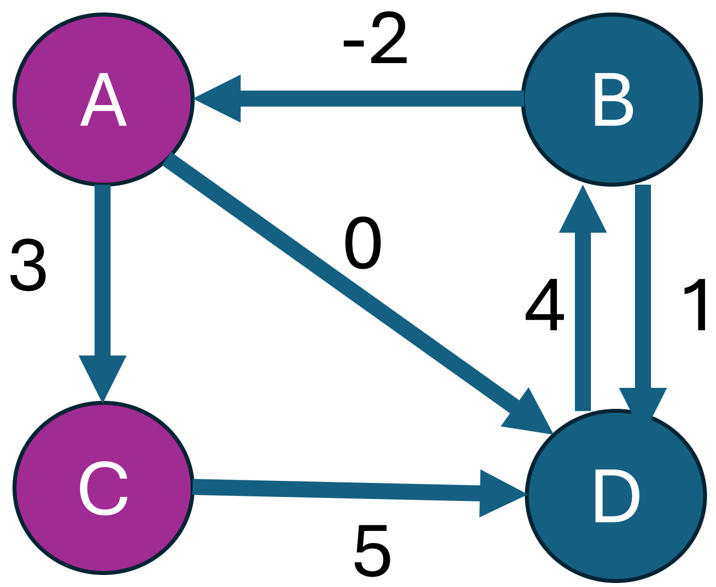
from	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AB = ∞ > AA = 0 + AB = ∞

```
if dist[1][2] > dist[1][1] + dist[1][2]
    dist[1][2] = dist[1][1] + dist[1][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

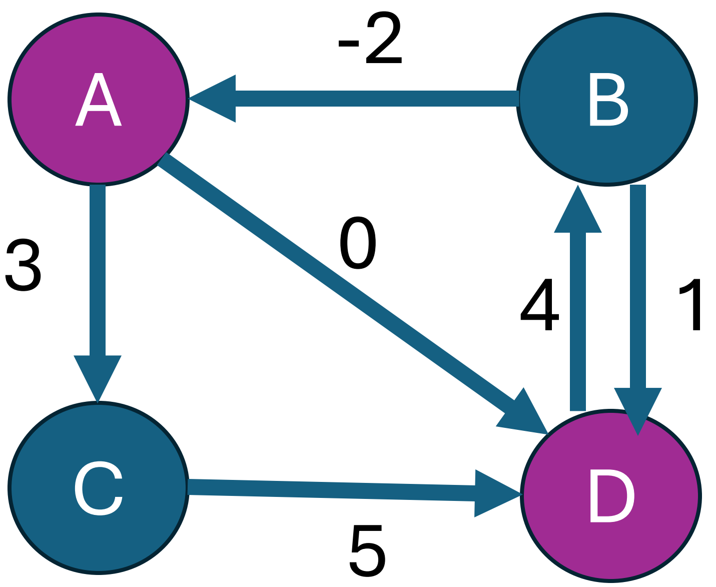
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

AC = 3 > AA = 0 + AC = 3

```
if dist[1][3] > dist[1][1] + dist[1][3]
    dist[1][3] = dist[1][1] + dist[1][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

from

	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

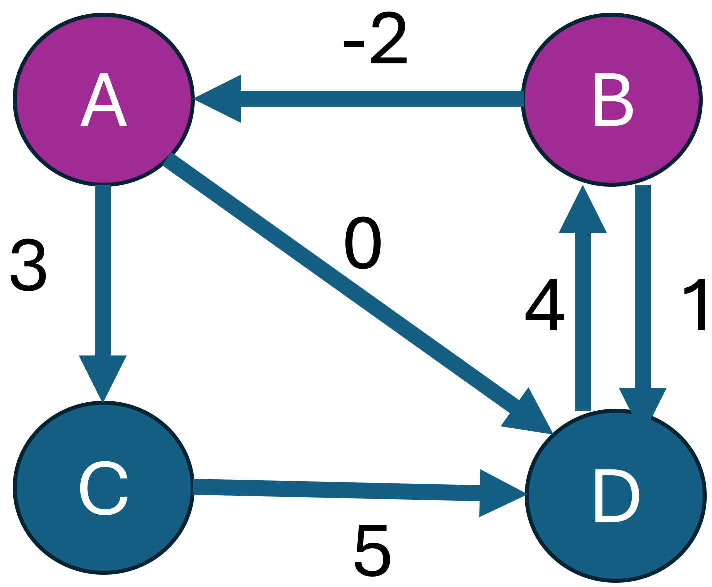
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

AD = 0 > AA = 0 + AD = 0

```
if dist[1][4] > dist[1][1] + dist[1][4]
    dist[1][4] = dist[1][1] + dist[1][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

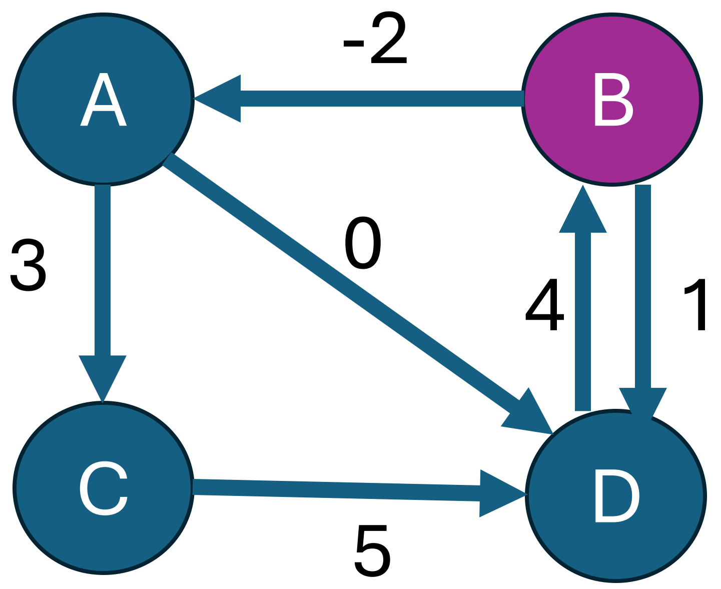
to

from	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
     dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

```
        BA = -2      >      BA = -2    +      AA = 0
if dist[2][1] > dist[2][1] + dist[1][1]
     dist[2][1] = dist[2][1] + dist[1][1]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	∞	1
C	∞	∞	0	5
D	∞	4	∞	0

to

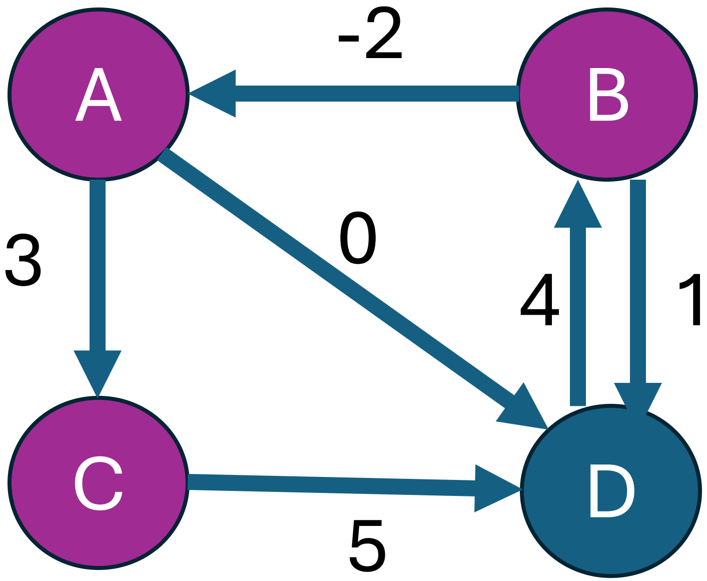
from

	A	B	C	D
A			A	A
B	B			B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

```
      BB = 0        >      BA = -2    +      AB = ∞
if dist[2][2] > dist[2][1] + dist[1][2]
    dist[2][2] = dist[2][1] + dist[1][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	1
C	∞	∞	0	5
D	∞	4	∞	0

to

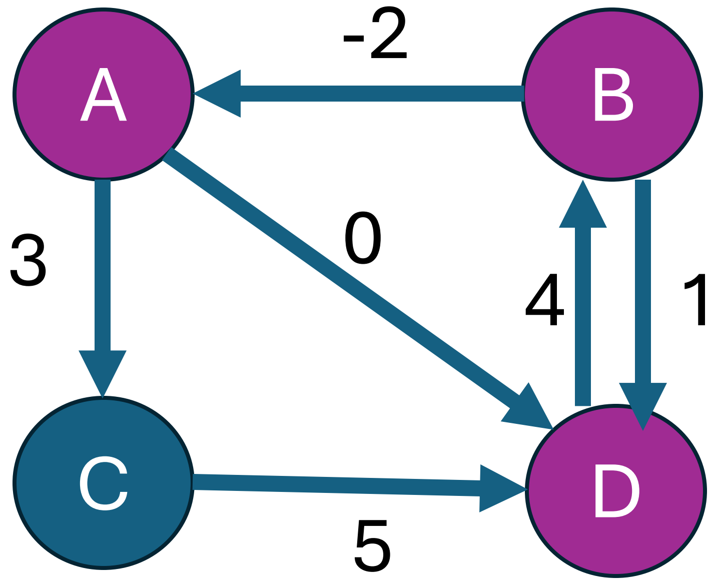
from	A	B	C	D
A			A	A
B	B		A	B
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k =	1	2	3	4
i =	1	2	3	4
j =	1	2	3	4

BC = ∞ > BA = -2 + AC = 3

```
if dist[2][3] > dist[2][1] + dist[1][3]
    dist[2][3] = dist[2][1] + dist[1][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

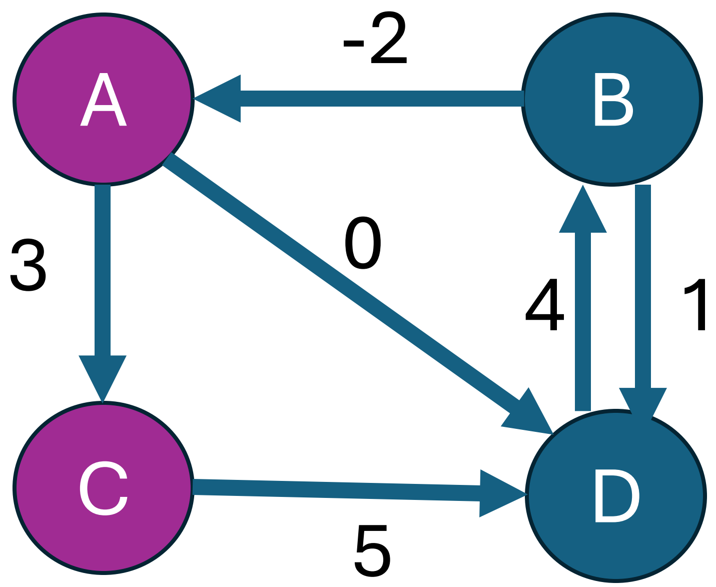
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

```
k = 1  2  3  4
i = 1  2  3  4
j = 1  2  3  4
```

YES!!!!!!

```
     BD = 1       >    BA = -2    +    AD = 0
if dist[2][4] > dist[2][1] + dist[1][4]
   dist[2][4] = dist[2][1] + dist[1][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

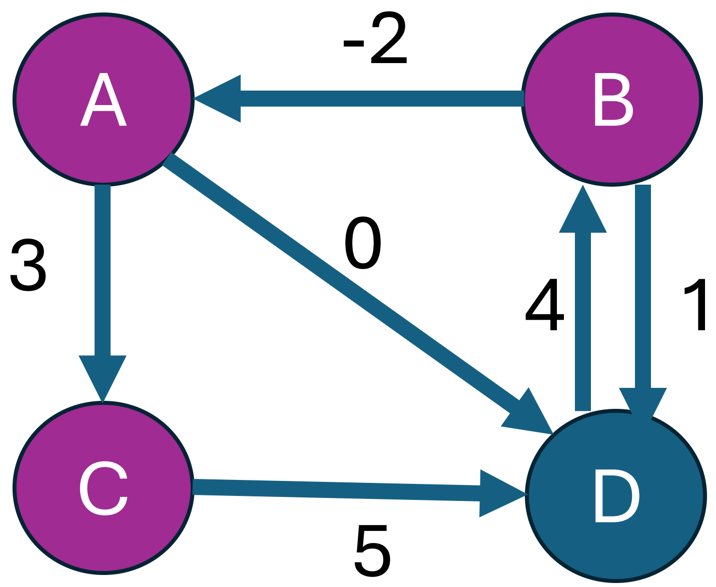
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

CA = ∞   >   CA = ∞   +   AA = 0

```
if dist[3][1] > dist[3][1] + dist[1][1]
    dist[3][1] = dist[3][1] + dist[1][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

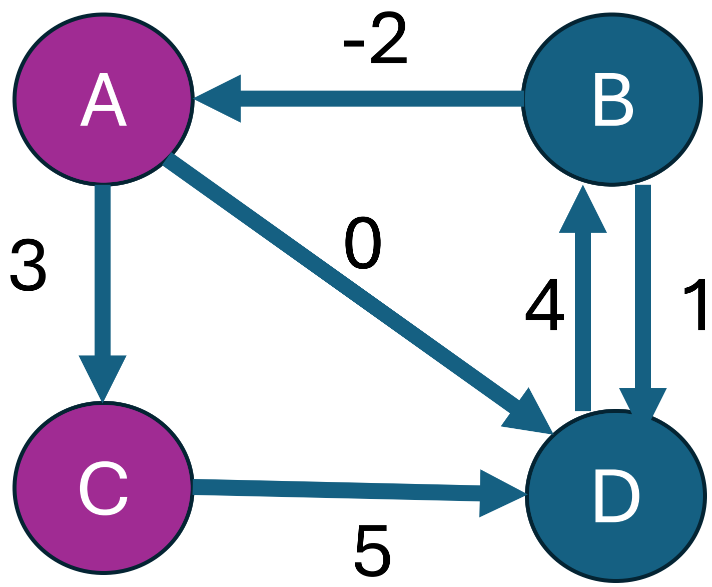
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

CB = ∞ > CA = ∞ + AB = 0

```
if dist[3][2] > dist[3][1] + dist[1][2]
    dist[3][2] = dist[3][1] + dist[1][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

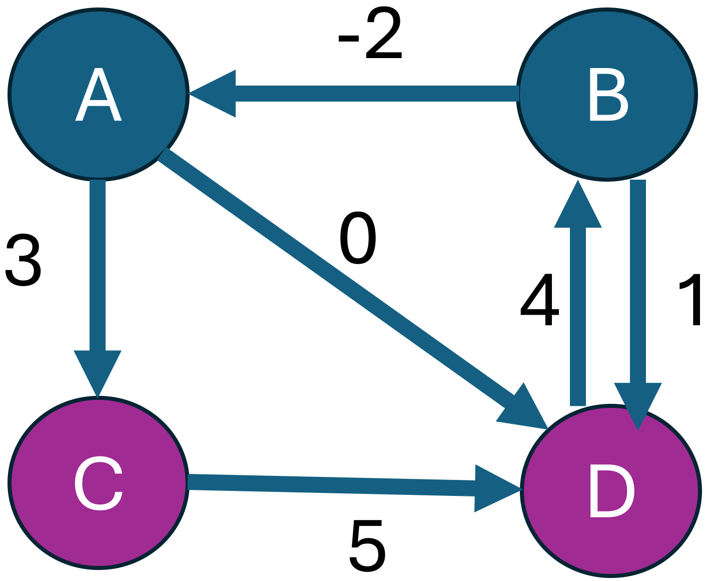
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CC = 0 > CA = ∞ + AC = 3

```
if dist[3][3] > dist[3][1] + dist[1][3]
    dist[3][3] = dist[3][1] + dist[1][3]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

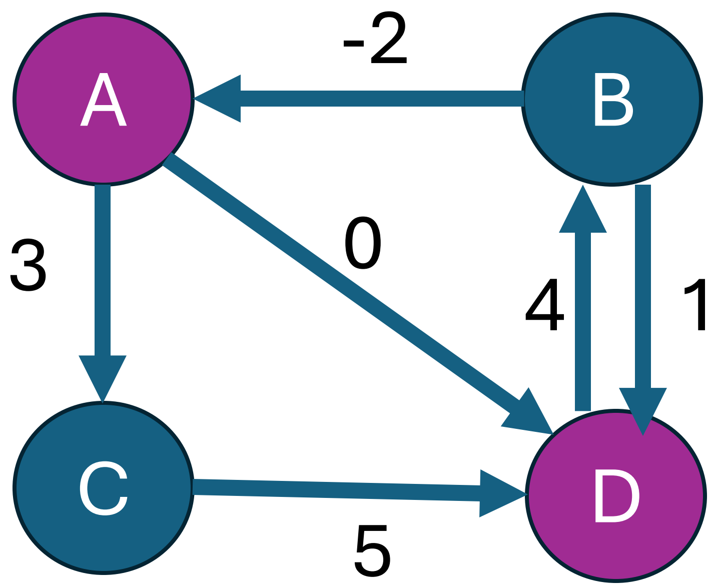
		to			
		A	B	C	D
from	A	0	∞	3	0
	B	-2	0	1	-2
	C	∞	∞	0	5
	D	∞	4	∞	0

		to			
		A	B	C	D
from	A			A	A
	B	B		A	A
	C				C
	D		D		

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CD = 5 > CA = ∞ + AD = 0

```
if dist[3][4] > dist[3][1] + dist[1][4]
    dist[3][4] = dist[3][1] + dist[1][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

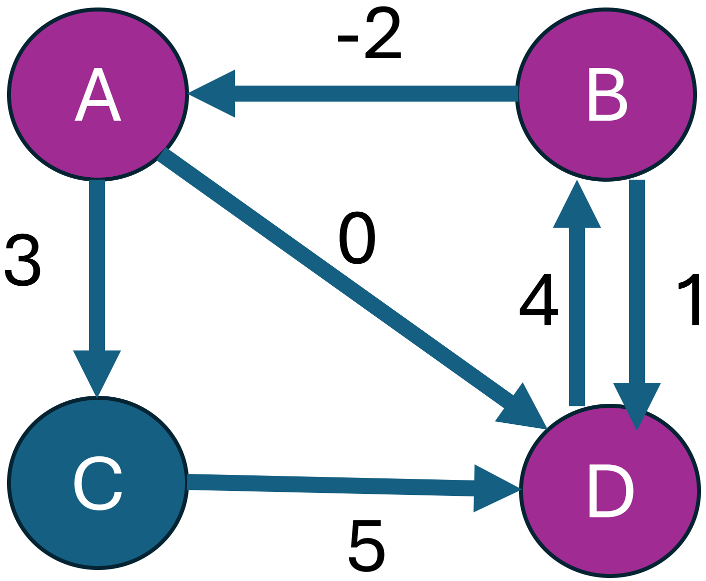
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

DA = ∞   >   DA = ∞   +   AA = 0

```
if dist[4][1] > dist[4][1] + dist[1][1]
    dist[4][1] = dist[3][1] + dist[1][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

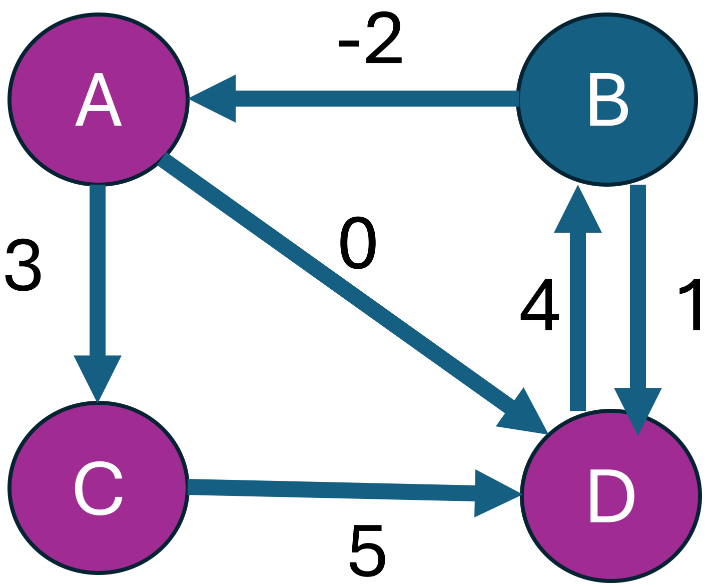
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DB = 4 > DA = ∞ + AB = ∞

```
if dist[4][2] > dist[4][1] + dist[1][2]
    dist[4][2] = dist[3][1] + dist[1][2]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from

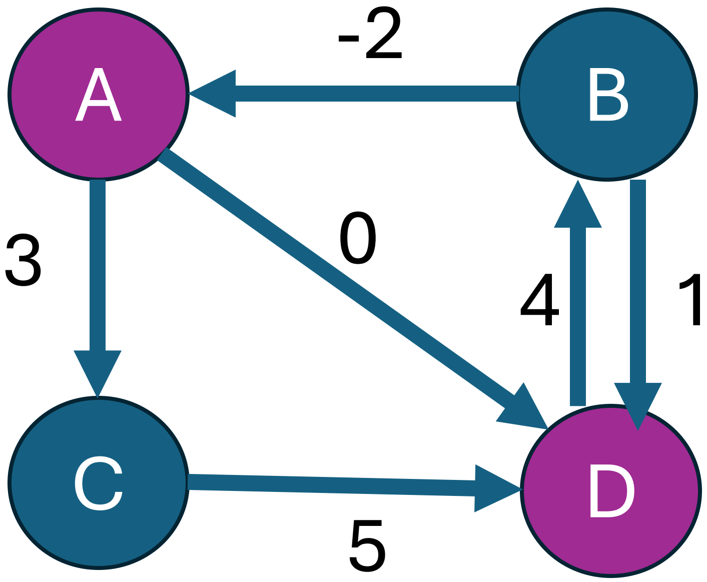
	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DC = ∞ > DA = ∞ + AC = 3

```
if dist[4][3] > dist[4][1] + dist[1][3]
    dist[4][3] = dist[3][1] + dist[1][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from

	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

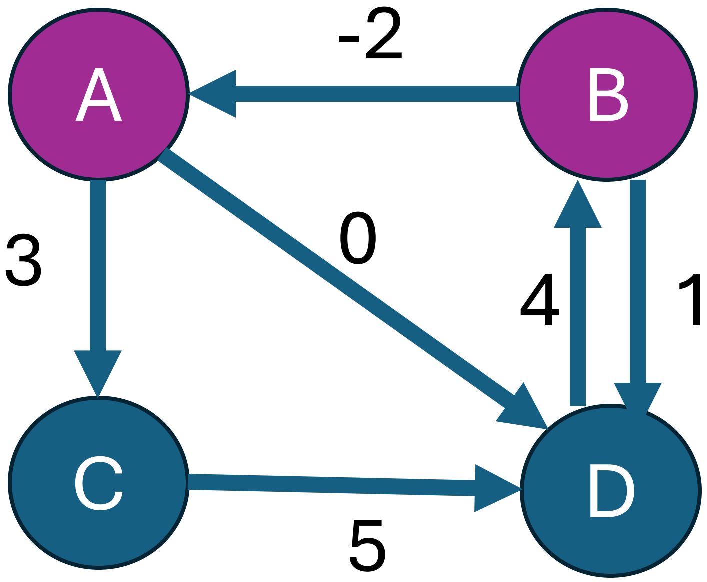
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

DD = 0 > DA = ∞ + AD = 0

```
if dist[4][4] > dist[4][1] + dist[1][4]
    dist[4][4] = dist[4][1] + dist[1][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

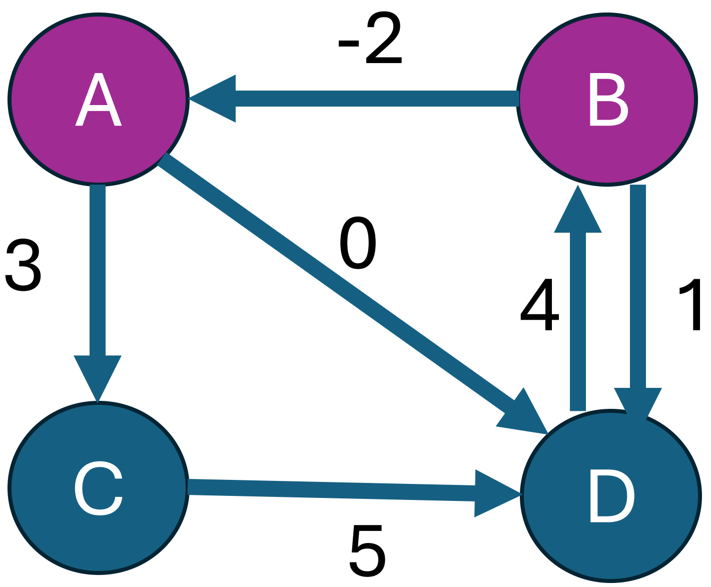
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AA = 0 > AB = ∞ + BA = -2

```
if dist[1][1] > dist[1][2] + dist[2][1]
    dist[1][1] = dist[1][2] + dist[2][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

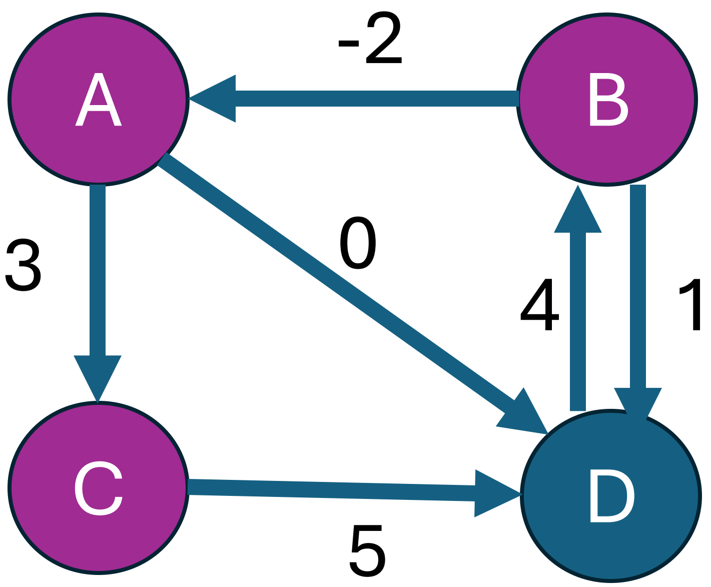
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

AB = ∞ > AB = ∞ + BB = 0

```
if dist[1][2] > dist[1][2] + dist[2][2]
    dist[1][2] = dist[1][2] + dist[2][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

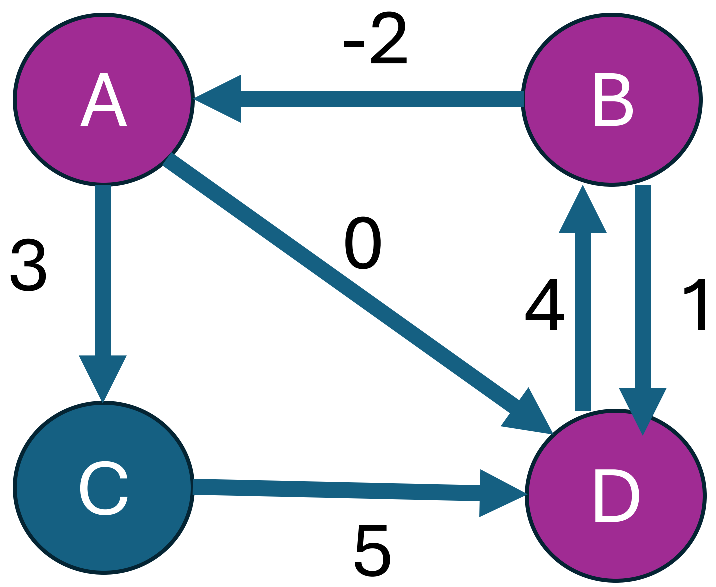
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AC = 3 > AB = ∞ + BC = 1

```
if dist[1][3] > dist[1][2] + dist[2][3]
    dist[1][3] = dist[1][2] + dist[2][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

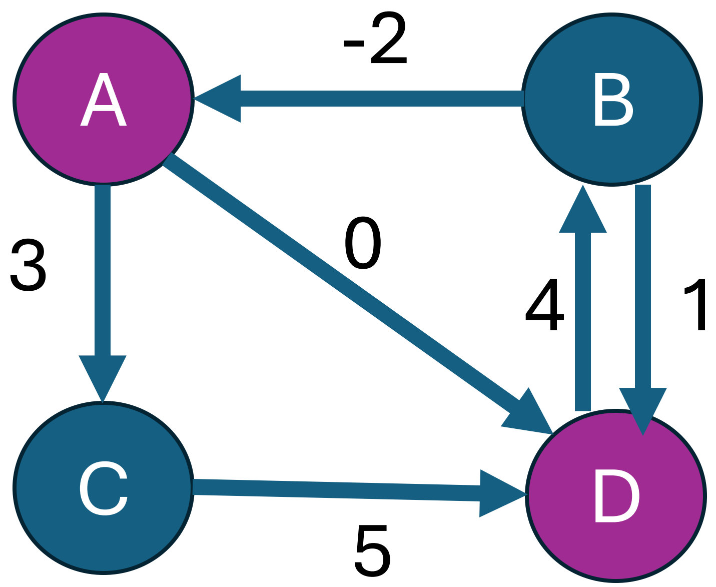
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AD = 0 > AB = ∞ + BD = -2

```
if dist[1][4] > dist[1][2] + dist[2][4]
    dist[1][4] = dist[1][2] + dist[2][4]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from

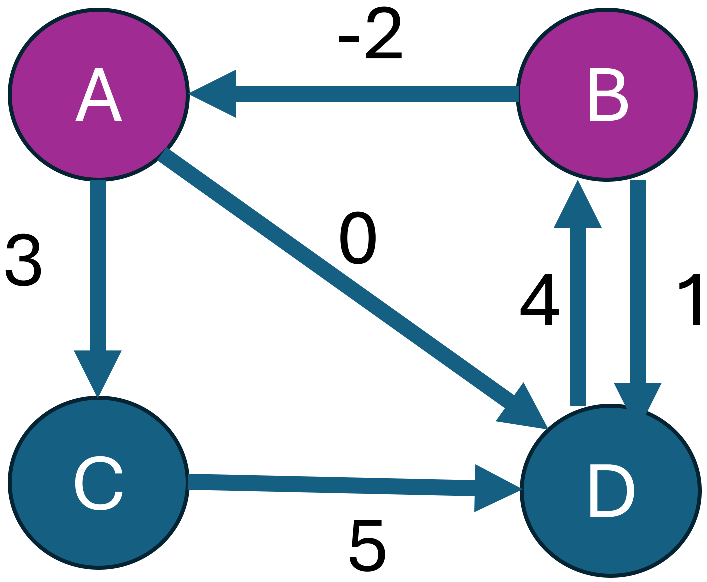
	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AD = 0 > AB = ∞ + BD = -2

```
if dist[1][4] > dist[1][2] + dist[2][4]
    dist[1][4] = dist[1][2] + dist[2][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

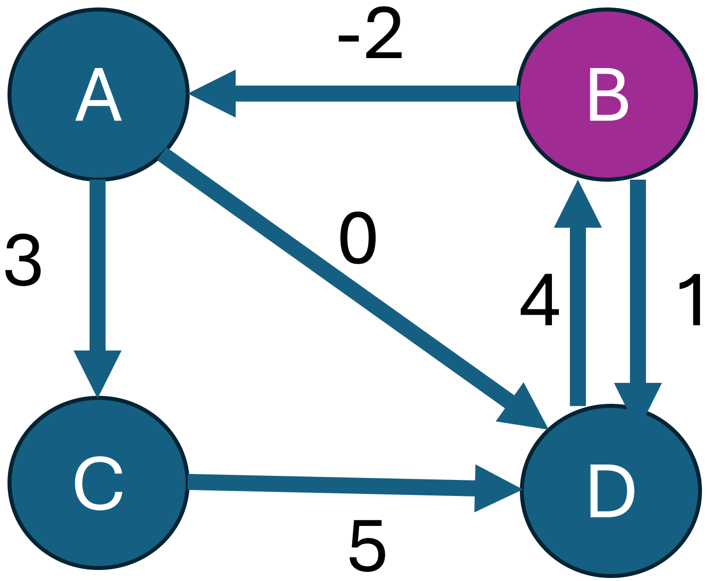
```
if dist[i][j] > dist[i][k] + dist[k][j]
   dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

```
       BA = -2       >      BB = 0      +      BA = -2
if dist[2][1] > dist[2][2] + dist[2][1]
   dist[2][1] = dist[2][2] + dist[2][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

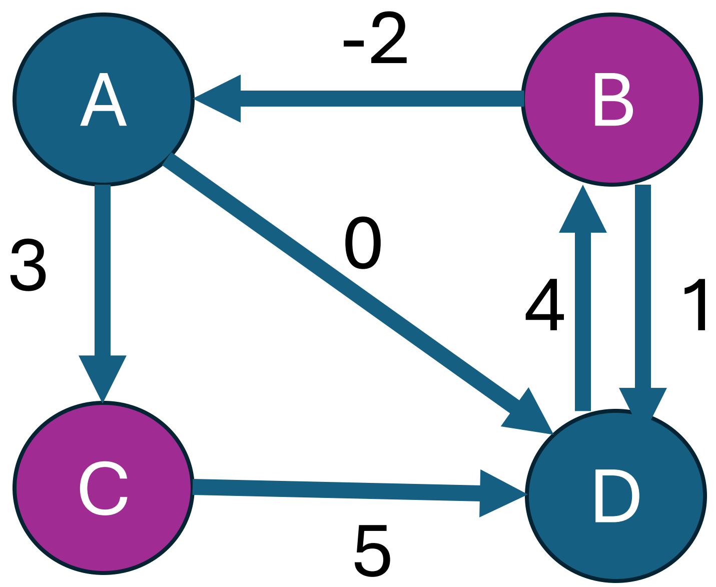
```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

```
     BB = 0          >      BB = 0      +     BB=0
if dist[2][2] > dist[2][2] + dist[2][2]
    dist[2][2] = dist[2][2] + dist[2][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

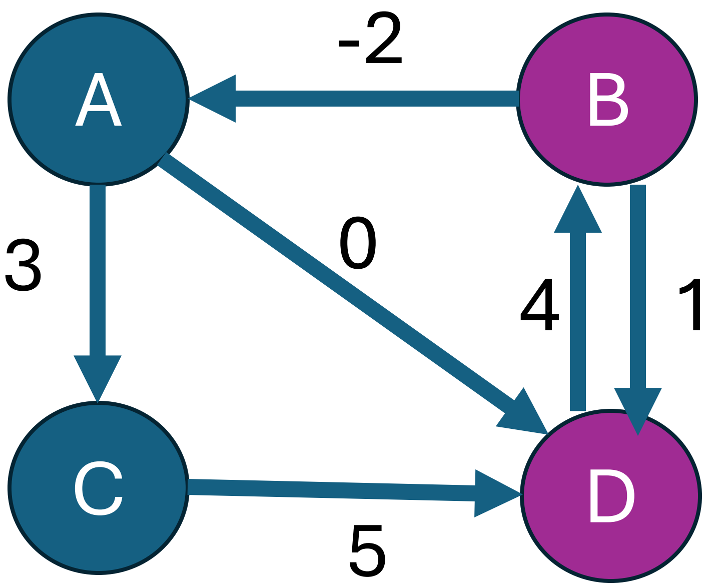
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

BC = 1 > BB = 0 + BC=1

```
if dist[2][3] > dist[2][2] + dist[2][3]
    dist[2][3] = dist[2][2] + dist[2][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

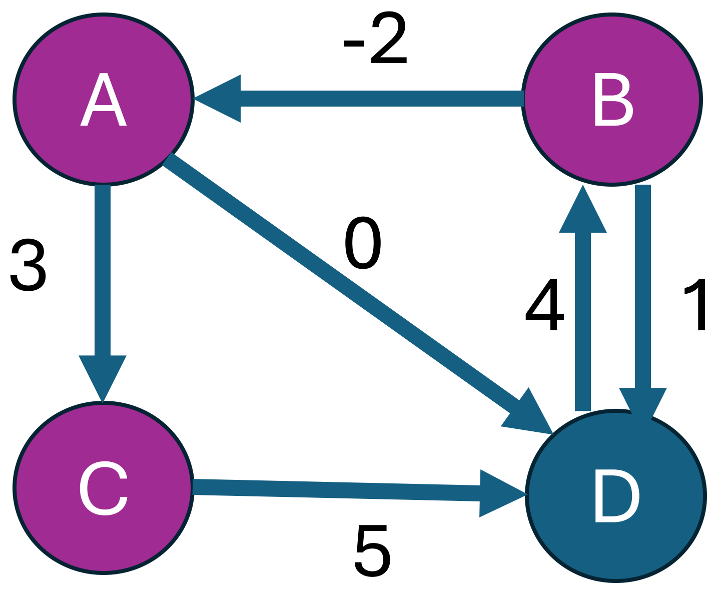
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

BD = -2 > BB = 0 + BD=-2

```
if dist[2][4] > dist[2][2] + dist[2][4]
    dist[2][4] = dist[2][2] + dist[2][4]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

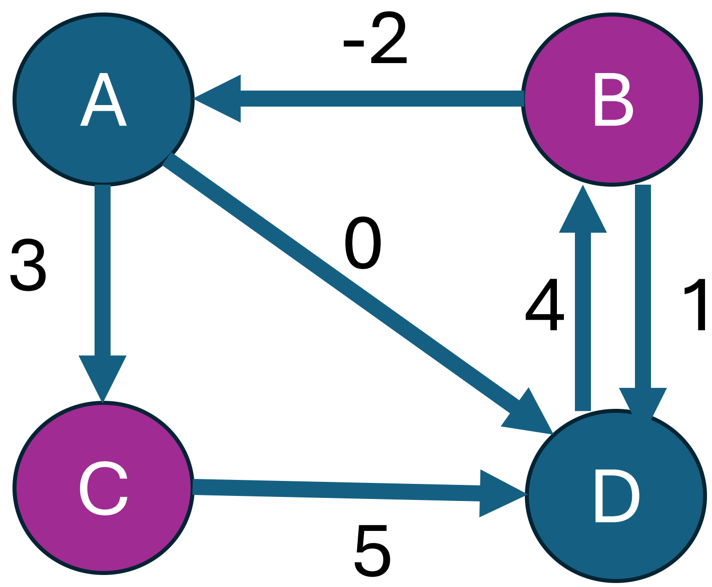
to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CA = ∞ > CB = ∞ + BA=-2

```
if dist[3][1] > dist[3][2] + dist[2][1]
    dist[3][1] = dist[3][2] + dist[2][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

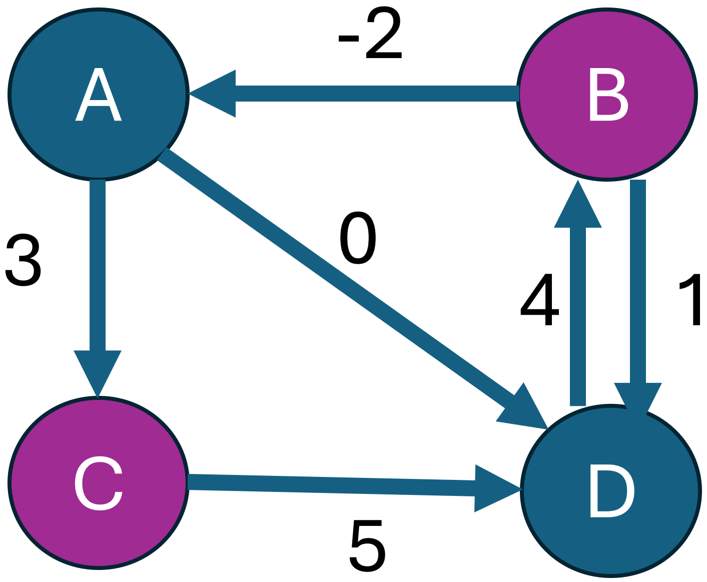
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CB = ∞ > CB = ∞ + BB=0

```
if dist[3][2] > dist[3][2] + dist[2][2]
    dist[3][2] = dist[3][2] + dist[2][2]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

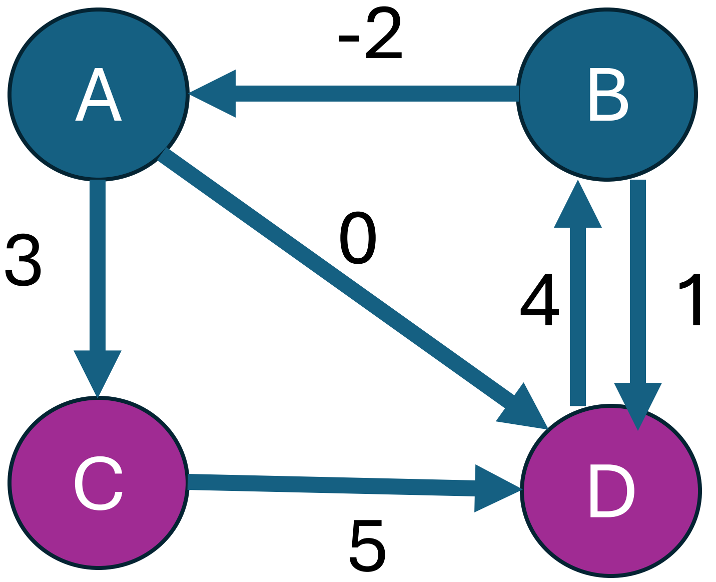
from

	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CC = 0 > CB = ∞ + BC=1

```
if dist[3][3] > dist[3][2] + dist[2][3]
    dist[3][3] = dist[3][2] + dist[2][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	∞	4	∞	0

to

from

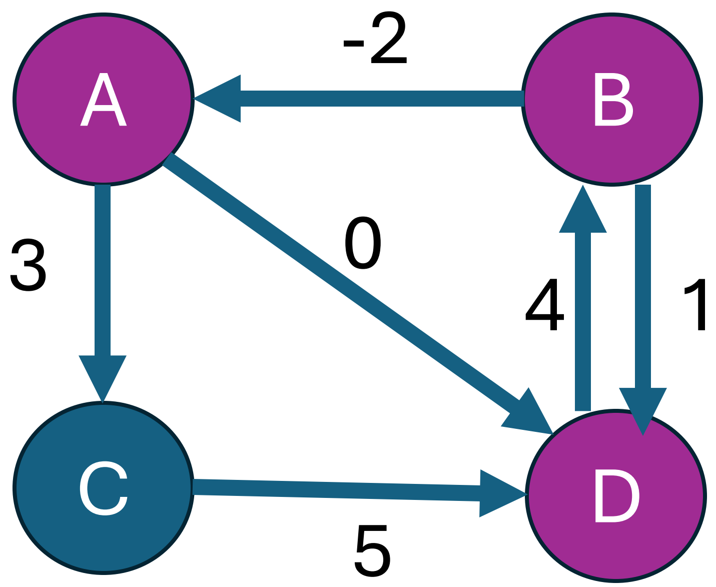
	A	B	C	D
A			A	A
B	B		A	A
C				C
D		D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CD = 5 > CB = ∞ + BD=-2

```
if dist[3][4] > dist[3][2] + dist[2][4]
    dist[3][4] = dist[3][2] + dist[2][4]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	∞	0

to

from

	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D		

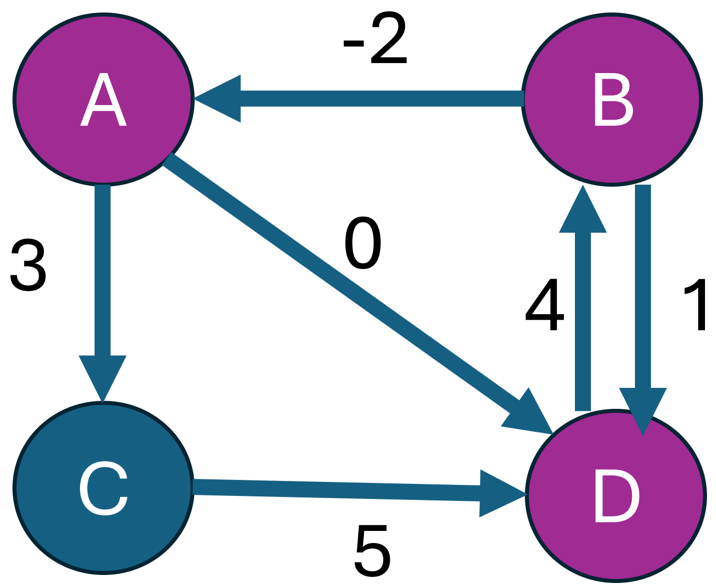
```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

YES!!!!!!

DA = ∞ > DB = 4 + BA=-2

```
if dist[4][1] > dist[4][2] + dist[2][1]
    dist[4][1] = dist[4][2] + dist[2][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	∞	0

to

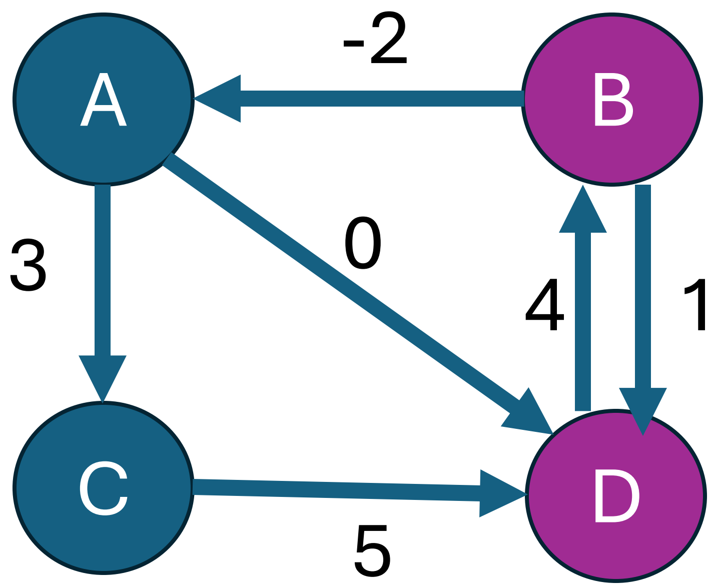
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DA = ∞ > DB = 1 + BA=-2

```
if dist[4][1] > dist[4][2] + dist[2][1]
    dist[4][1] = dist[4][2] + dist[2][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	∞	0

to

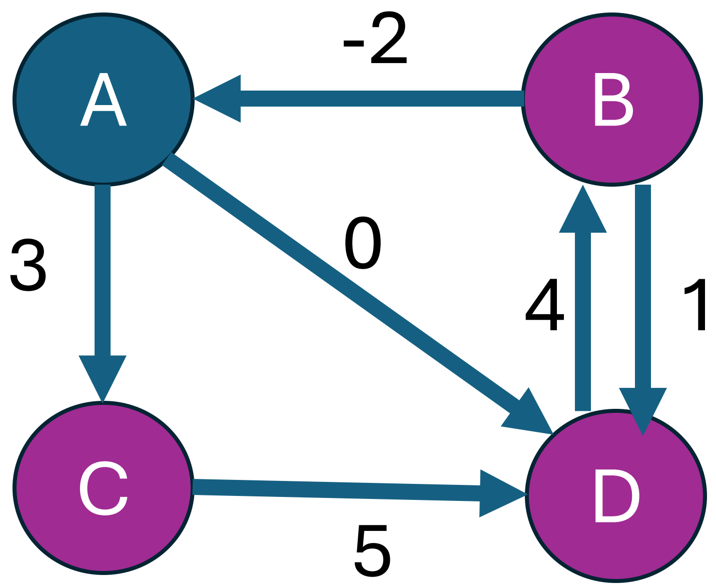
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D		

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DB = 4 > DB = 4 + BB=0

```
if dist[4][2] > dist[4][2] + dist[2][2]
    dist[4][2] = dist[4][2] + dist[2][2]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

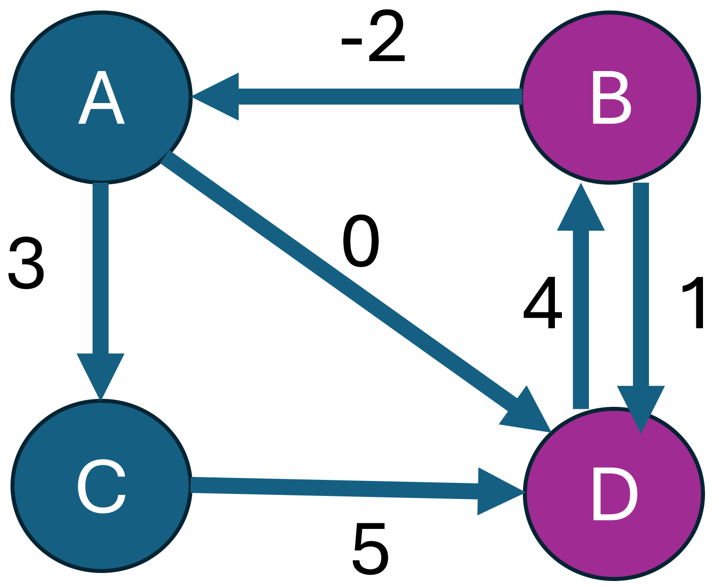
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

YES!!!!!!

DC= ∞ > DB = 4 + BC=1

```
if dist[4][3] > dist[4][2] + dist[2][3]
    dist[4][3] = dist[4][2] + dist[2][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

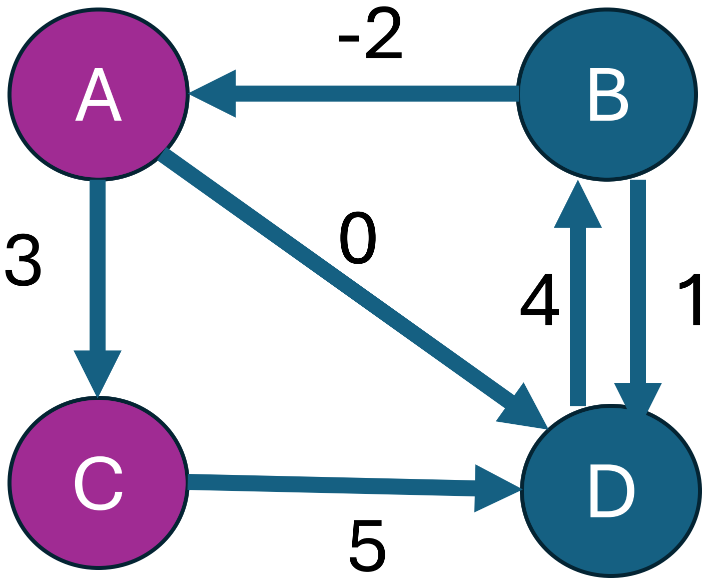
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DD= 0 > DB = 4 + BD=-2

```
if dist[4][4] > dist[4][2] + dist[2][4]
    dist[4][4] = dist[4][2] + dist[2][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

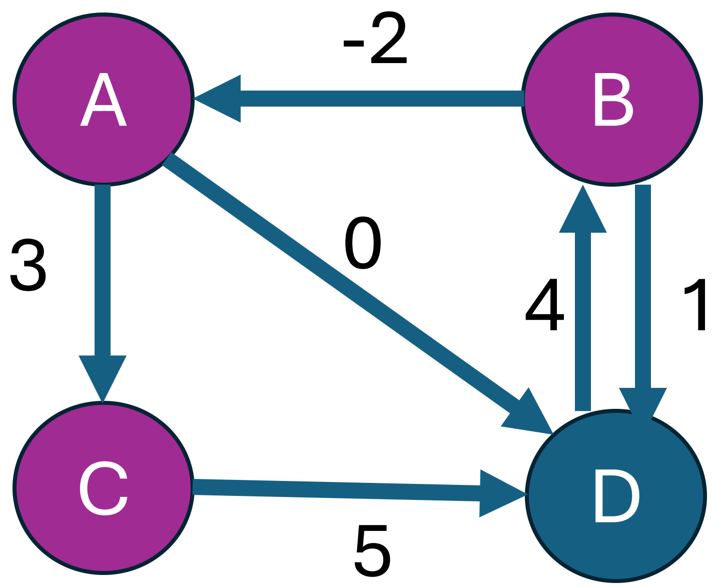
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AA= 0 > AC = 3 + CA=∞

```
if dist[1][1] > dist[1][3] + dist[3][1]
    dist[1][1] = dist[1][3] + dist[3][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

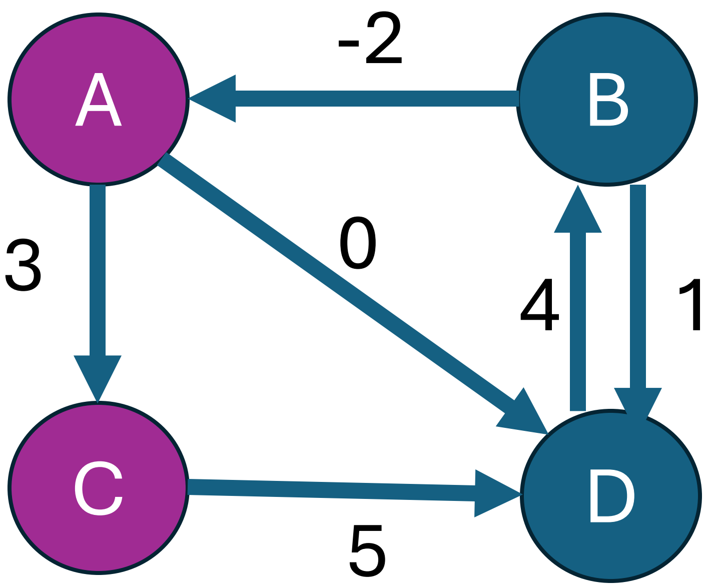
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AB= ∞ > AC = 3 + CB=∞

```
if dist[1][2] > dist[1][3] + dist[3][2]
    dist[1][2] = dist[1][3] + dist[3][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

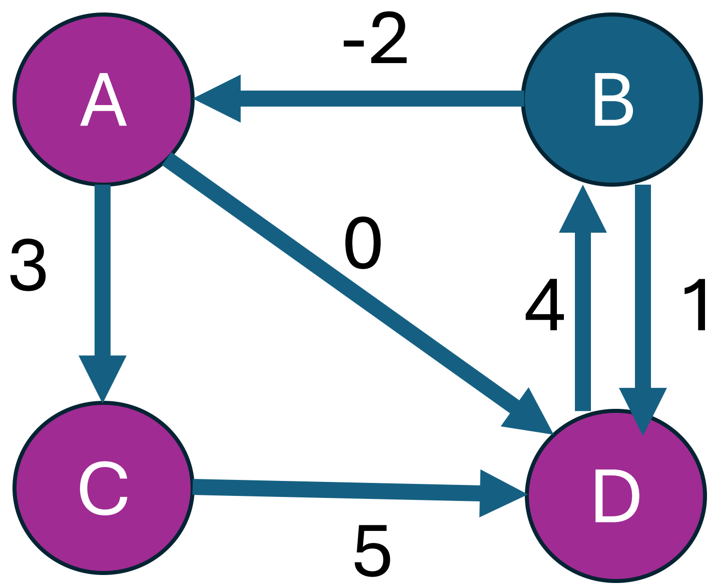
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AC= 3 > AC = 3 + CC=0

```
if dist[1][3] > dist[1][3] + dist[3][3]
    dist[1][3] = dist[1][3] + dist[3][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

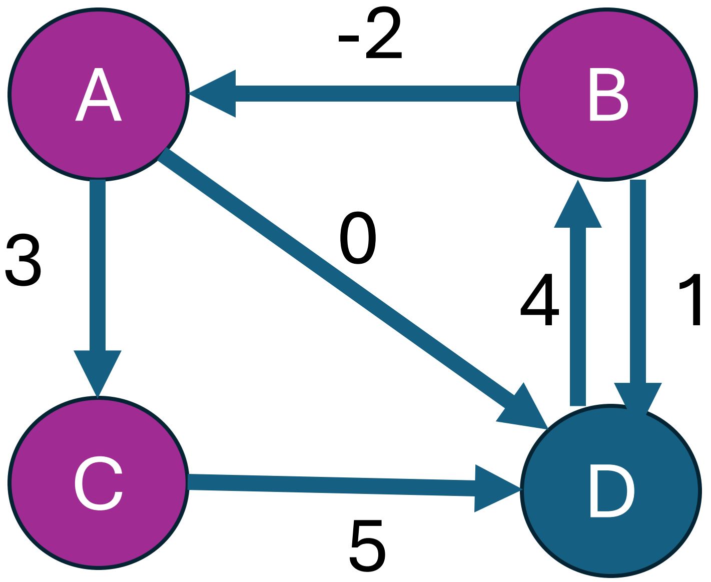
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AD= 0 > AC = 3 + CD=5

```
if dist[1][4] > dist[1][3] + dist[3][4]
    dist[1][4] = dist[1][3] + dist[3][4]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

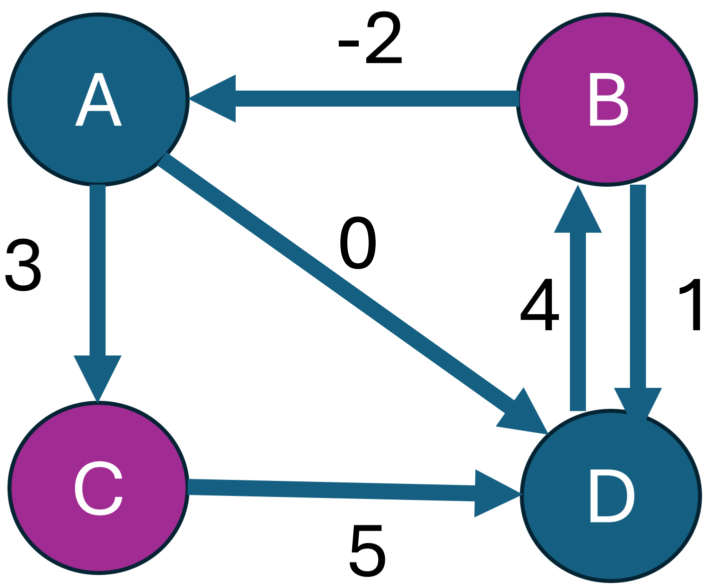
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

BA= -2 > BC = 1 + CA= ∞

```
if dist[2][1] > dist[2][3] + dist[3][1]
    dist[2][1] = dist[2][3] + dist[3][1]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

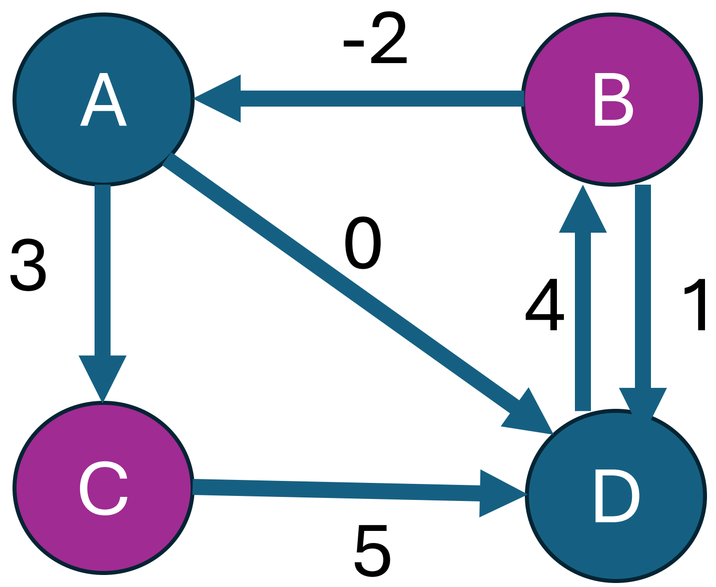
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

BB= 0 > BC = 1 + CB= ∞

```
if dist[2][2] > dist[2][3] + dist[3][2]
    dist[2][2] = dist[2][3] + dist[3][2]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

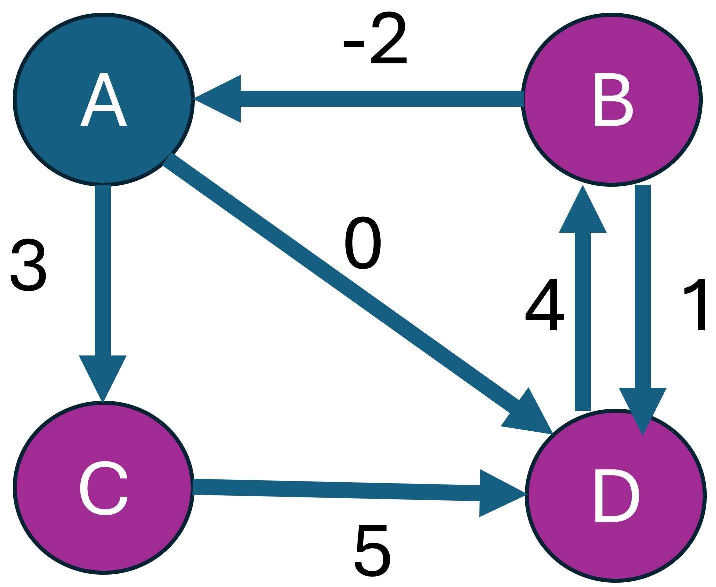
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

BC= 1   >   BC = 1   +   CC= 0

```
if dist[2][3] > dist[2][3] + dist[3][3]
    dist[2][3] = dist[2][3] + dist[3][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

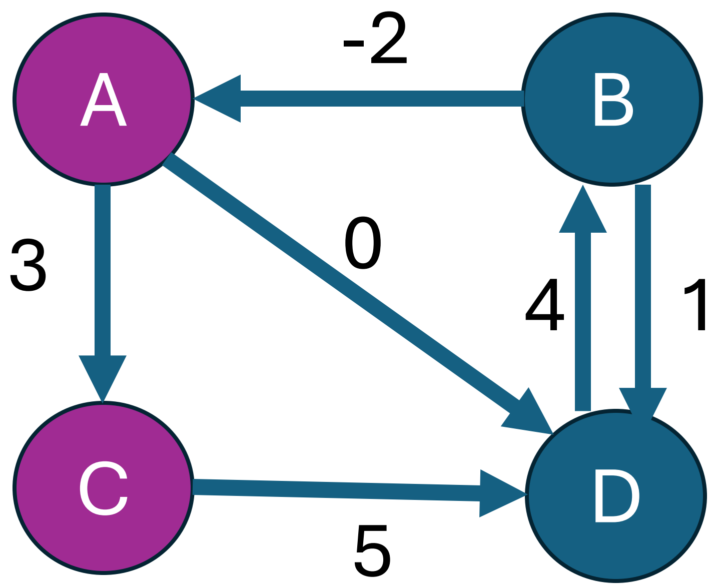
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

BD= -2 > BC = 1 + CD= 5

```
if dist[2][4] > dist[2][3] + dist[3][4]
    dist[2][4] = dist[2][3] + dist[3][4]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

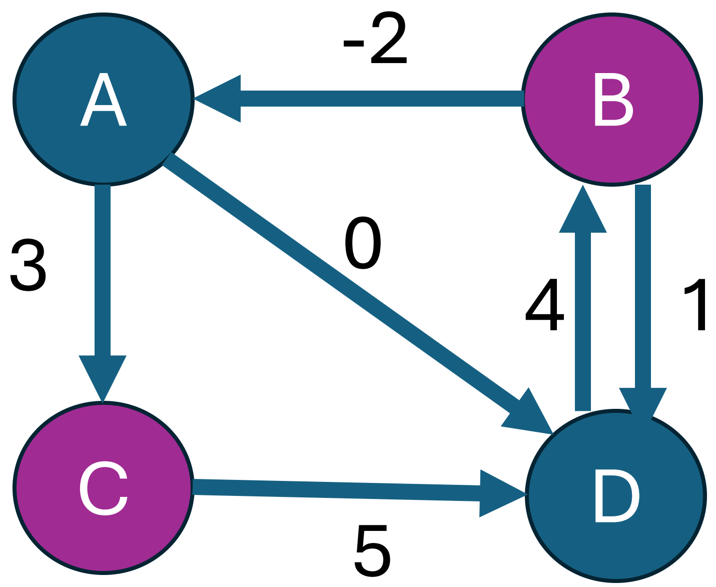
from

	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
k = 1  2  3  4
i = 1  2  3  4
j = 1  2  3  4
```

CA= ∞ > CC = 0 + CA= ∞

```
if dist[3][1] > dist[3][3] + dist[3][1]
    dist[3][1] = dist[3][3] + dist[3][1]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

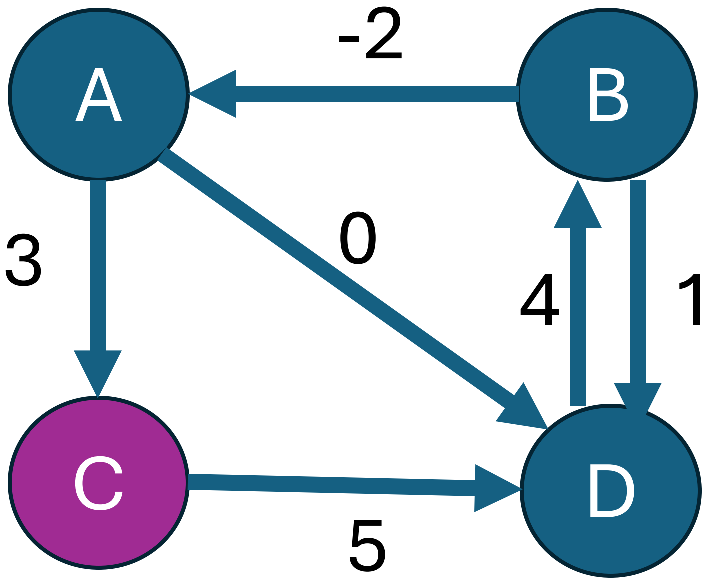
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CB= ∞ > CC = 0 + CB= ∞

```
if dist[3][2] > dist[3][3] + dist[3][2]
    dist[3][2] = dist[3][3] + dist[3][2]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

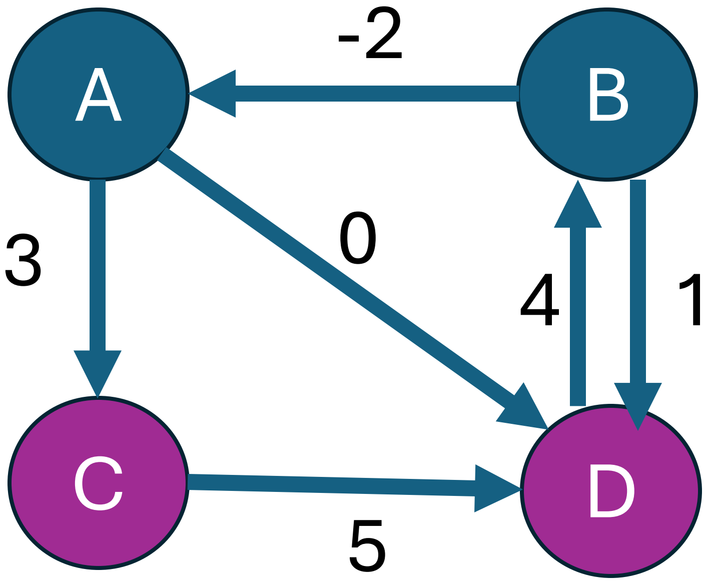
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

CC= 0 > CC = 0 + CC= 0

```
if dist[3][3] > dist[3][3] + dist[3][3]
    dist[3][3] = dist[3][3] + dist[3][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

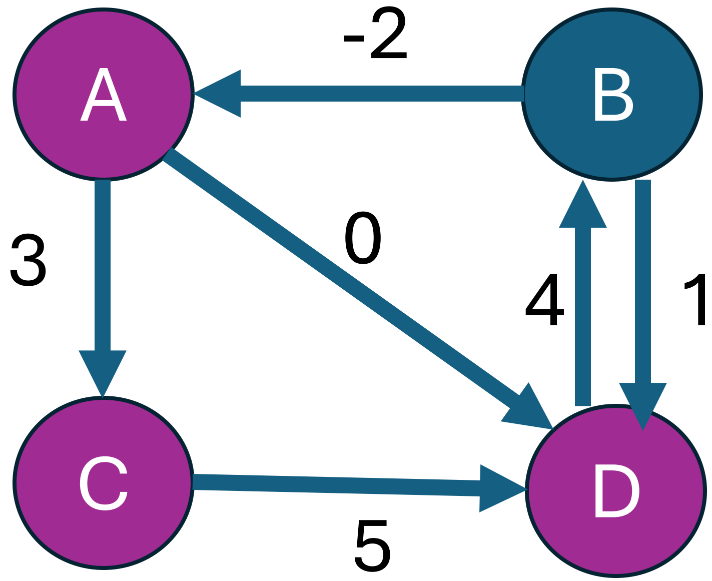
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

CD= 5 > CC = 0 + CD= 5

```
if dist[3][4] > dist[3][3] + dist[3][4]
    dist[3][4] = dist[3][3] + dist[3][4]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

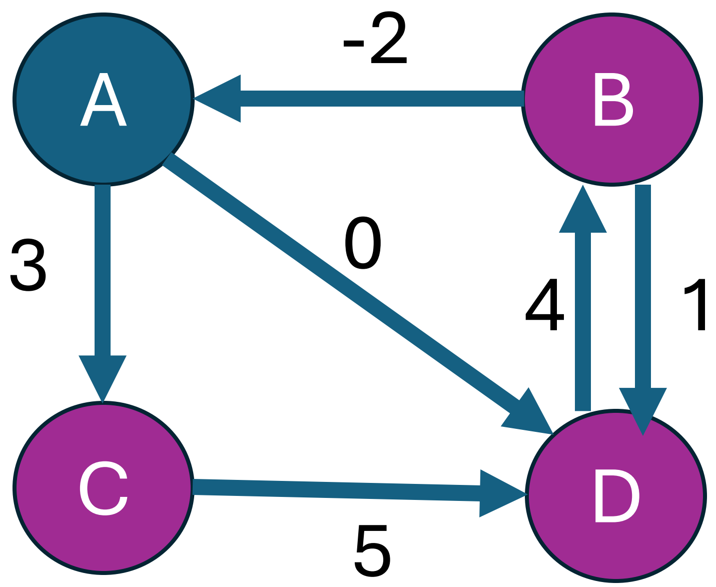
to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

```
     DA= 2          >      DC = 5     +     CA= ∞
if dist[4][1] > dist[4][3] + dist[3][1]
    dist[4][1] = dist[4][3] + dist[3][1]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

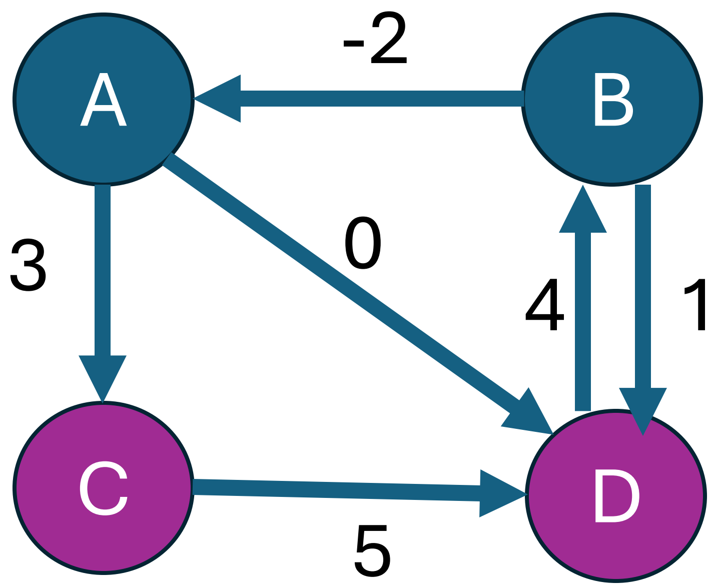
from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DB= 4 > DC = 5 + CB= ∞

```
if dist[4][2] > dist[4][3] + dist[3][2]
    dist[4][2] = dist[4][3] + dist[3][2]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

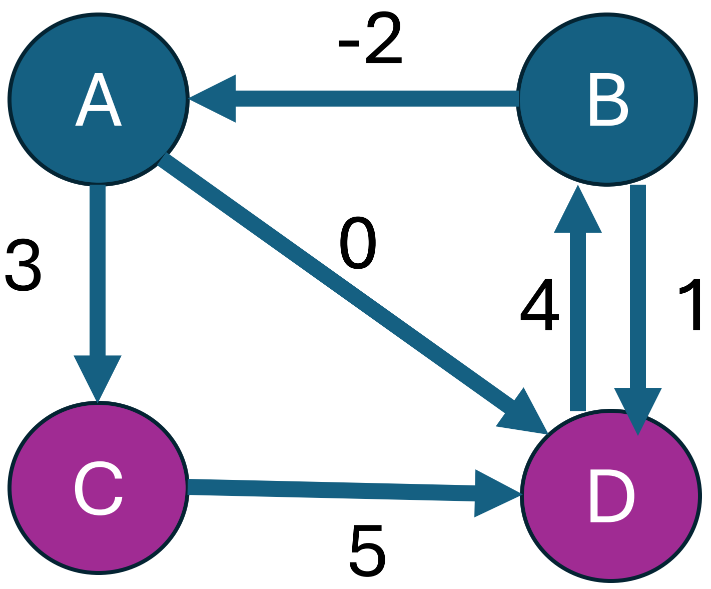
to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DC= 5 > DC = 5 + CC= 0

```
if dist[4][3] > dist[4][3] + dist[3][3]
    dist[4][3] = dist[4][3] + dist[3][3]
```



to

from	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

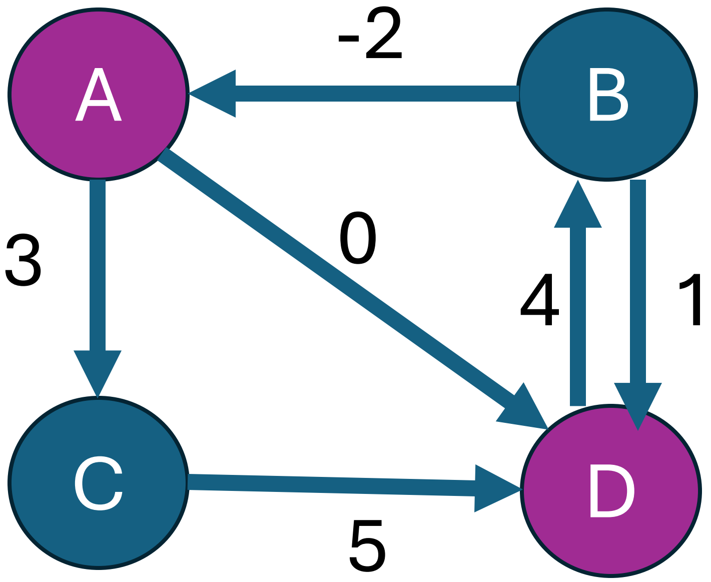
to

from	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

```
     DC= 5           >     DC = 5      +    CC= 0
if dist[4][3] > dist[4][3] + dist[3][3]
    dist[4][3] = dist[4][3] + dist[3][3]
```



to

from

	A	B	C	D
A	0	∞	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

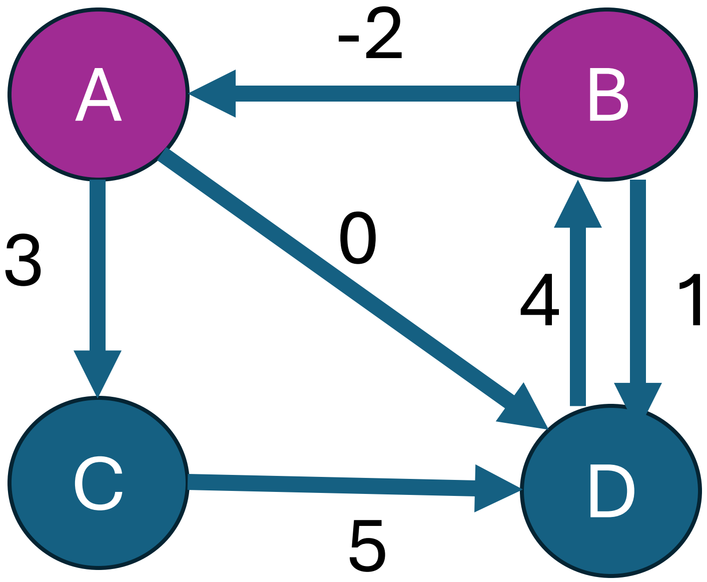
	A	B	C	D
A			A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AA= 0 > AD = 0 + DA= 0

```
if dist[1][1] > dist[1][4] + dist[4][1]
    dist[1][1] = dist[1][4] + dist[4][1]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

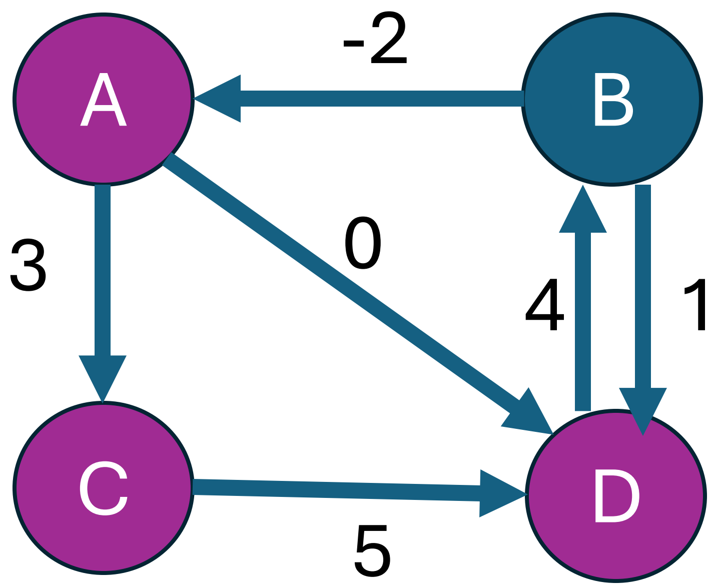
```
if dist[i][j] > dist[i][k] + dist[k][j]
     dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

YES!!!!!!

AB= ∞ > AD = 0 + DB= 4

```
if dist[1][2] > dist[1][4] + dist[4][2]
     dist[1][2] = dist[1][4] + dist[4][2]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

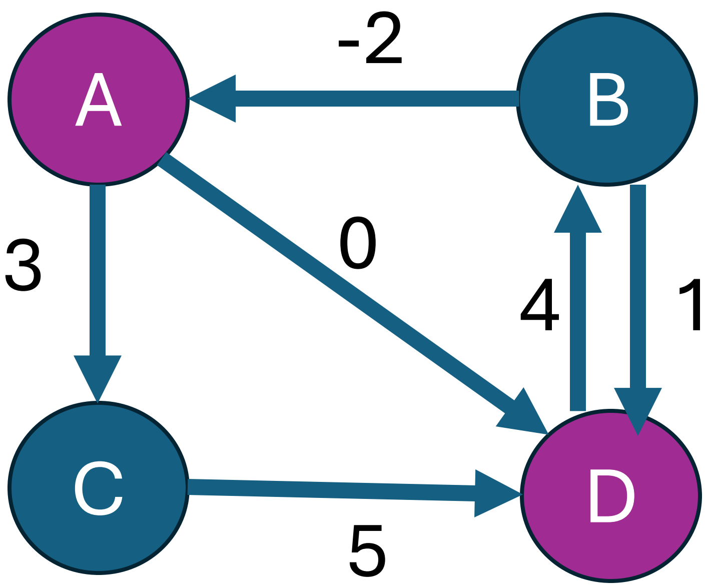
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

AC= 3 > AD = 0 + DC= 5

```
if dist[1][3] > dist[1][4] + dist[4][3]
    dist[1][3] = dist[1][4] + dist[4][3]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

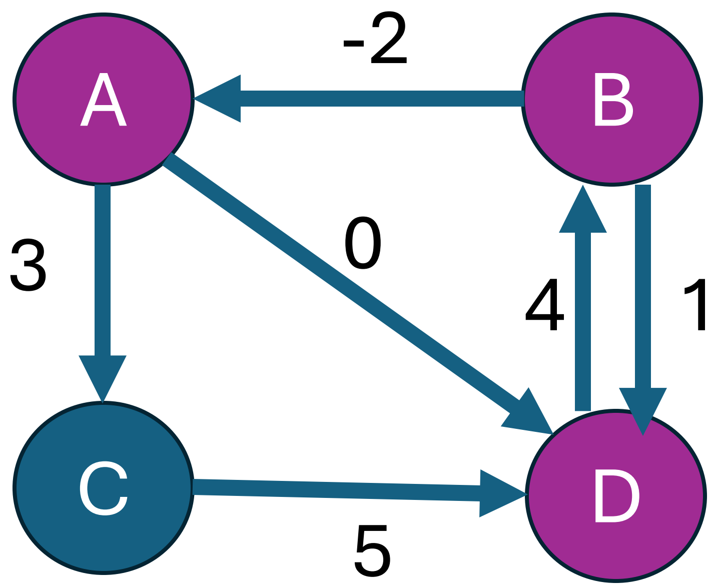
from	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

AD= 0 > AD = 0 + DD= 0

```
if dist[1][4] > dist[1][4] + dist[4][4]
    dist[1][4] = dist[1][4] + dist[4][4]
```



```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

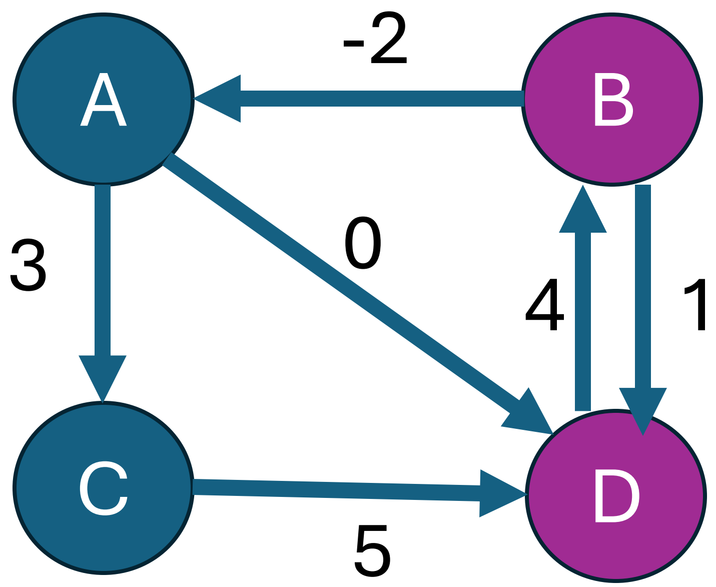
to

from	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

BA= 0 > BD = -2 + DA= 2

```
if dist[2][1] > dist[2][4] + dist[4][1]
    dist[2][1] = dist[2][4] + dist[4][1]
```



		to			
		A	B	C	D
from	A	0	4	3	0
	B	-2	0	1	-2
	C	∞	∞	0	5
	D	2	4	5	0

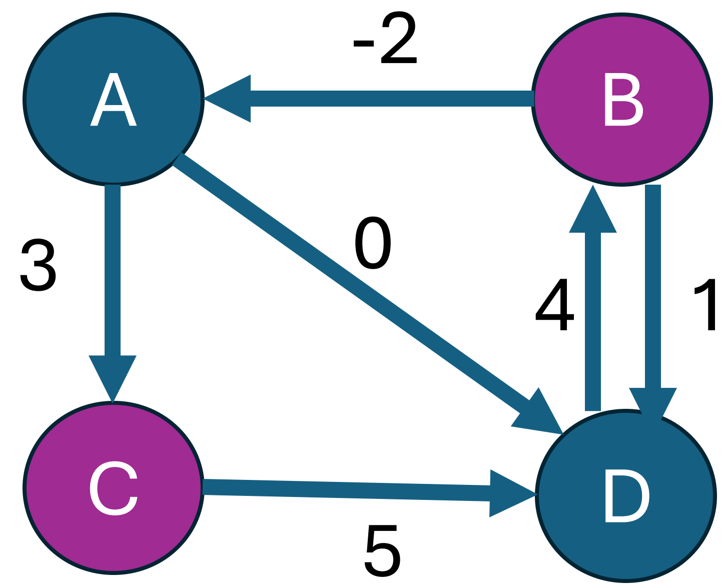
		to			
		A	B	C	D
from	A		D	A	A
	B	B		A	A
	C				C
	D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

BB= 0   >   BD = -2   +   DB= 4

```
if dist[2][2] > dist[2][4] + dist[4][2]
    dist[2][2] = dist[2][4] + dist[4][2]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

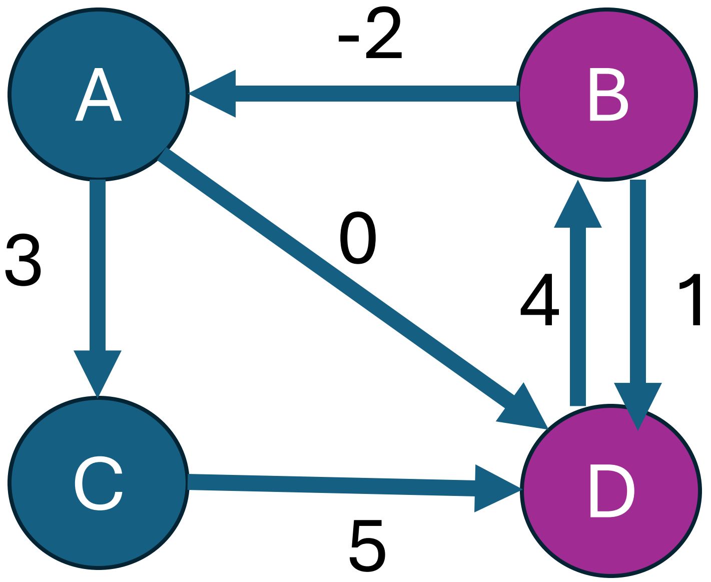
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

BC= 1 > BD = -2 + DC= 5

```
if dist[2][3] > dist[2][4] + dist[4][3]
    dist[2][3] = dist[2][4] + dist[4][3]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	∞	∞	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C				C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

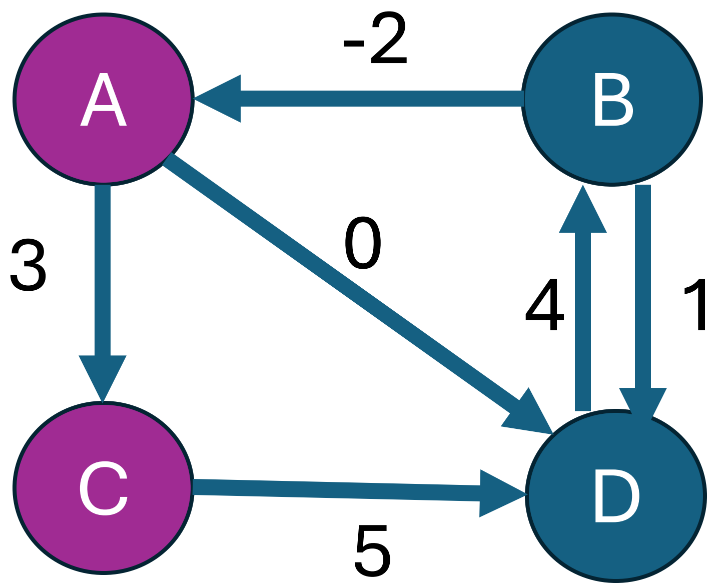
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

BD= -2 > BD = -2 + DD= 0

```
if dist[2][4] > dist[2][4] + dist[4][4]
    dist[2][4] = dist[2][4] + dist[4][4]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	∞	0	5
D	2	4	5	0

to

from

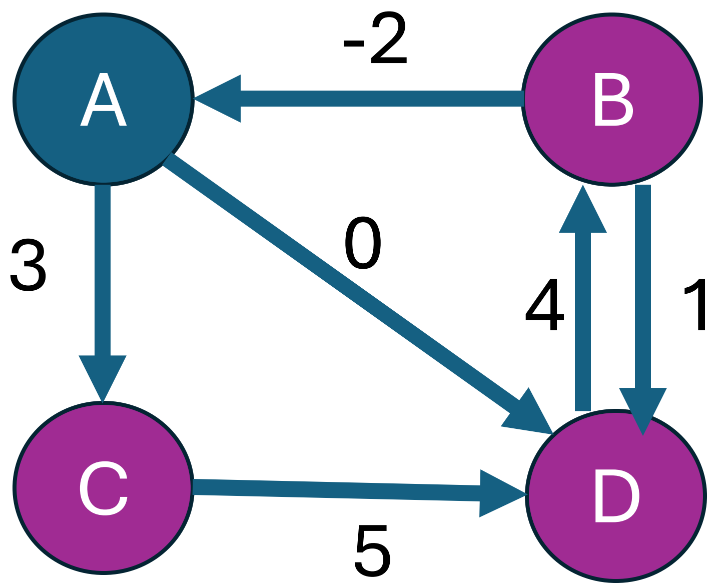
	A	B	C	D
A		D	A	A
B	B		A	A
C	D			C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

YES!!!!!!

```
      CA= ∞        >     CD = 5     +     DA= 2
if dist[3][1] > dist[3][4] + dist[4][1]
    dist[3][1] = dist[3][4] + dist[4][1]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

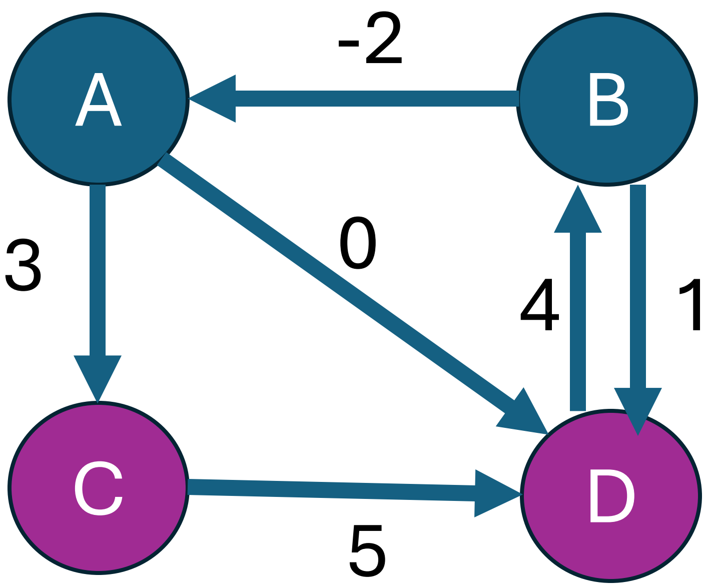
```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

YES!!!!!!

CB= ∞ > CD = 5 + DB= 4

```
if dist[3][2] > dist[3][4] + dist[4][2]
    dist[3][2] = dist[3][4] + dist[4][2]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

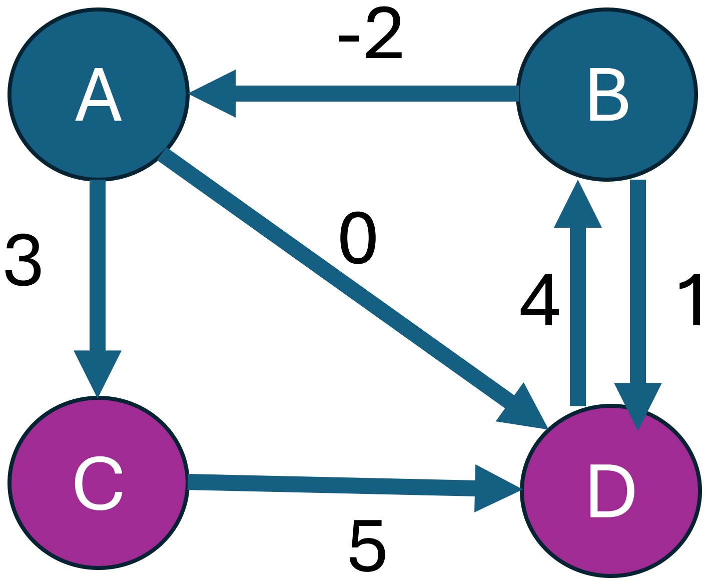
from	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

```
k = 1  2  3  4
i = 1  2  3  4
j = 1  2  3  4
```

CC= 0 > CD = 5 + DC= 5

```
if dist[3][3] > dist[3][4] + dist[4][3]
    dist[3][3] = dist[3][4] + dist[4][3]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

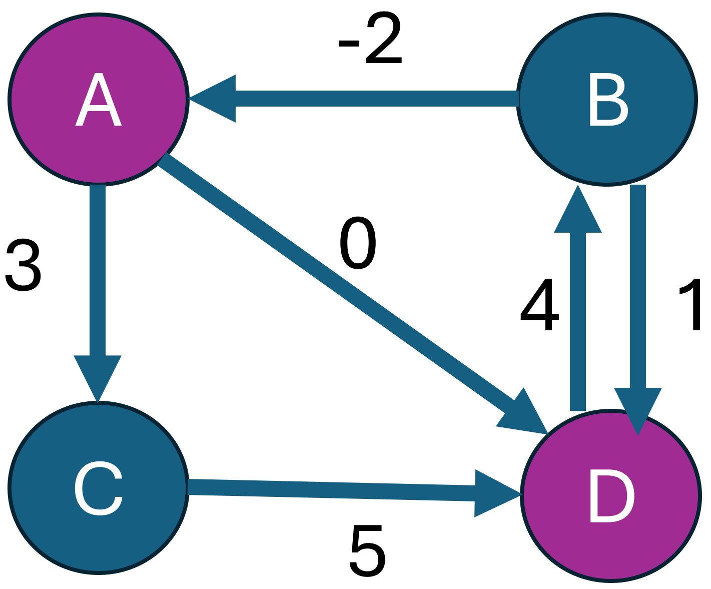
```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

```
         CD= 5          >      CD = 5      +     DD= 0
if dist[3][4] > dist[3][4] + dist[4][4]
   dist[3][4] = dist[3][4] + dist[4][4]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

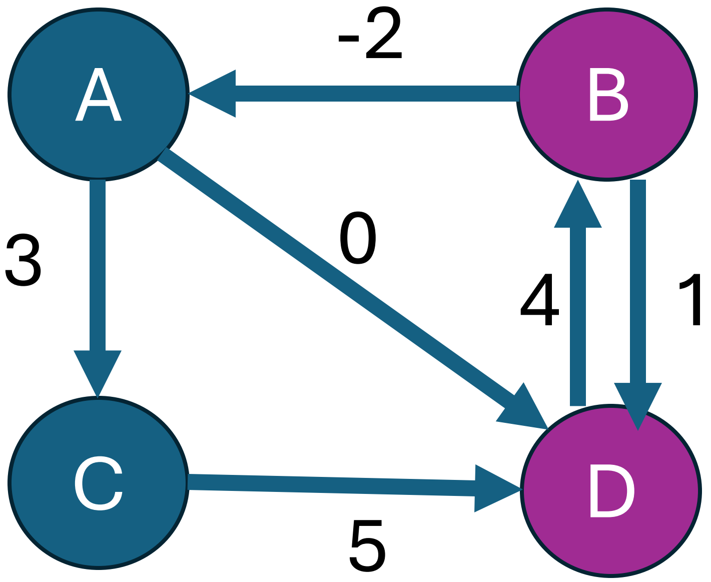
from	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DA= 2 > DD = 0 + DA= 2

```
if dist[4][1] > dist[4][4] + dist[4][1]
    dist[4][1] = dist[4][4] + dist[4][1]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

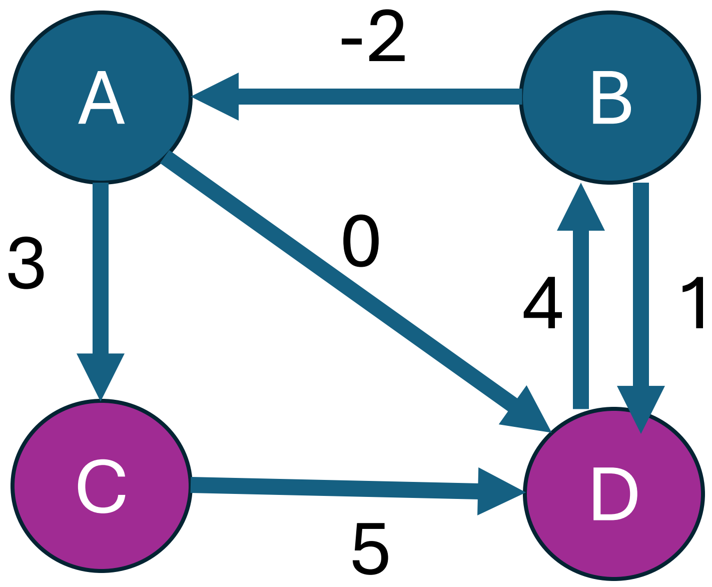
from	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4
i = 1 2 3 4
j = 1 2 3 4

DB= 4 > DD = 0 + DB= 4

```
if dist[4][2] > dist[4][4] + dist[4][2]
    dist[4][2] = dist[4][4] + dist[4][2]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from

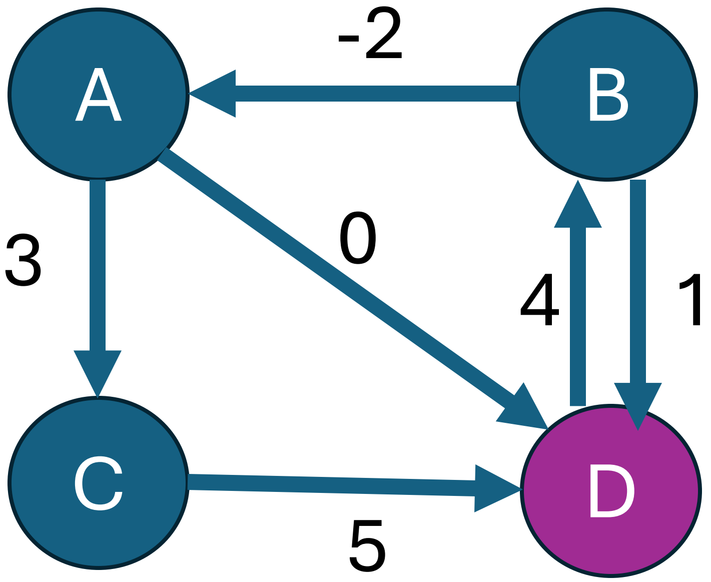
	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1   2   3   4
i = 1   2   3   4
j = 1   2   3   4

DC= 5   >   DD = 0   +   DC= 5

```
if dist[4][3] > dist[4][4] + dist[4][3]
    dist[4][3] = dist[4][4] + dist[4][3]
```



to

from	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

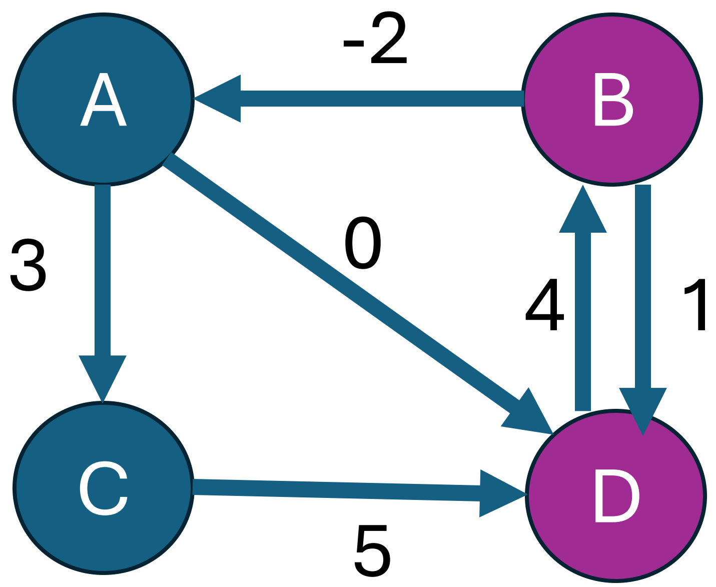
```
if dist[i][j] > dist[i][k] + dist[k][j]
   dist[i][j] = dist[i][k] + dist[k][j]
```

k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

```
     DD= 0          >       DD = 0      +      DD= 0
if dist[4][4] > dist[4][4] + dist[4][4]
   dist[4][4] = dist[4][4] + dist[4][4]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

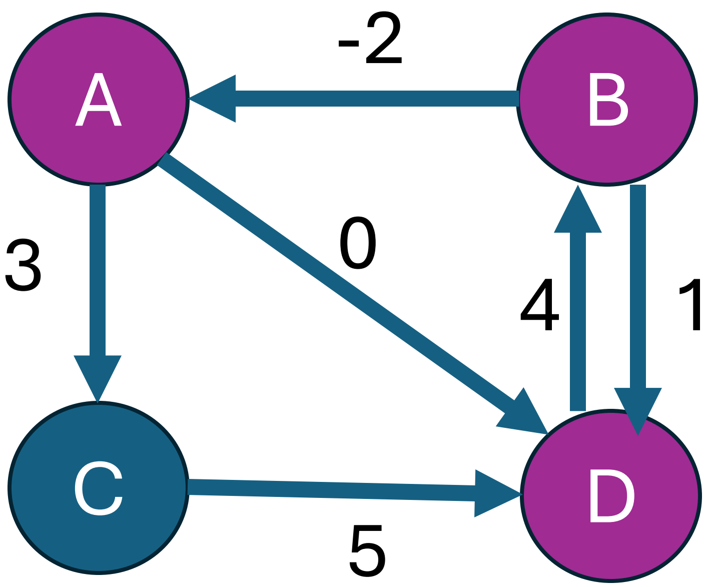
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

DD= 0 > DD = 0 + DD= 0

```
if dist[4][4] > dist[4][4] + dist[4][4]
    dist[4][4] = dist[4][4] + dist[4][4]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

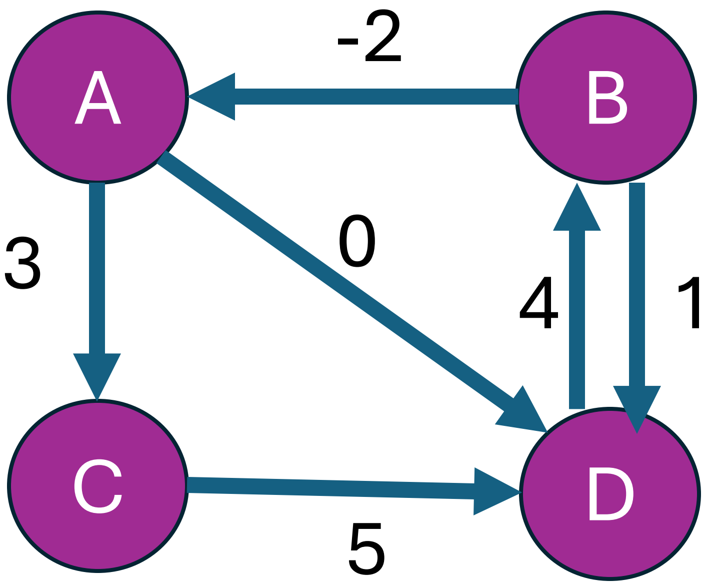
k = 1 2 3 4

i = 1 2 3 4

j = 1 2 3 4

DD= 0 > DD = 0 + DD= 0

```
if dist[4][4] > dist[4][4] + dist[4][4]
    dist[4][4] = dist[4][4] + dist[4][4]
```



to

from

	A	B	C	D
A	0	4	3	0
B	-2	0	1	-2
C	7	9	0	5
D	2	4	5	0

to

from

	A	B	C	D
A		D	A	A
B	B		A	A
C	D	D		C
D	B	D	B	

```
if dist[i][j] > dist[i][k] + dist[k][j]
    dist[i][j] = dist[i][k] + dist[k][j]
```

```
k = 1  2  3  4
i = 1  2  3  4
j = 1  2  3  4
```

```
       DD= 0         >      DD = 0     +    DD= 0
if dist[4][4] > dist[4][4] + dist[4][4]
    dist[4][4] = dist[4][4] + dist[4][4]
```

Johnson’s Algorithm

Johnson’s Algorithm

```
Johnson(G)
create G` where G`.V = G.V + {s}
G`.E = G.E + ((s, u) for u in G.V),
and weight(s, u) = 0 for u in G.V

if Bellman-Ford(s) == False
    return "The input graph has a negative weight cycle"
else:
    for vertex v in G`.V:
        h(v) = distance(s, v) computed by Bellman-Ford
    for edge (u, v) in G`.E:
        weight`(u, v) = weight(u, v) + h(u) - h(v)

D = new matrix of distances initialized to infinity
for vertex u in G.V:
    run Dijkstra(G, weight`, u) to compute distance`(u, v) for all v in G.V
    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

Johnson’s Algorithm

Johnson(G)

```
create G` where G`.V = G.V + {s}
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    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

. Adding a new vertex, *ss*, to the graph and connecting it to all other vertices with a zero weight edge

Johnson’s Algorithm

```
Johnson(G)
create G` where G`.V = G.V + {s}
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    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

Reweighting is a process by which edge weight is changed to satisfy two properties.

1. For all pairs of vertices u, v in the graph, if a certain path is the shortest path between those vertices before reweighting, it must also be the shortest path between those vertices after reweighting.
2. For all edges, (u, v), in the graph, weight(u, v) must be non-negative.

Johnson’s Algorithm

```
Johnson(G)
create G` where G`.V = G.V + {s}
G`.E = G.E + ((s, u) for u in G.V),
and weight(s, u) = 0 for u in G.V

if Bellman-Ford(s) == False
    return "The input graph has a negative weight cycle"
else:
    for vertex v in G`.V:
        h(v) = distance(s, v) computed by Bellman-Ford
    for edge (u, v) in G`.E:
        weight`(u, v) = weight(u, v) + h(u) - h(v)

D = new matrix of distances initialized to infinity
for vertex u in G.V:
    run Dijkstra(G, weight`, u) to compute distance`(u, v) for all v in G.V
    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

Finally, Dijkstra's algorithm is run on all vertices to find the shortest path. This is possible because the weights have been transformed into non-negative weights.

Johnson’s Algorithm

```
Johnson(G)
create G` where G`.V = G.V + {s}
G`.E = G.E + ((s, u) for u in G.V),
and weight(s, u) = 0 for u in G.V

if Bellman-Ford(s) == False
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else:
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        weight`(u, v) = weight(u, v) + h(u) - h(v)

D = new matrix of distances initialized to infinity
for vertex u in G.V:
    run Dijkstra(G, weight`, u) to compute distance`(u, v) for all v in G.V
    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

O(V)

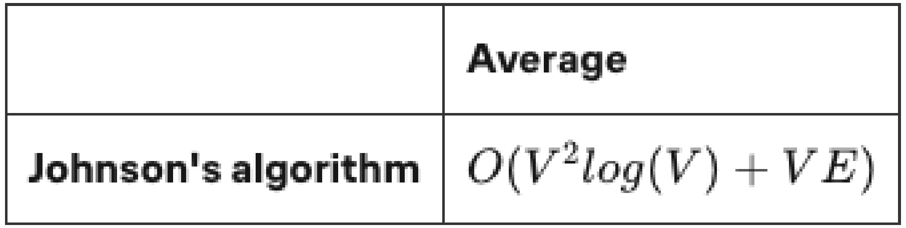
Johnson’s Algorithm

```
Johnson(G)
create G` where G`.V = G.V + {s}                                O(V)
G`.E = G.E + ((s, u) for u in G.V),
and weight(s, u) = 0 for u in G.V

if Bellman-Ford(s) == False
    return "The input graph has a negative weight cycle"       O(VE)
else:
    for vertex v in G`.V:
        h(v) = distance(s, v) computed by Bellman-Ford
    for edge (u, v) in G`.E:
        weight`(u, v) = weight(u, v) + h(u) - h(v)

D = new matrix of distances initialized to infinity
for vertex u in G.V:
    run Dijkstra(G, weight`, u) to compute distance`(u, v) for all v in G.V
    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

Johnson’s Algorithm



	Average
Johnson's algorithm	$O(V^2log(V)+VE)$

```
Johnson(G)
create G` where G`.V = G.V + {s}
G`.E = G.E + ((s, u) for u in G.V),
and weight(s, u) = 0 for u in G.V
```

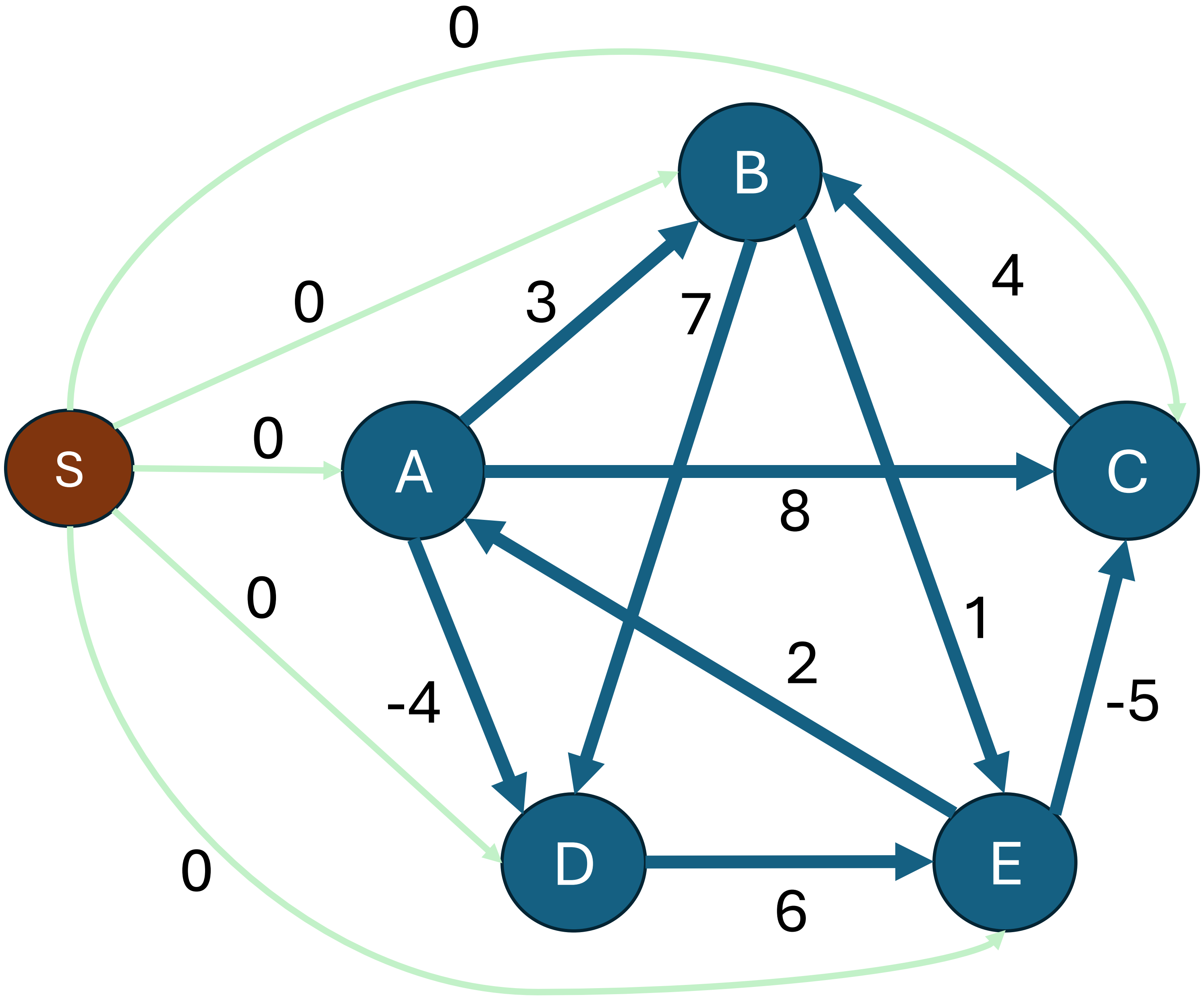
O(V)

```
if Bellman-Ford(s) == False
    return "The input graph has a negative weight cycle"
else:
    for vertex v in G`.V:
        h(v) = distance(s, v) computed by Bellman-Ford
    for edge (u, v) in G`.E:
        weight`(u, v) = weight(u, v) + h(u) - h(v)
```

O(VE)

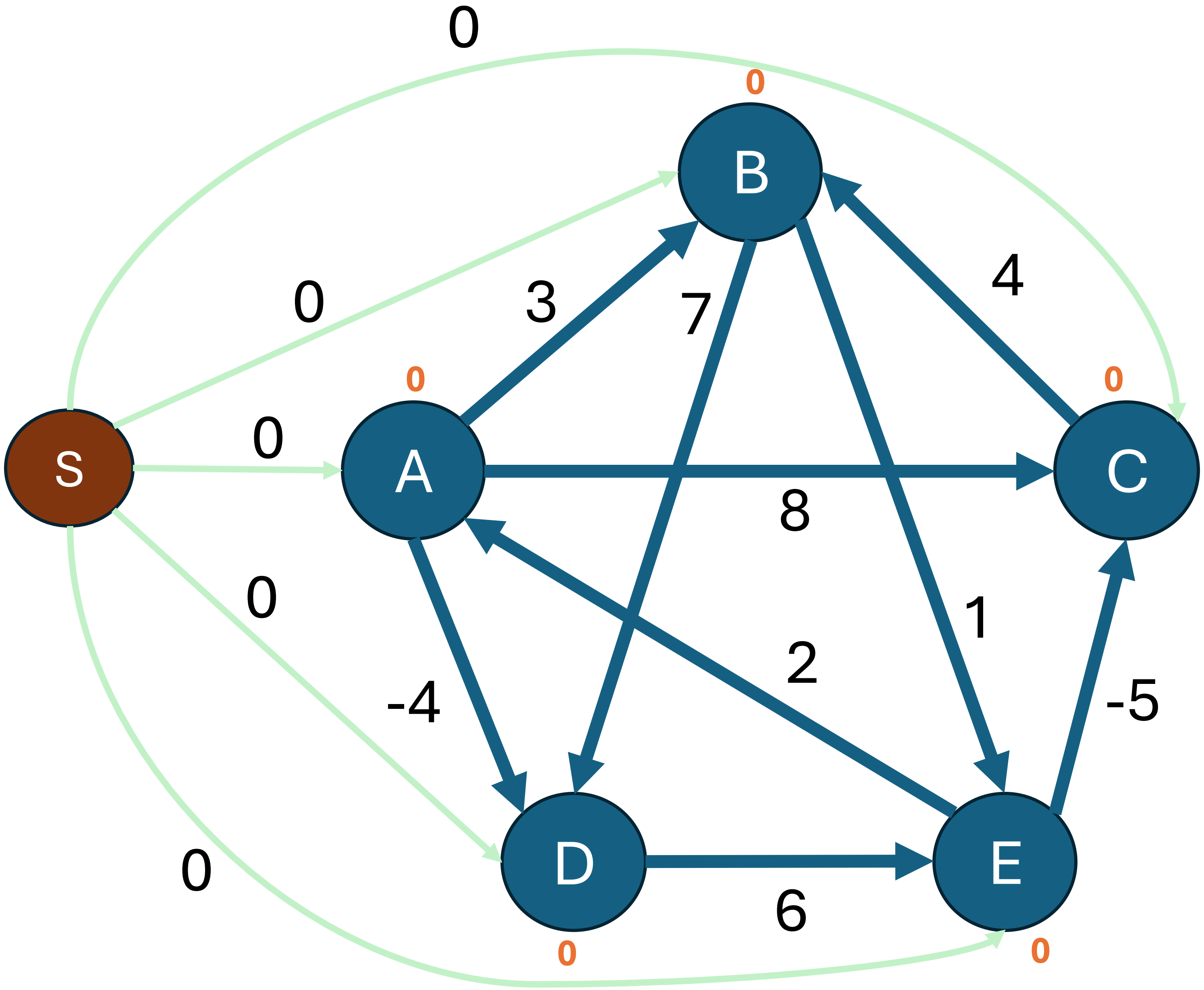
```
D = new matrix of distances initialized to infinity
for vertex u in G.V:
    run Dijkstra(G, weight`, u) to compute distance`(u, v) for all v in G.V
    for each vertex v in G.V:
            D_(u, v) = distance`(u, v) + h(v) - h(u) return D
```

O(V)
O((V+E)LogV)



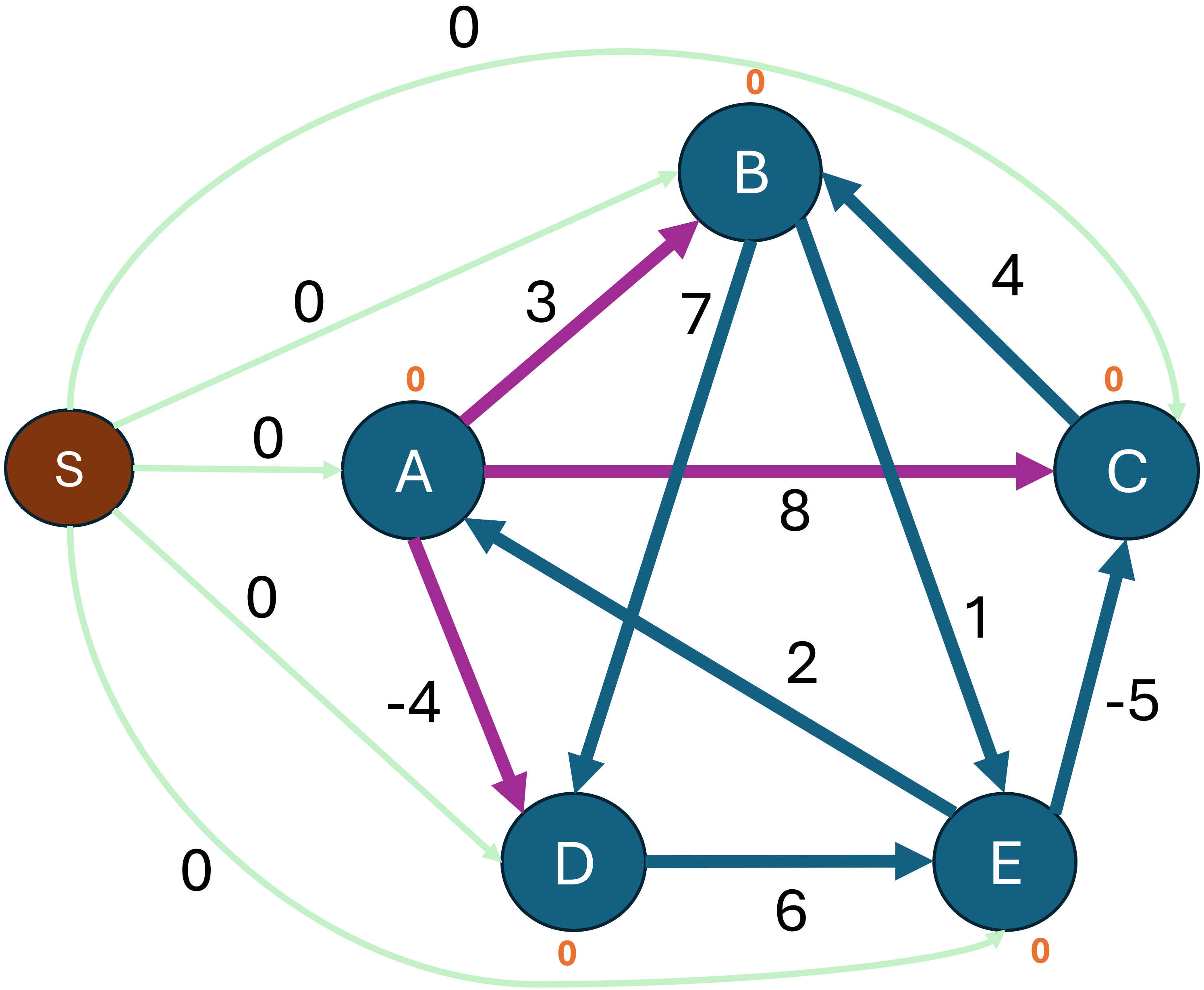
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	0	S
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



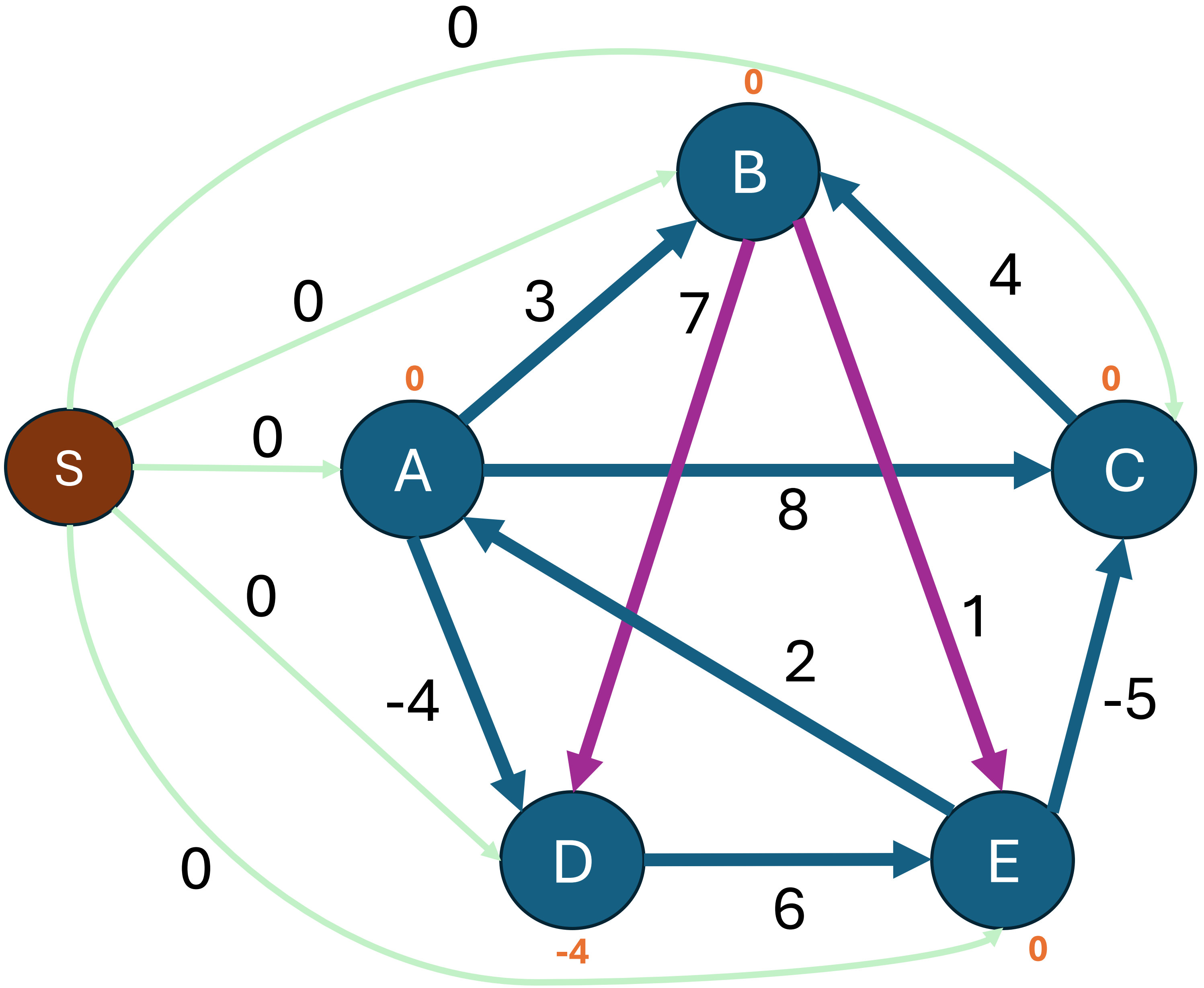
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	0	S
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



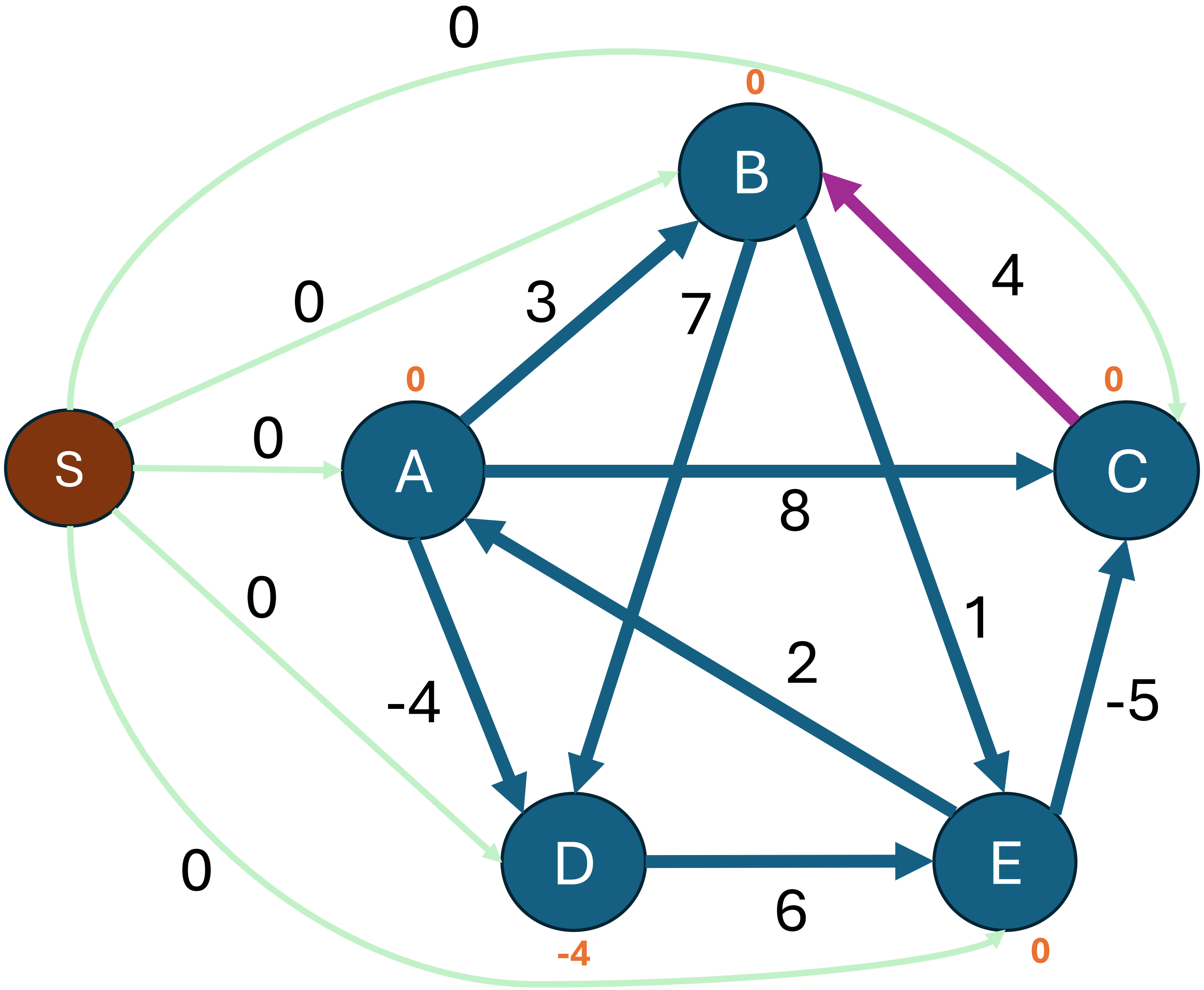
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



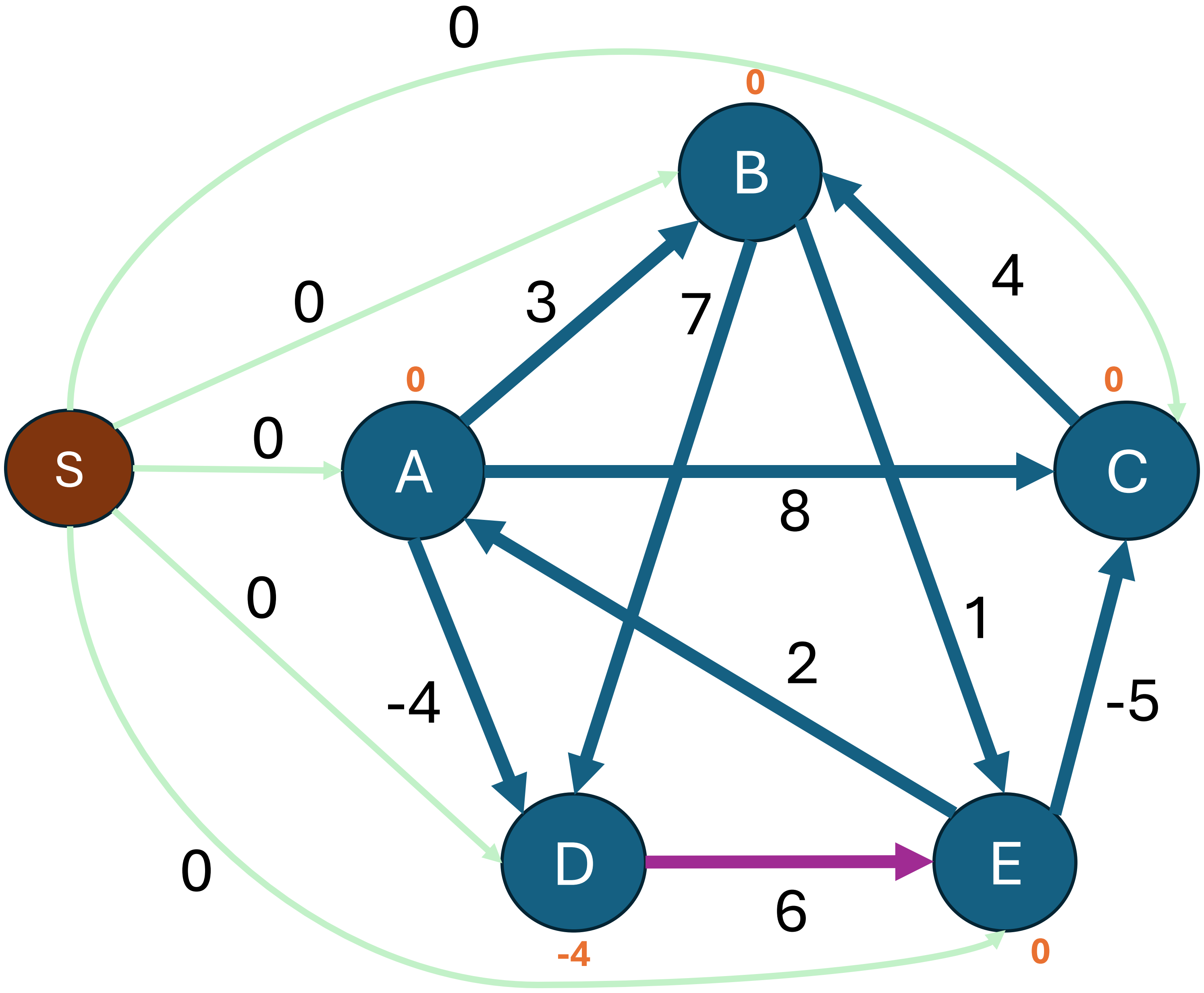
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



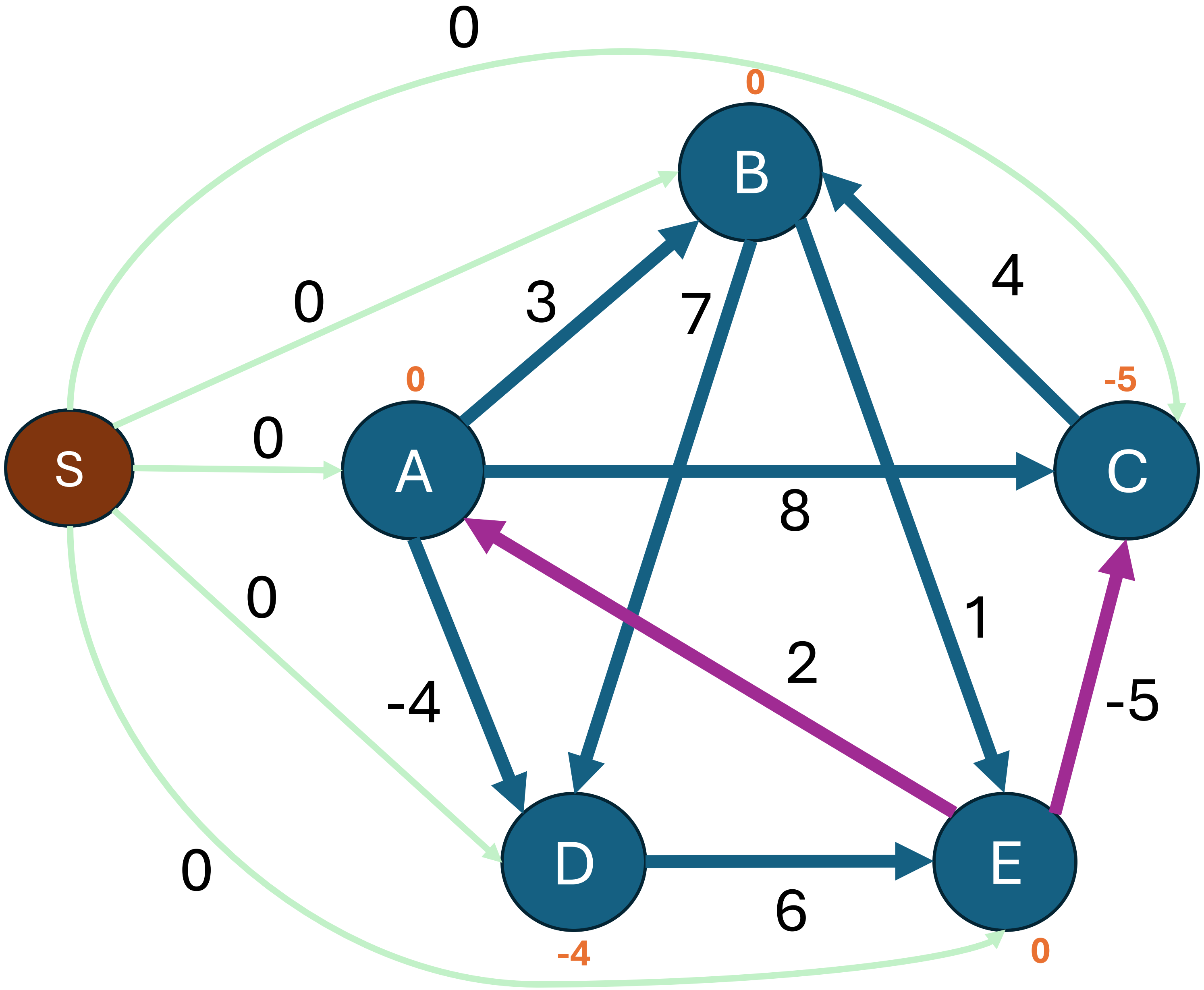
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



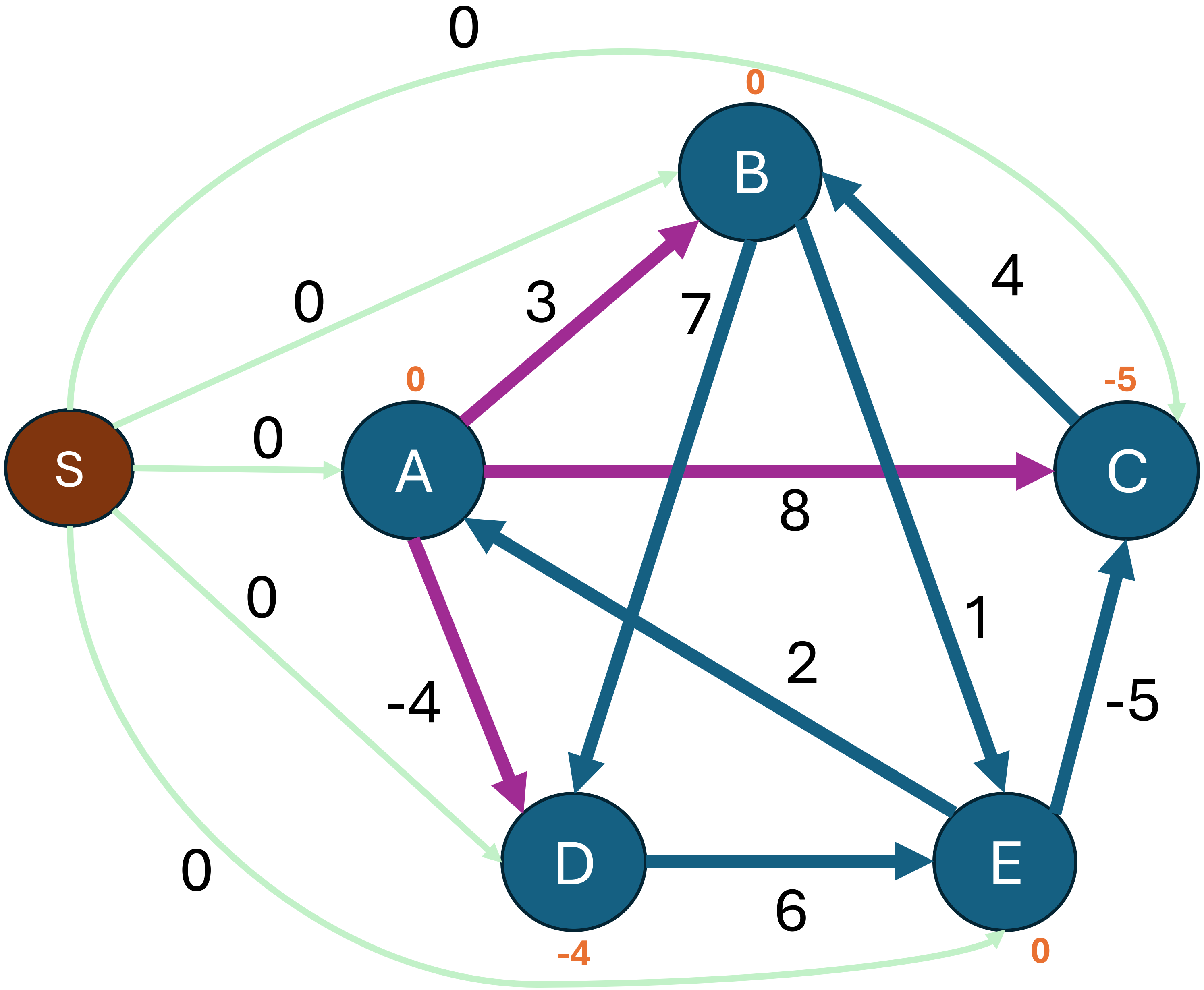
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	0	S
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



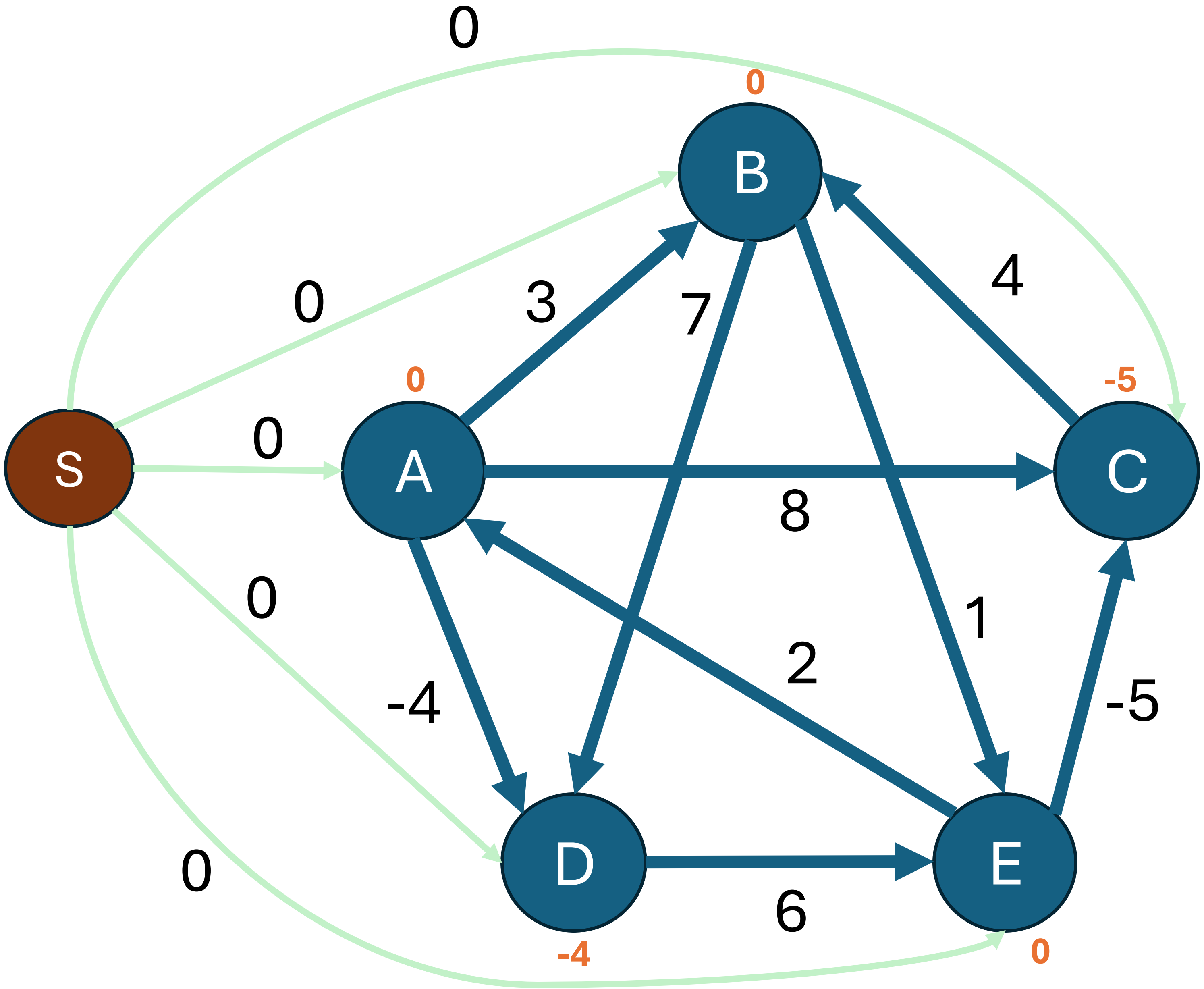
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



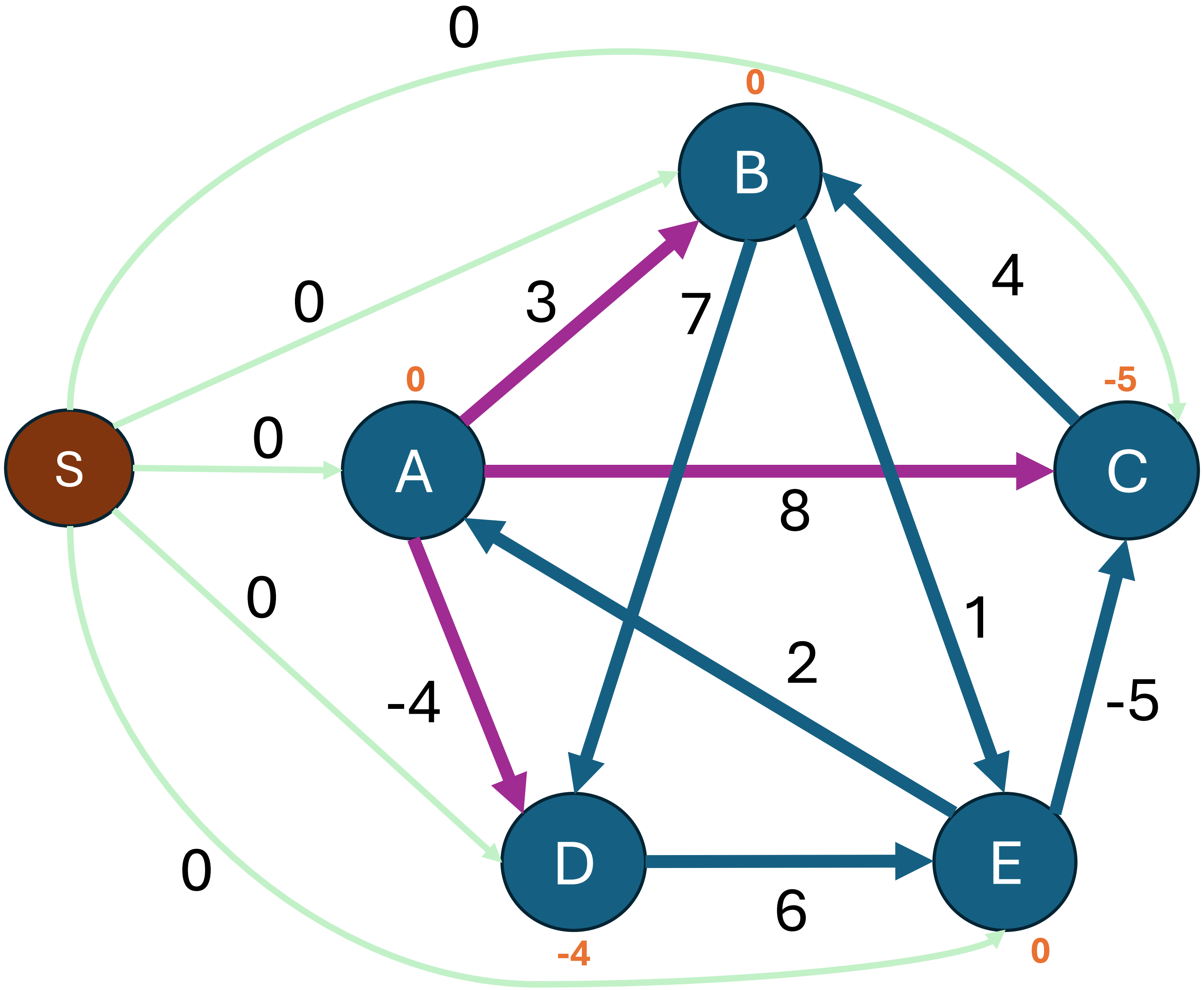
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



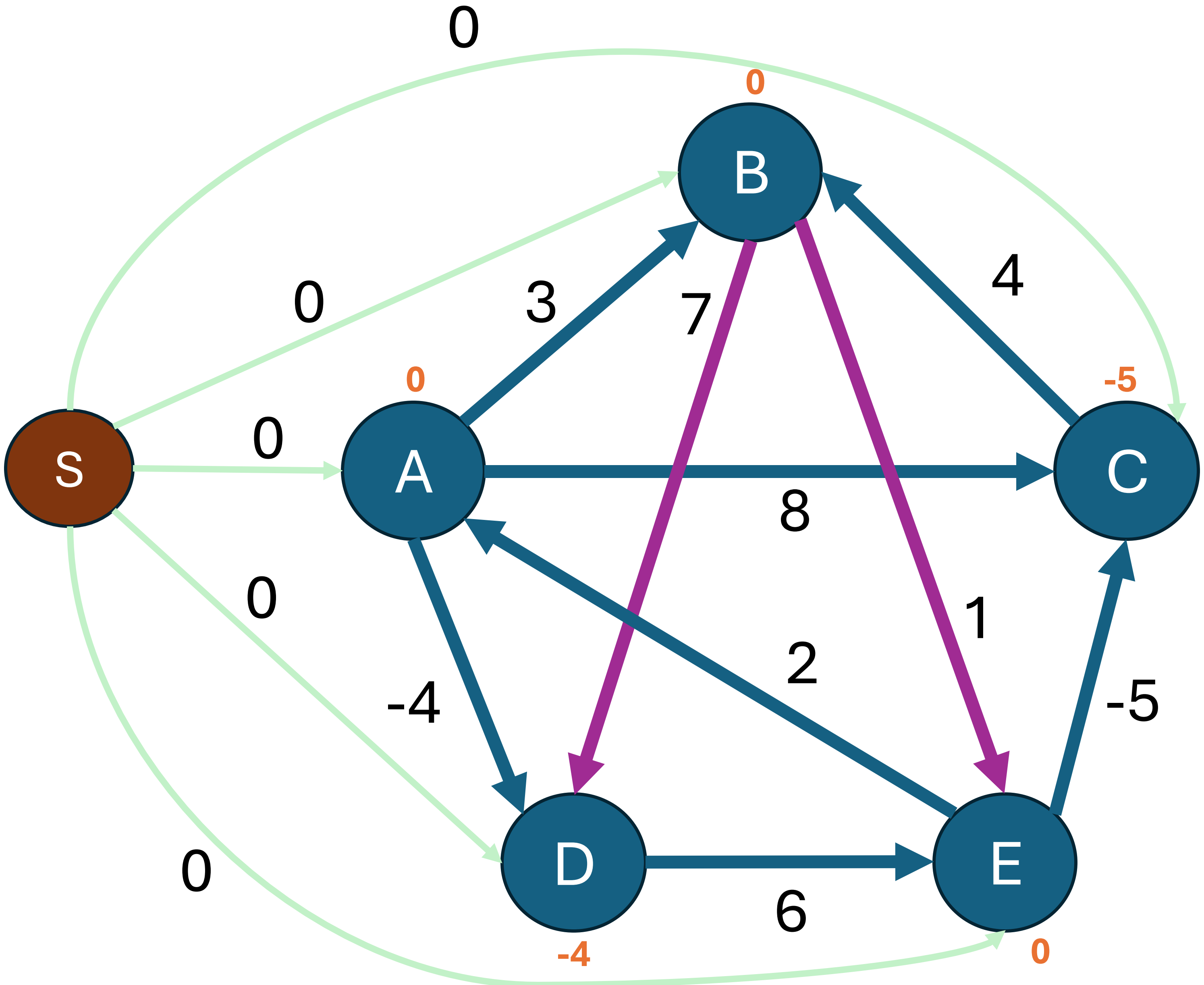
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



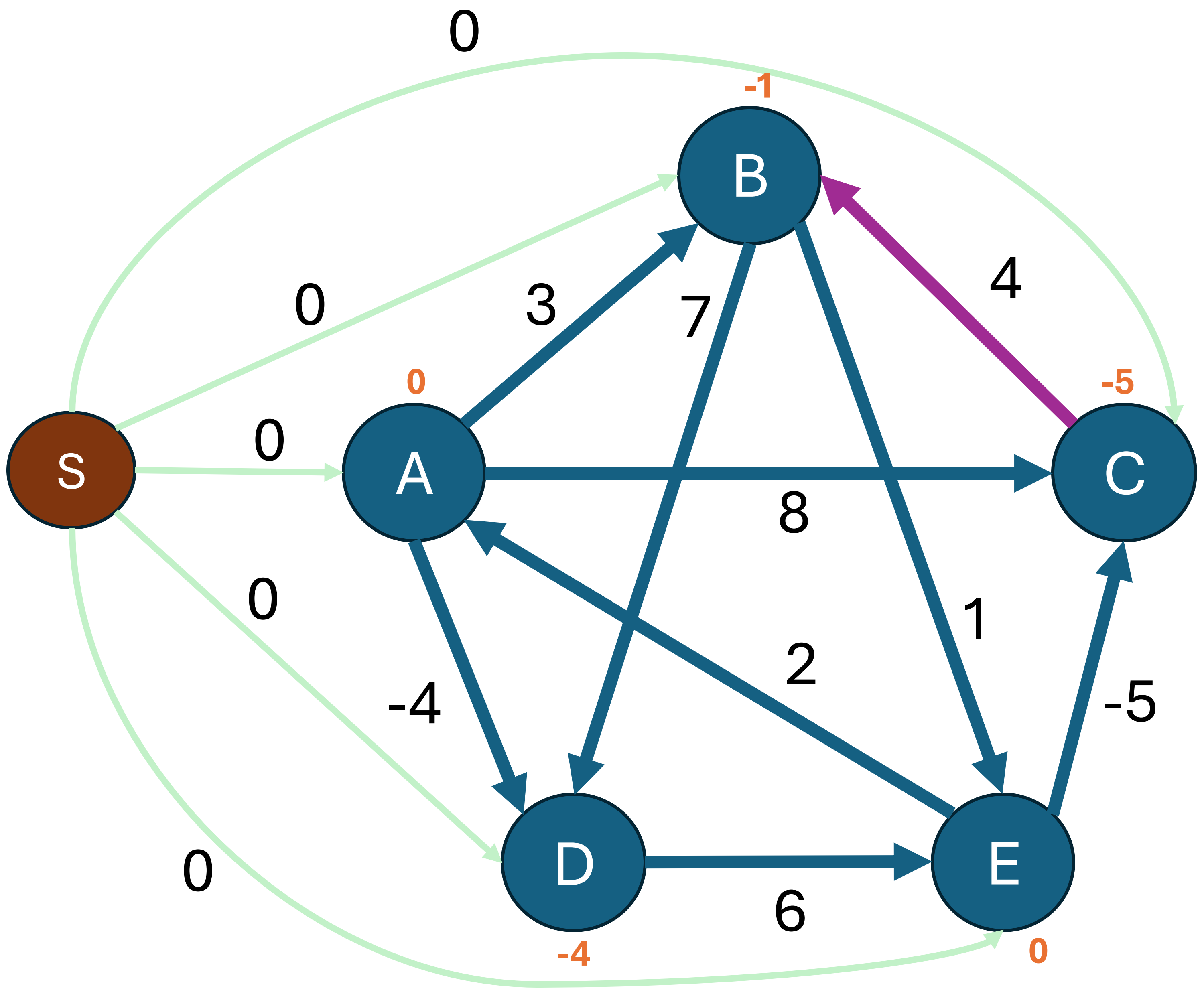
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



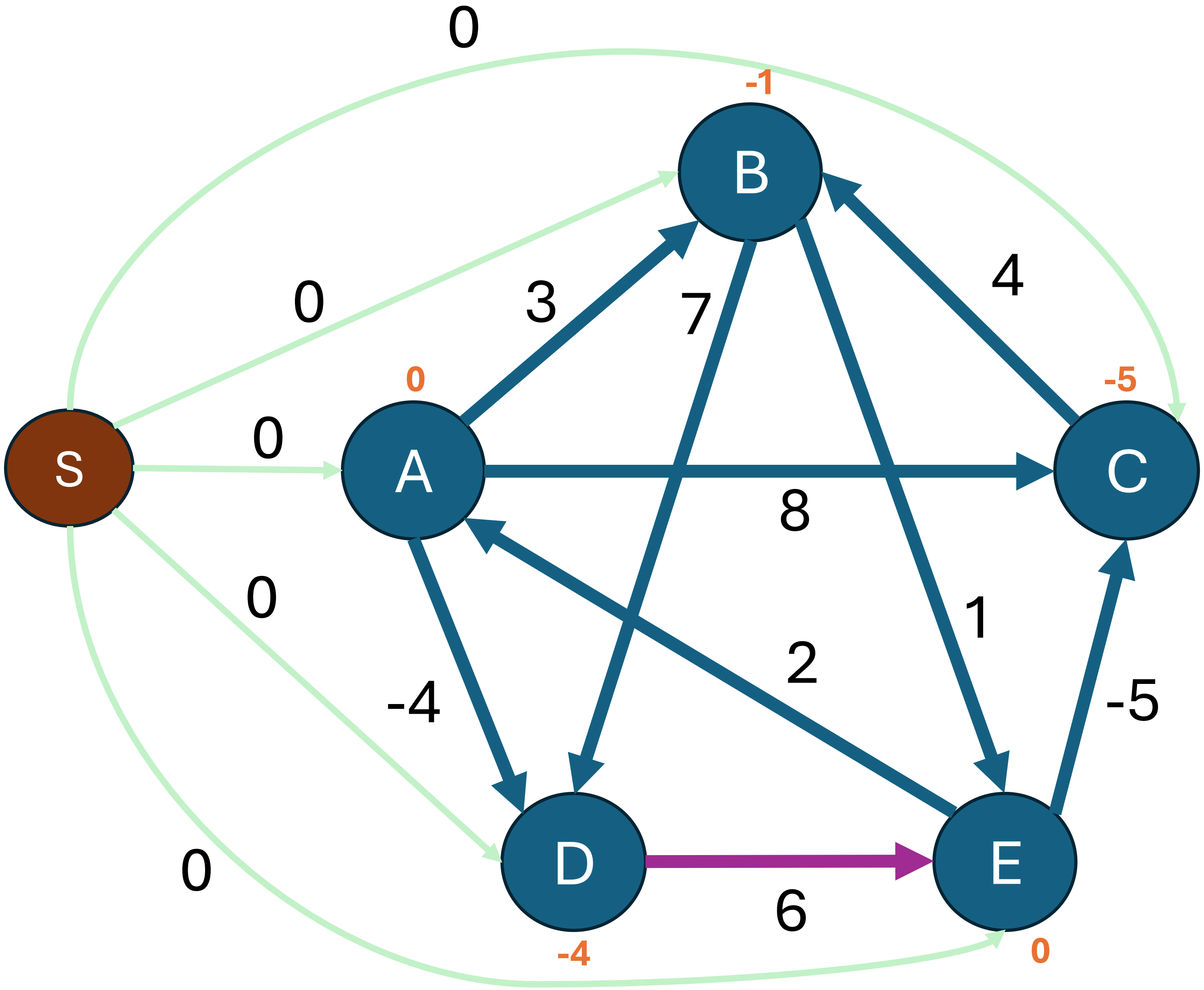
	Cost	Prev
S	0	-
A	0	S
B	0	S
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



	Cost	Prev
S	0	-
A	0	S
B	-1	C
C	-5	E
D	-4	A
E	0	S

SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



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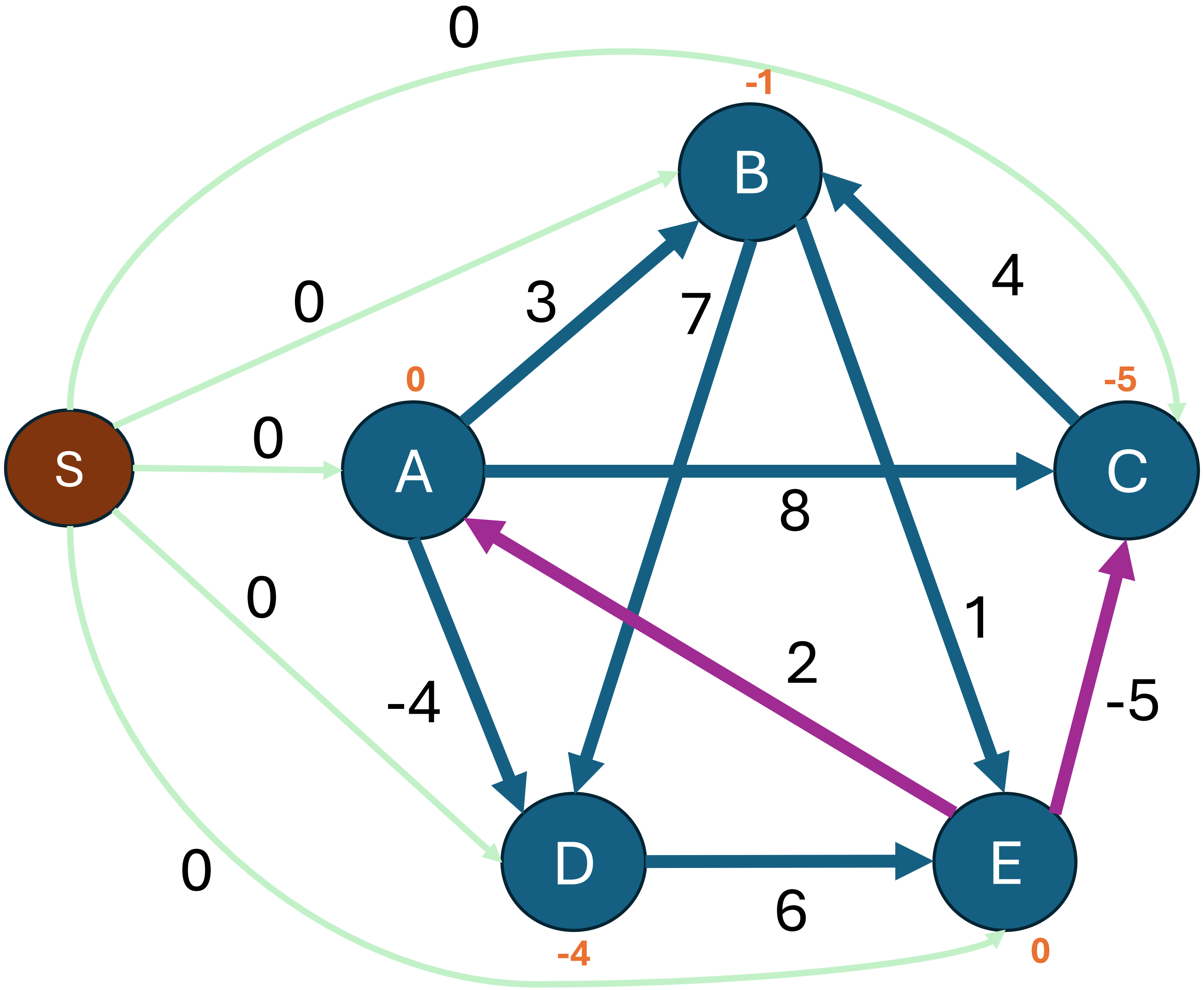
SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



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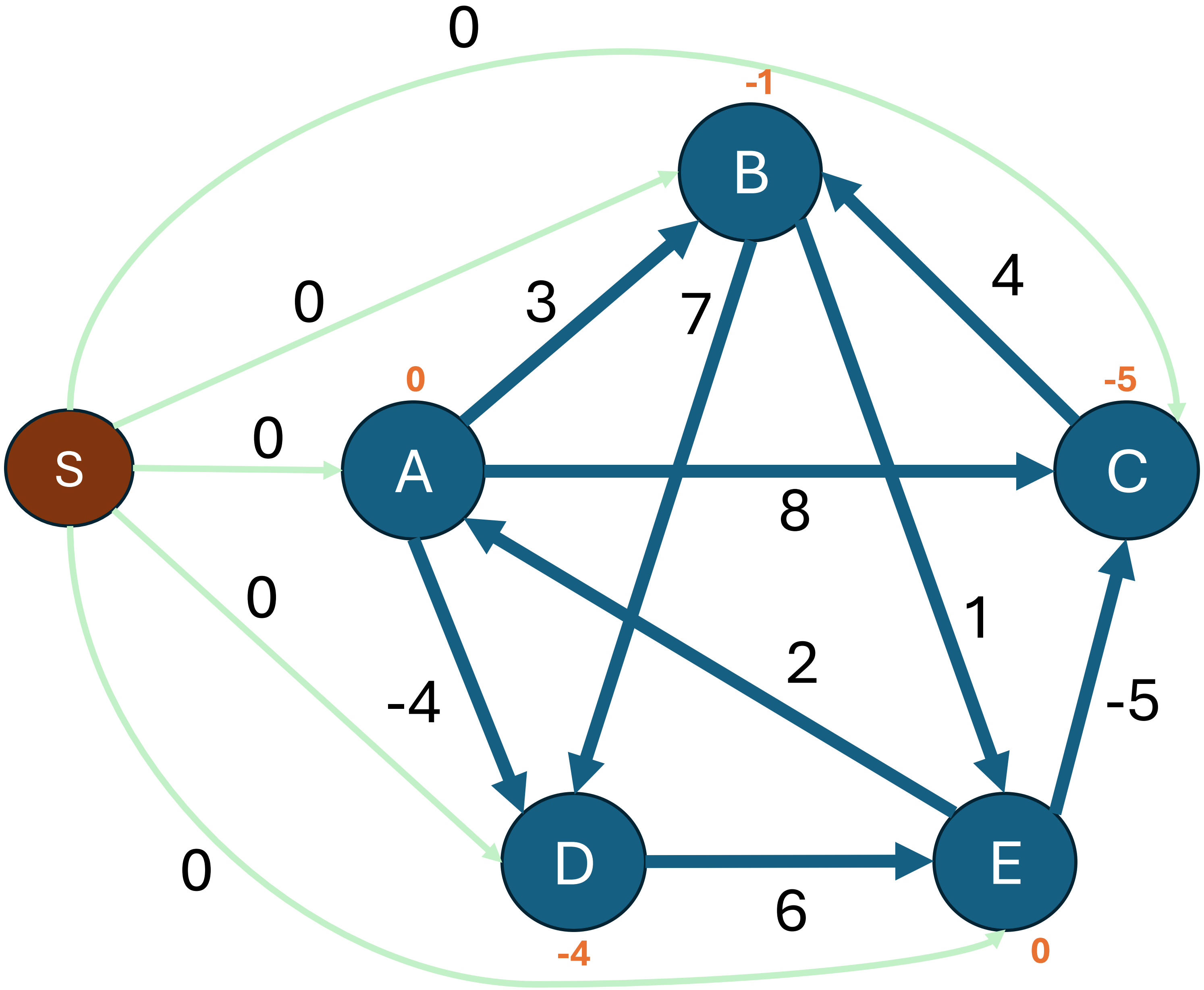

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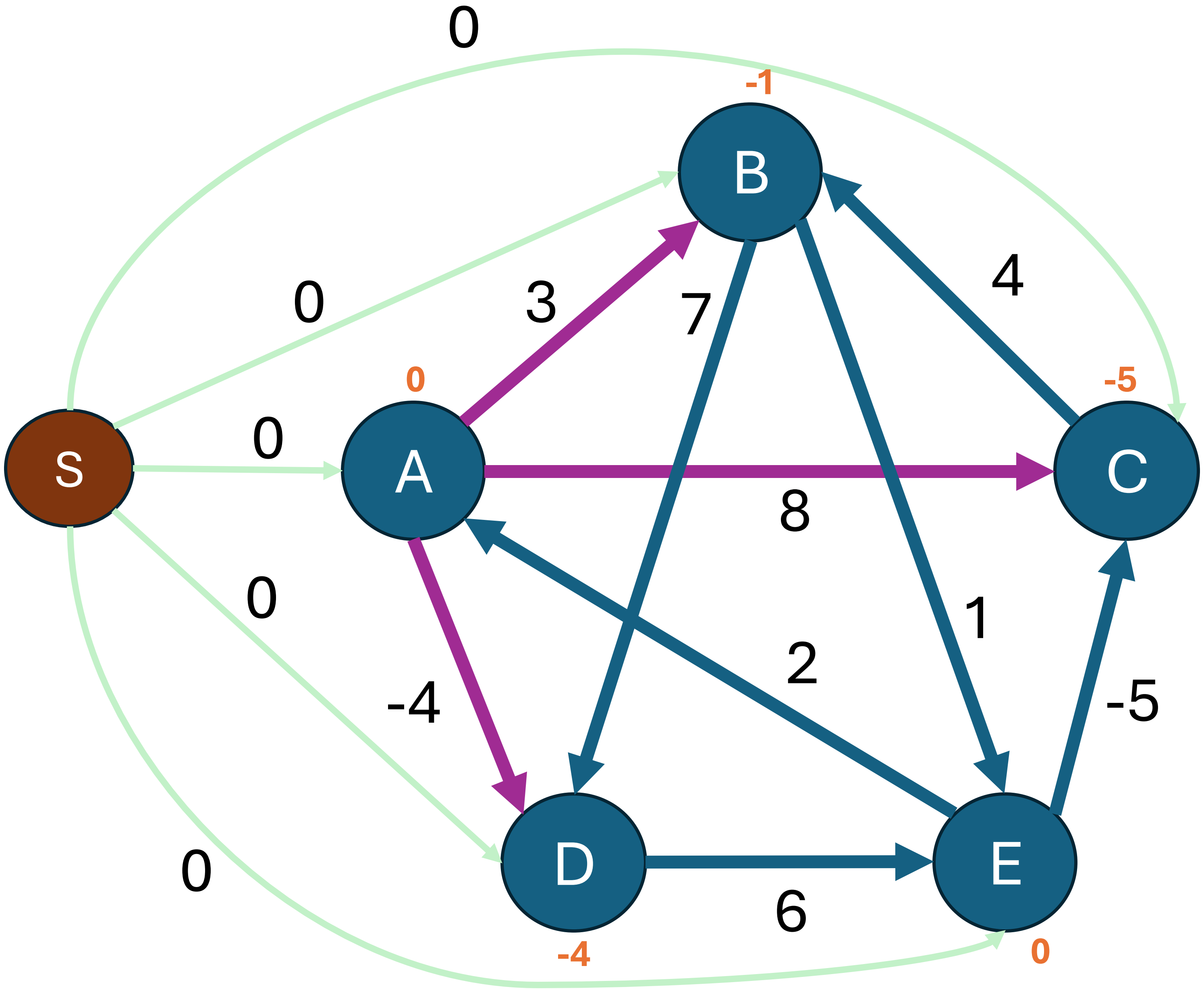

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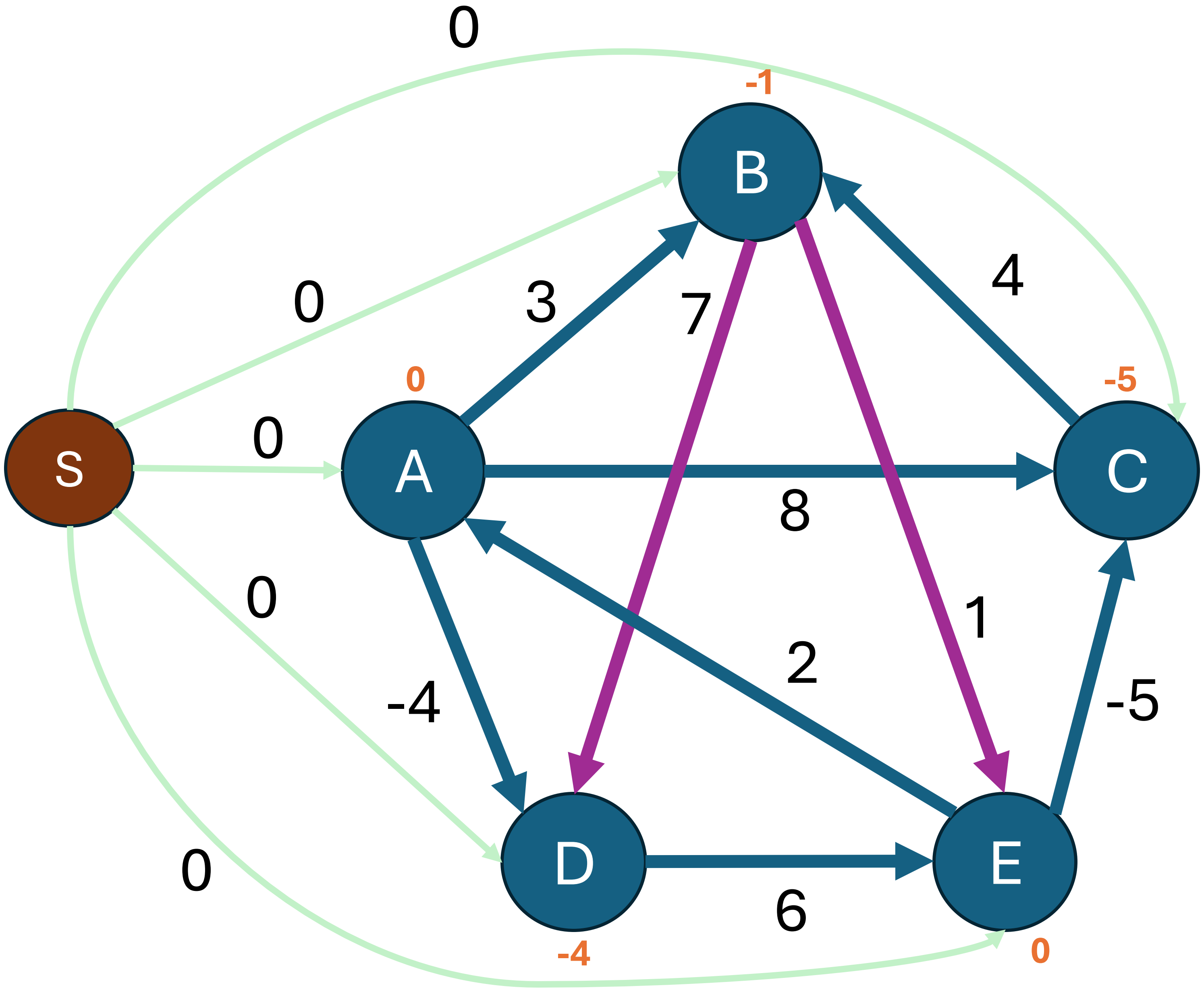

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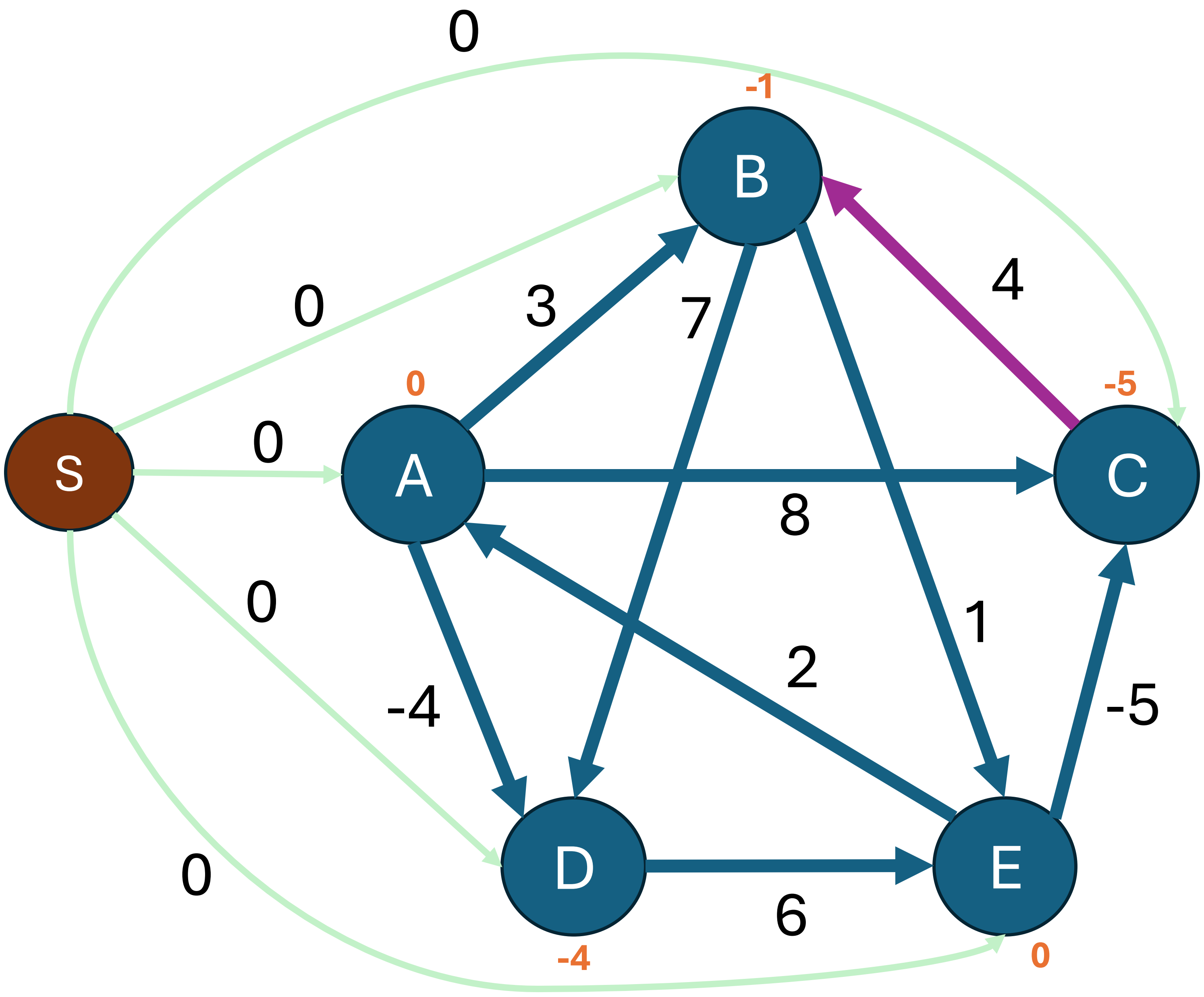

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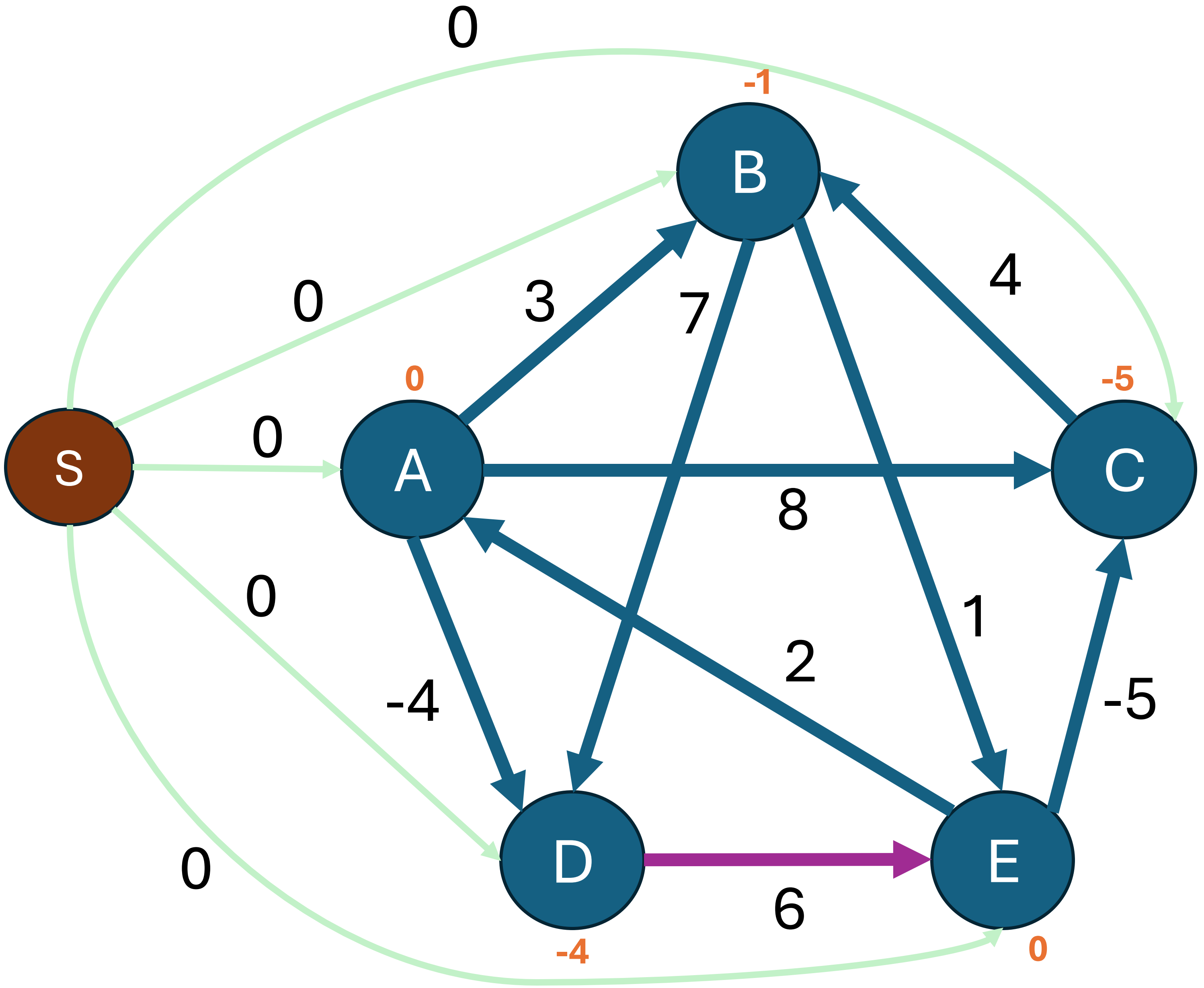

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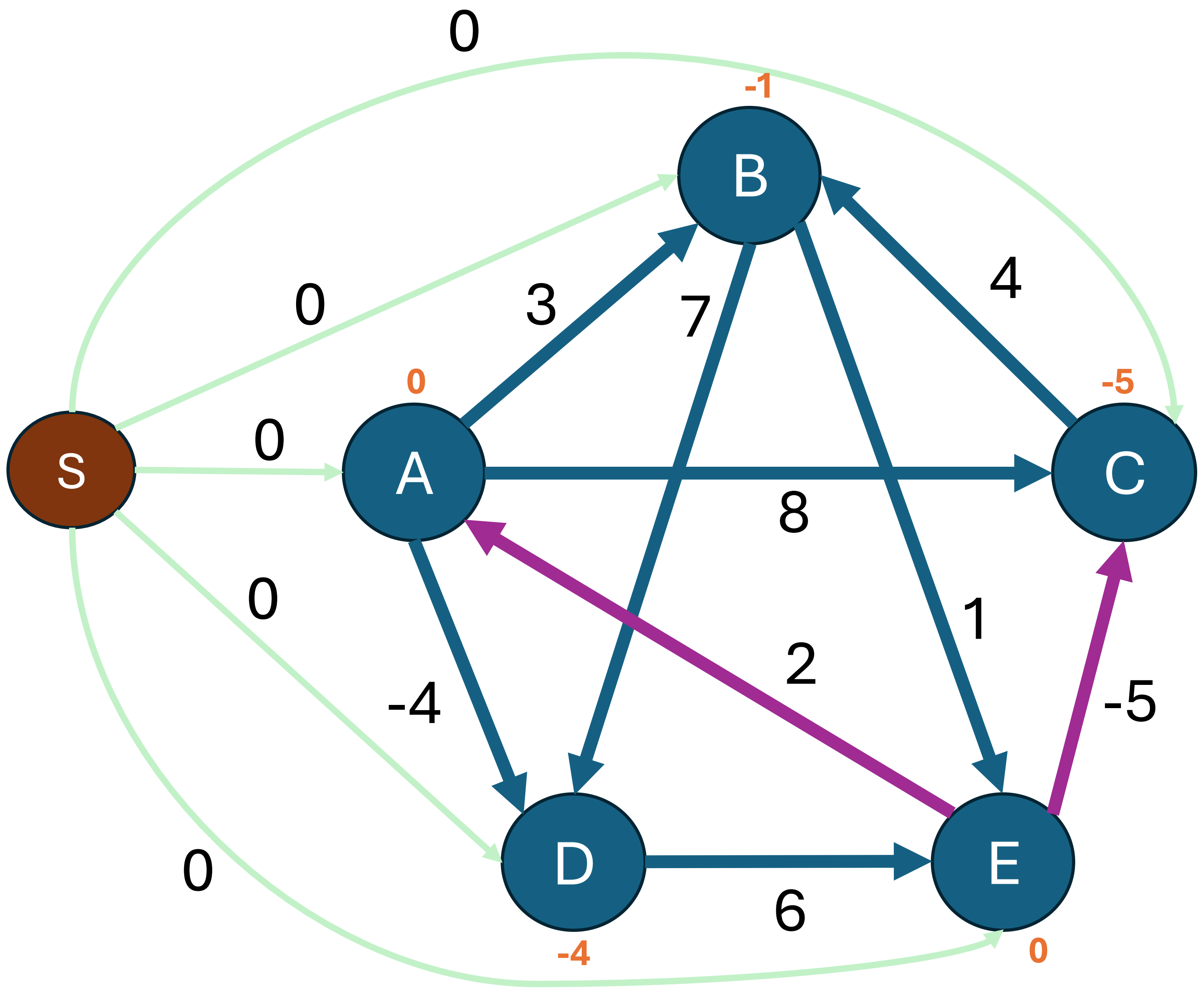

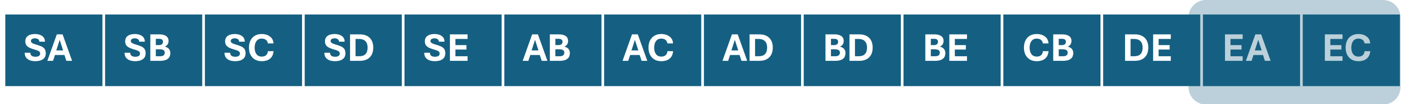

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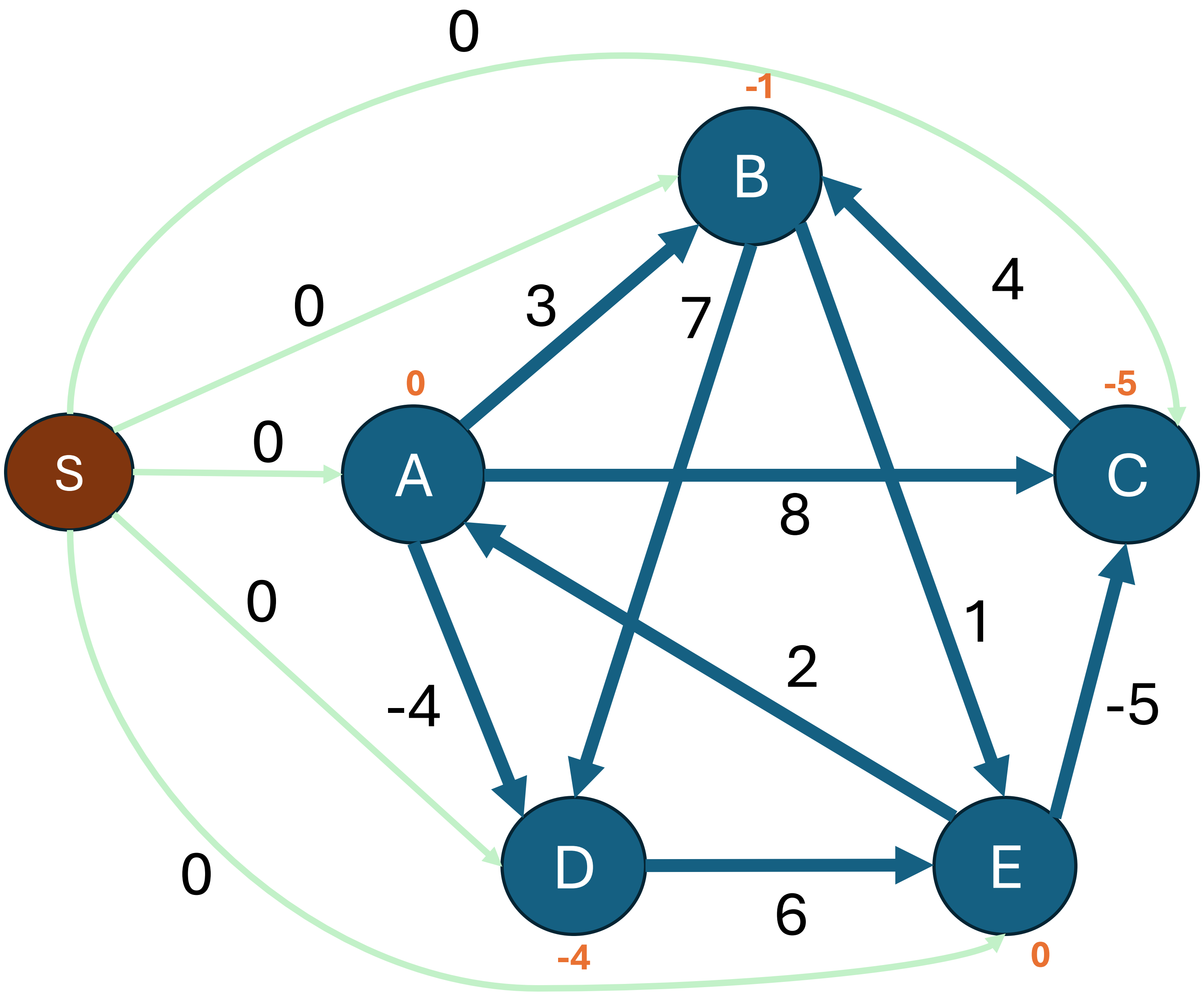

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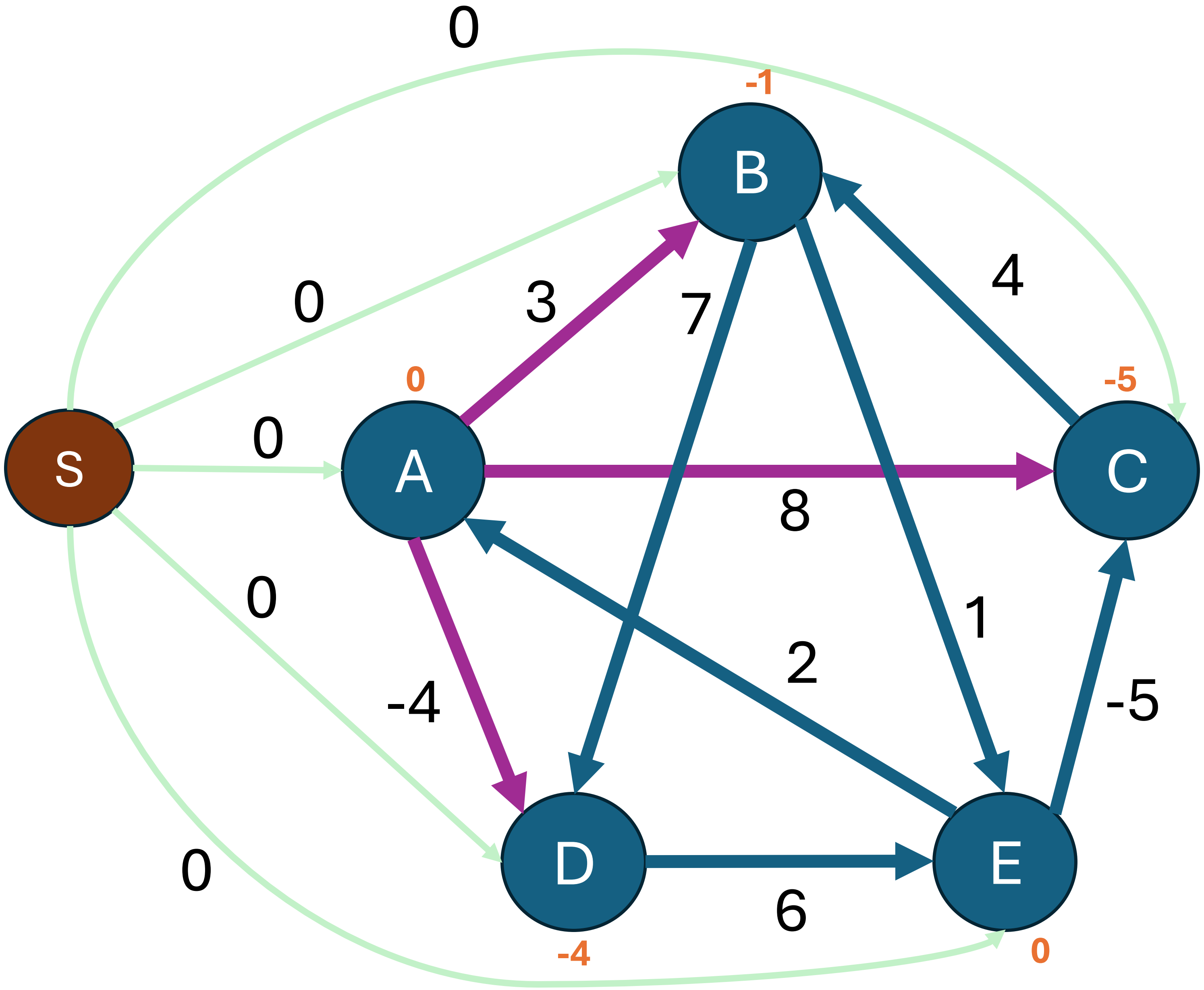

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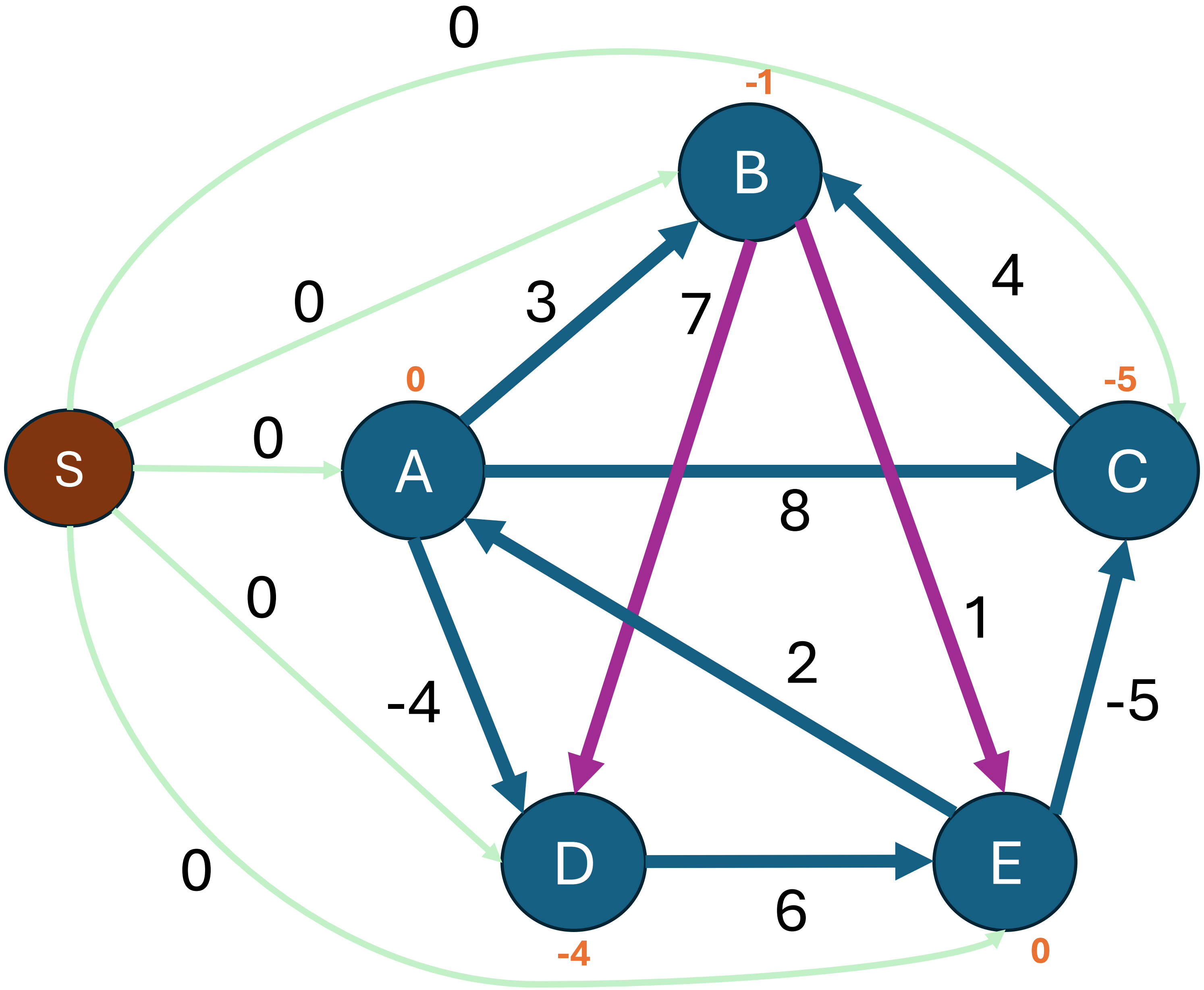

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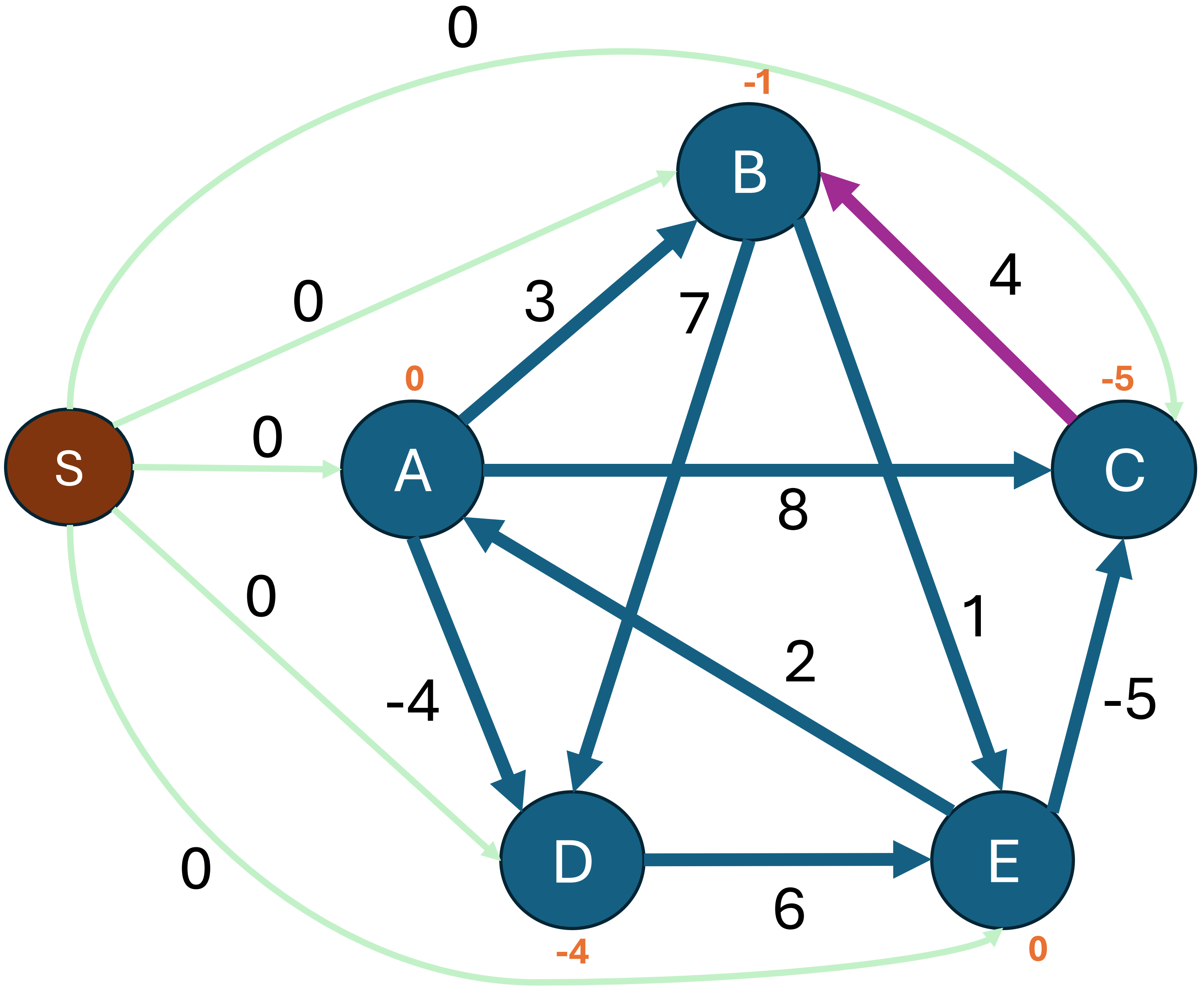

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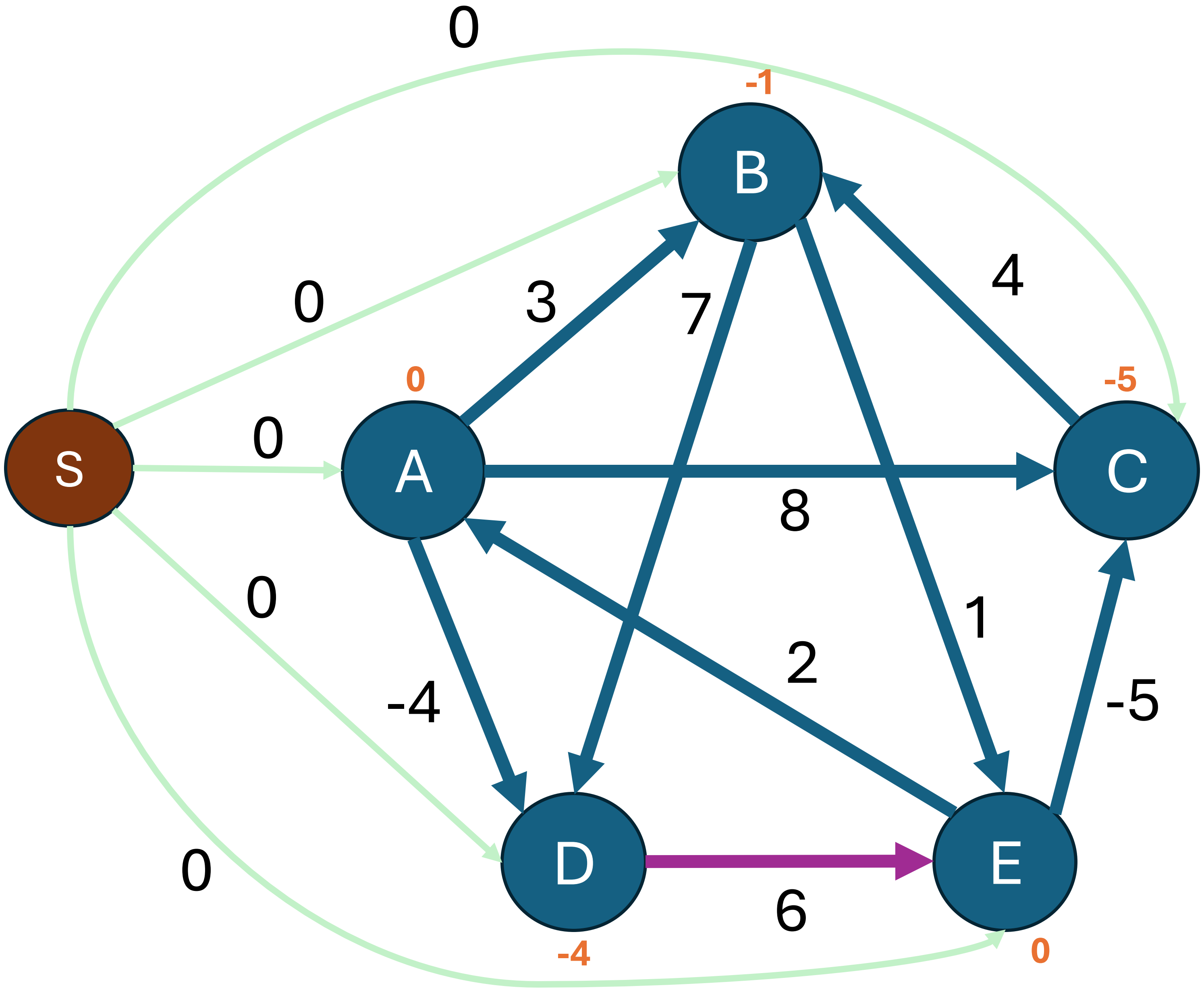

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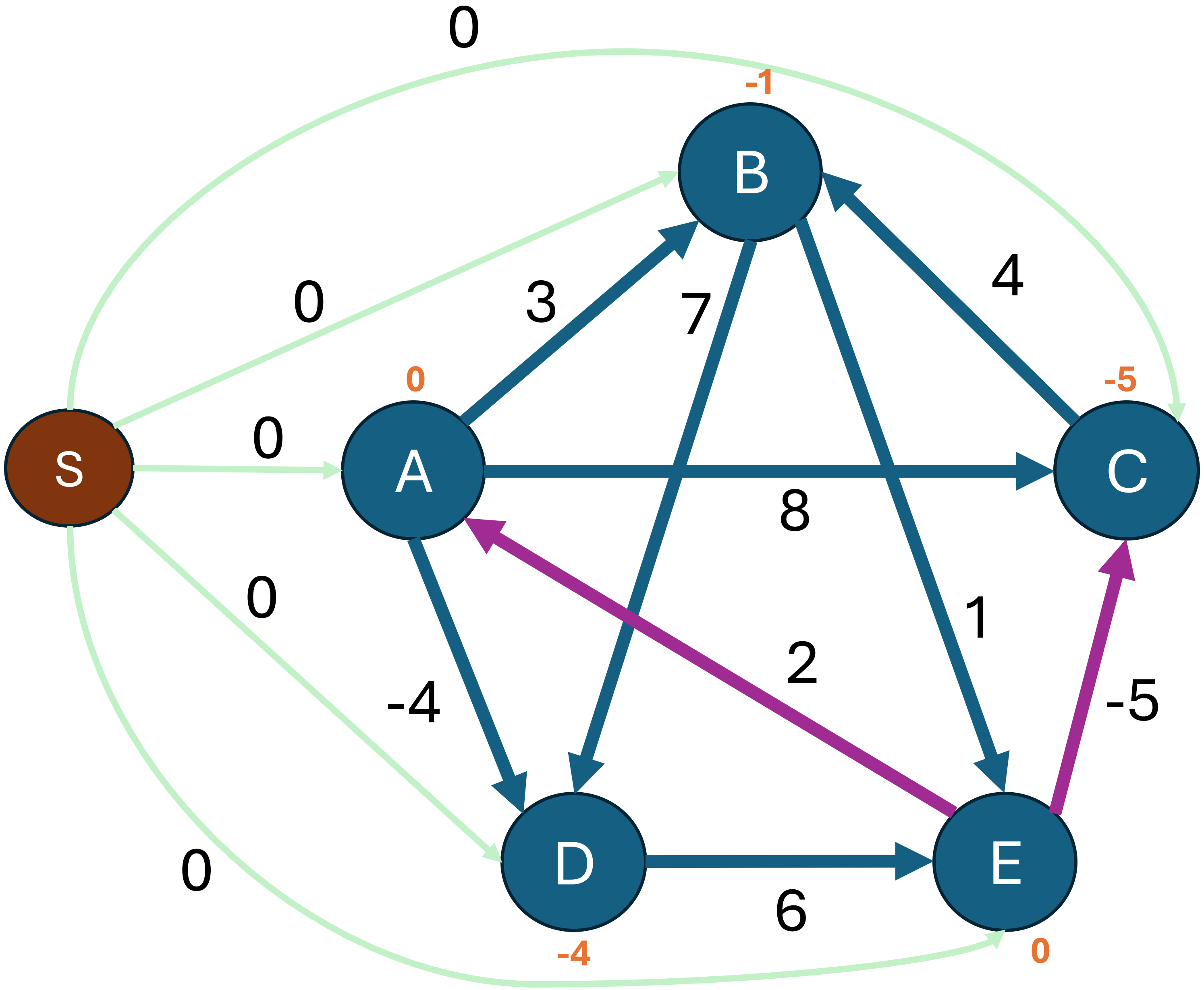

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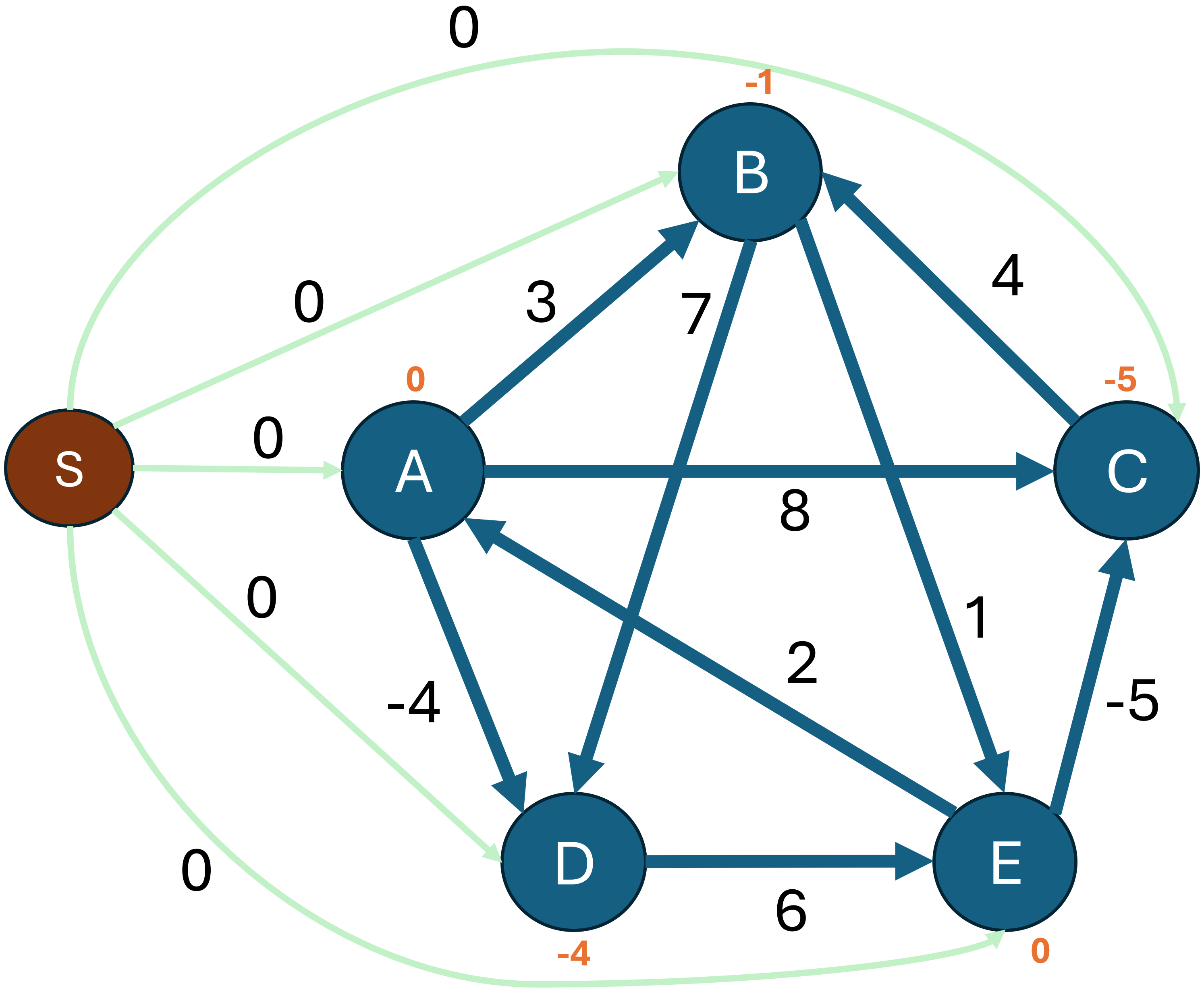

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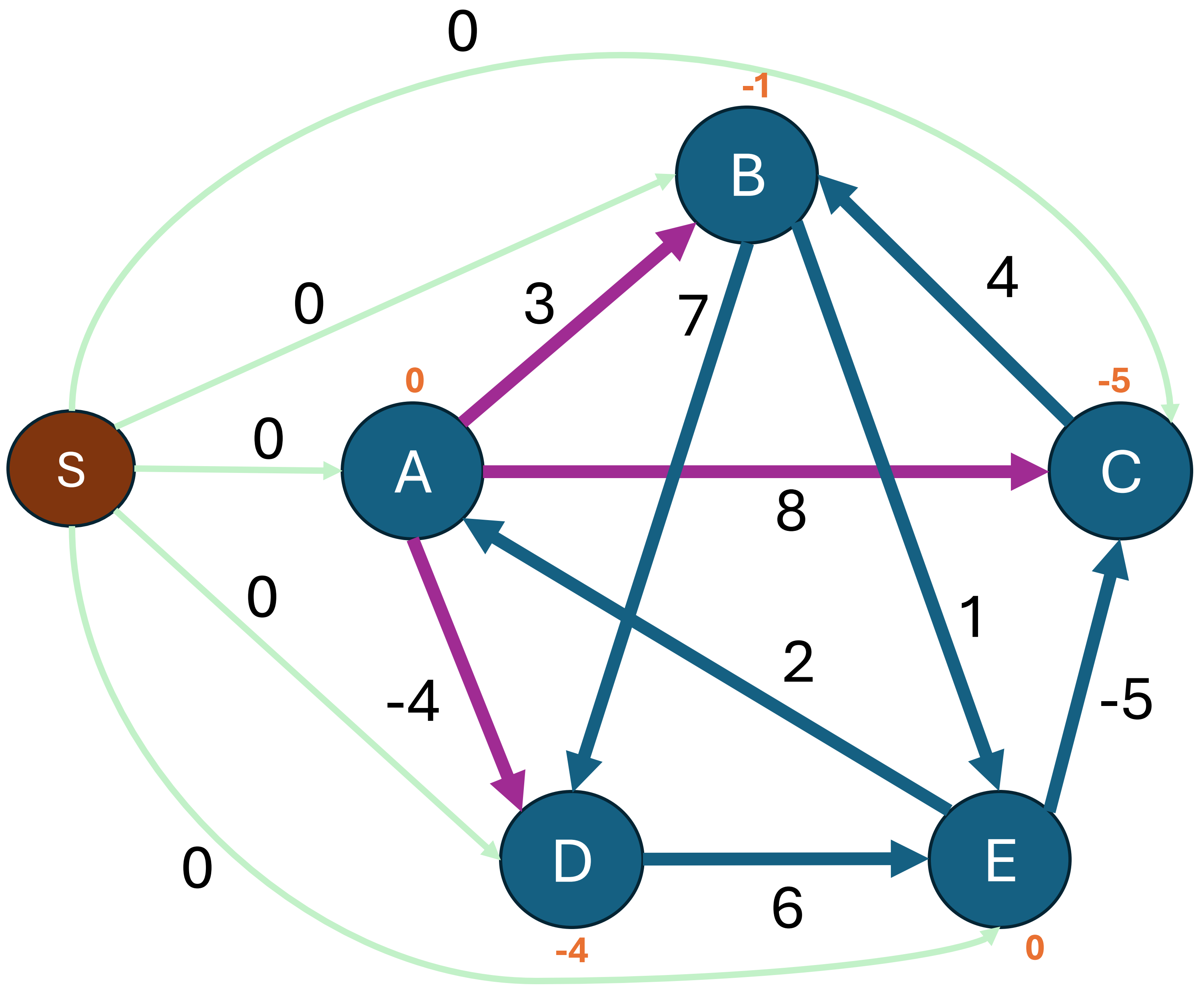

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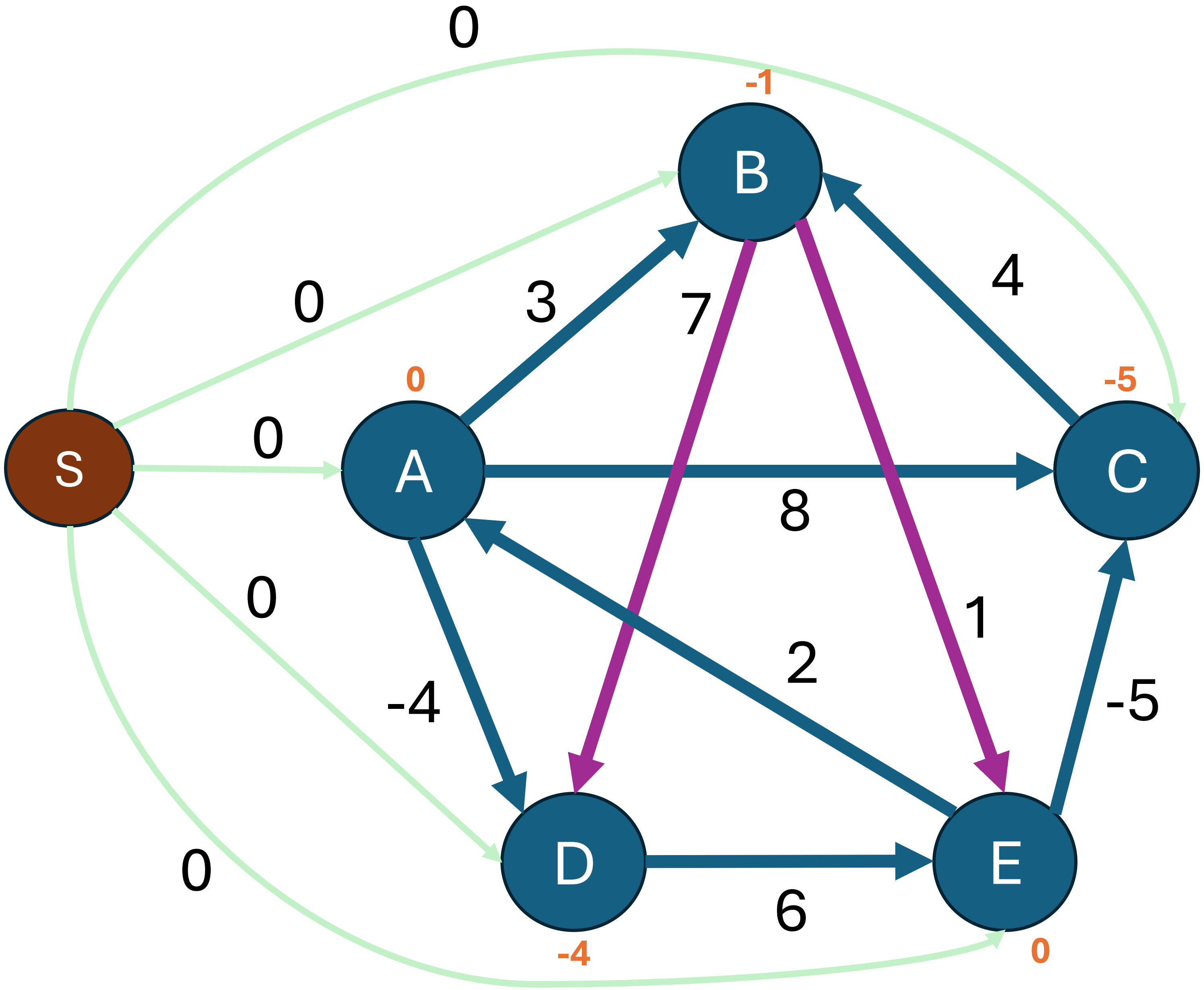

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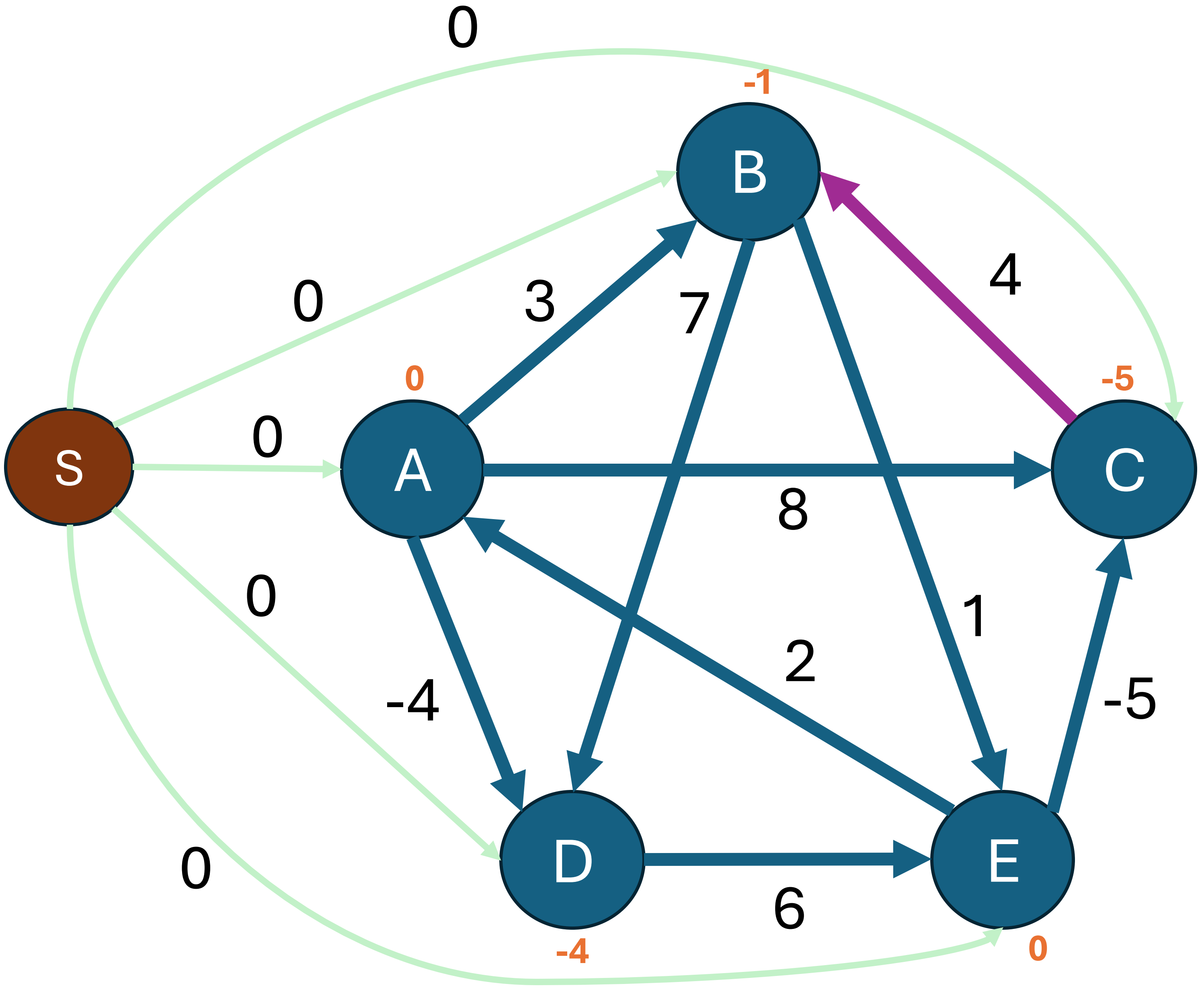

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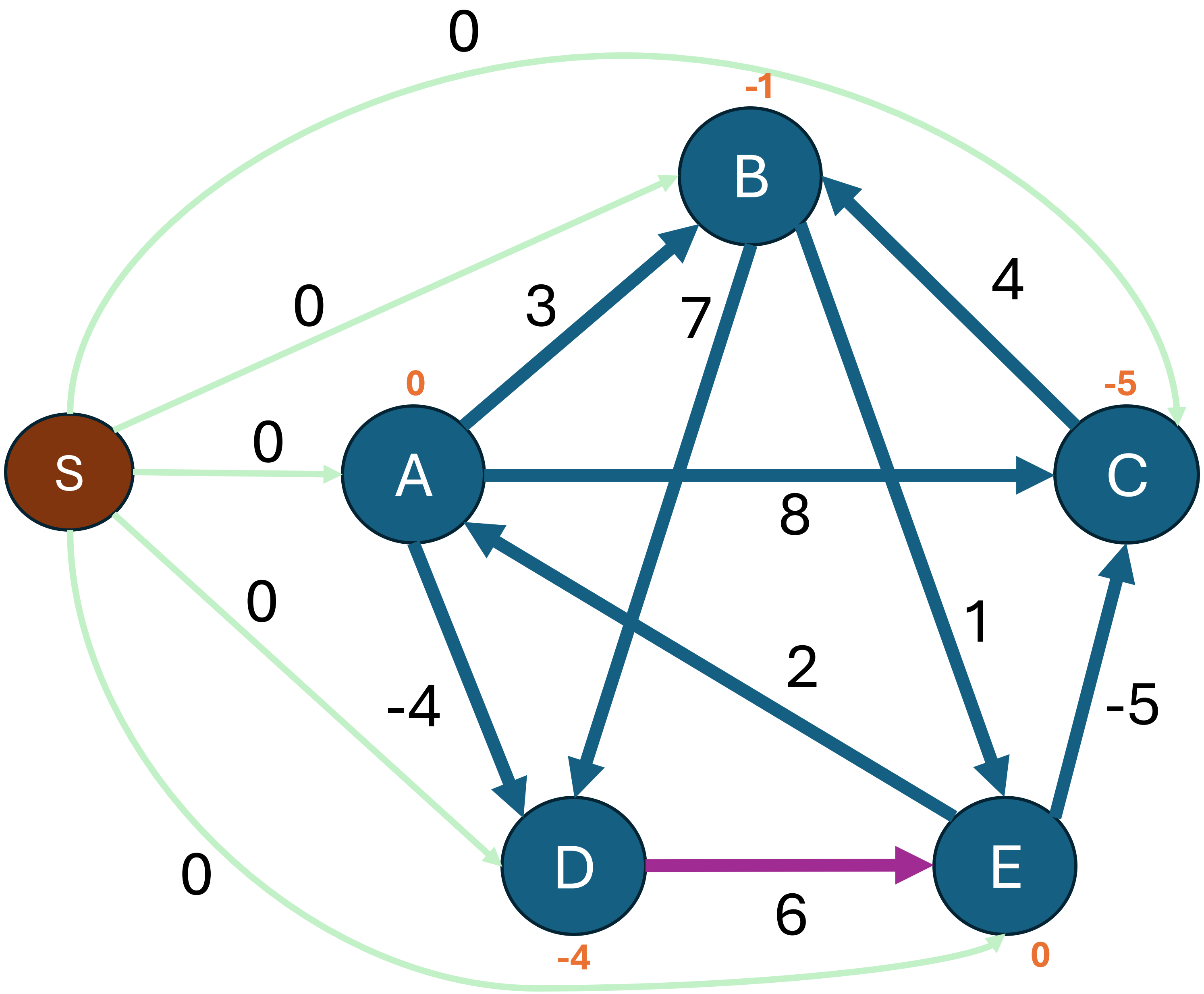

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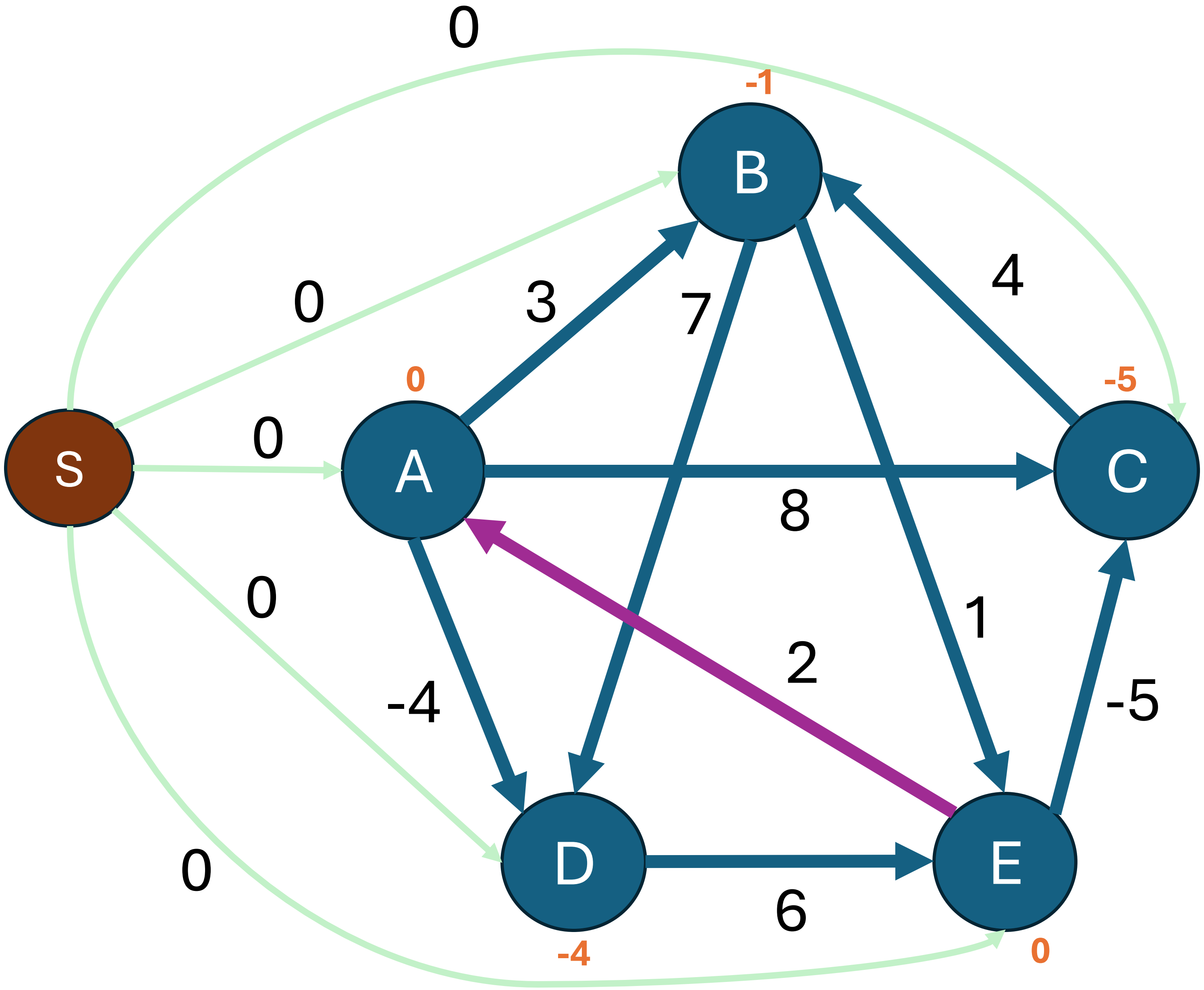
SA	SB	SC	SD	SE	AB	AC	AD	BD	BE	CB	DE	EA	EC



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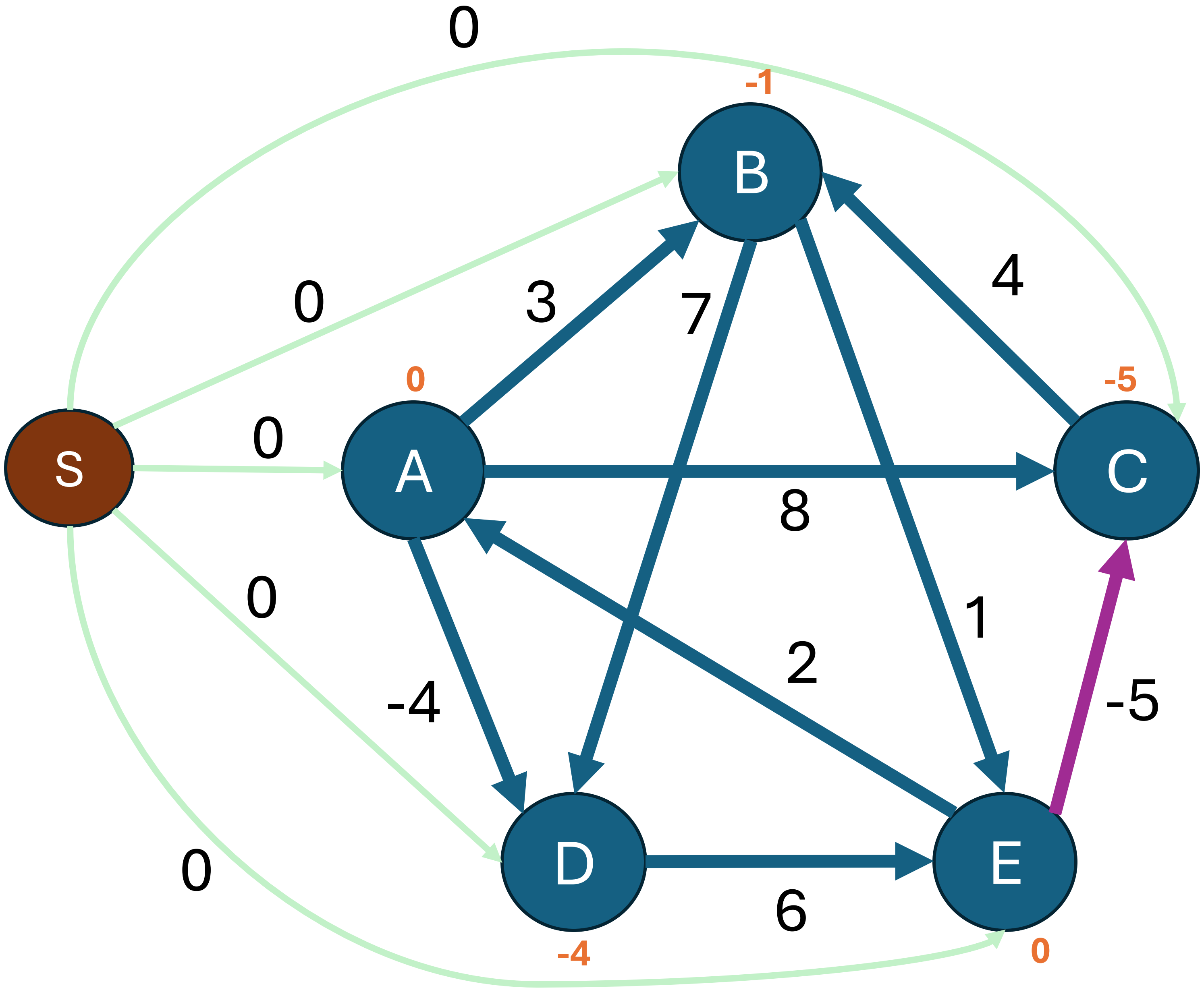

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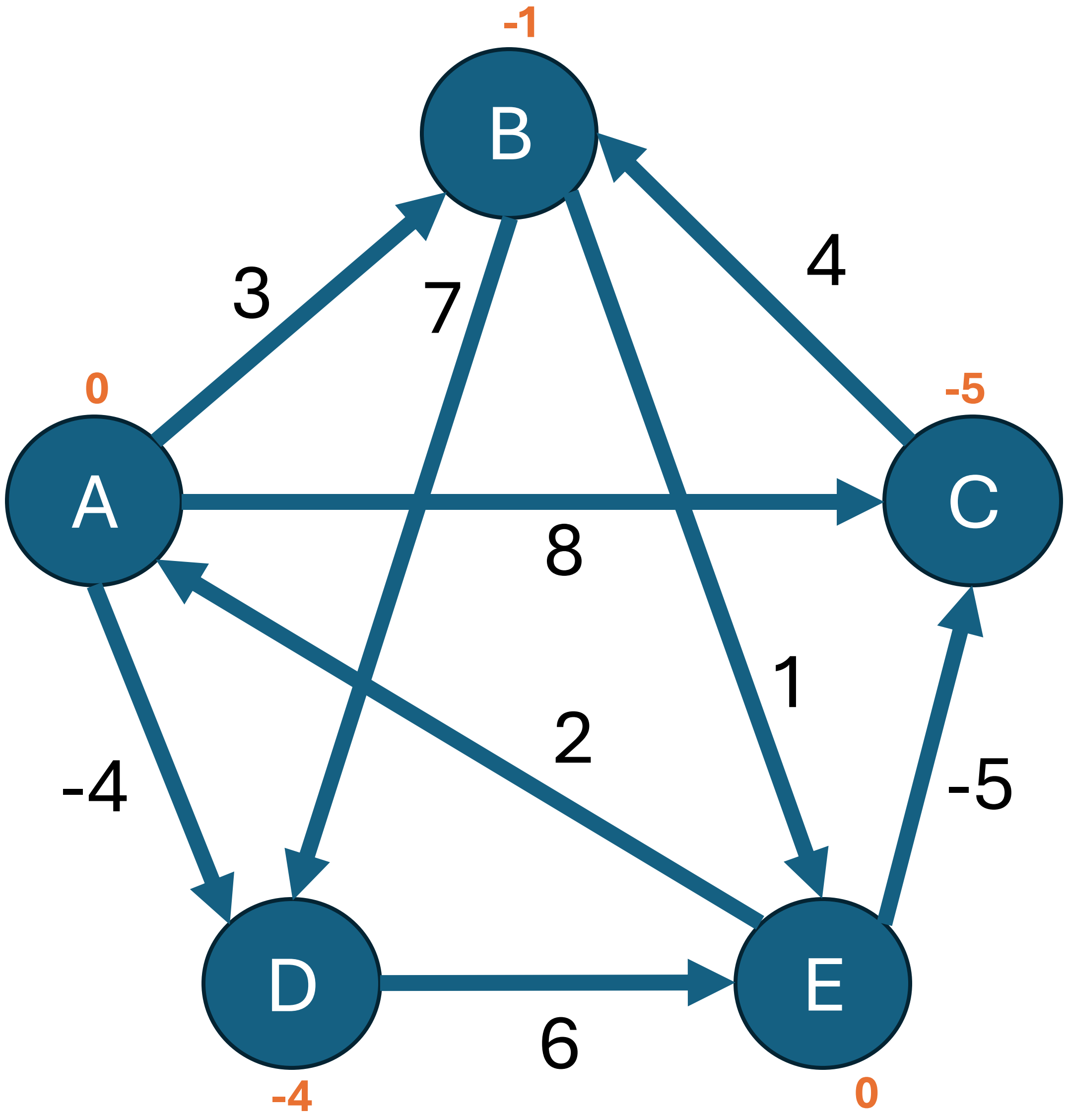

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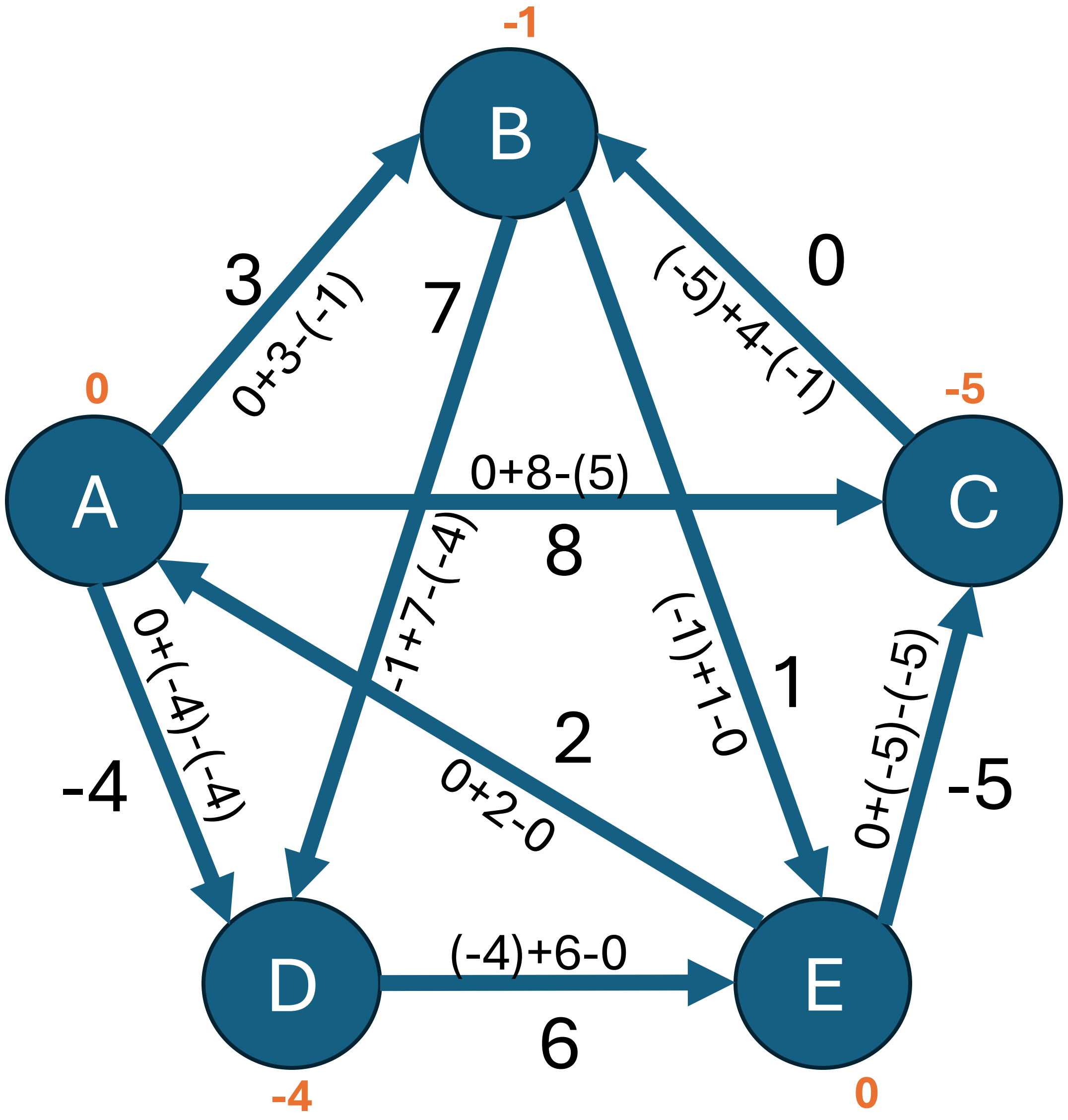
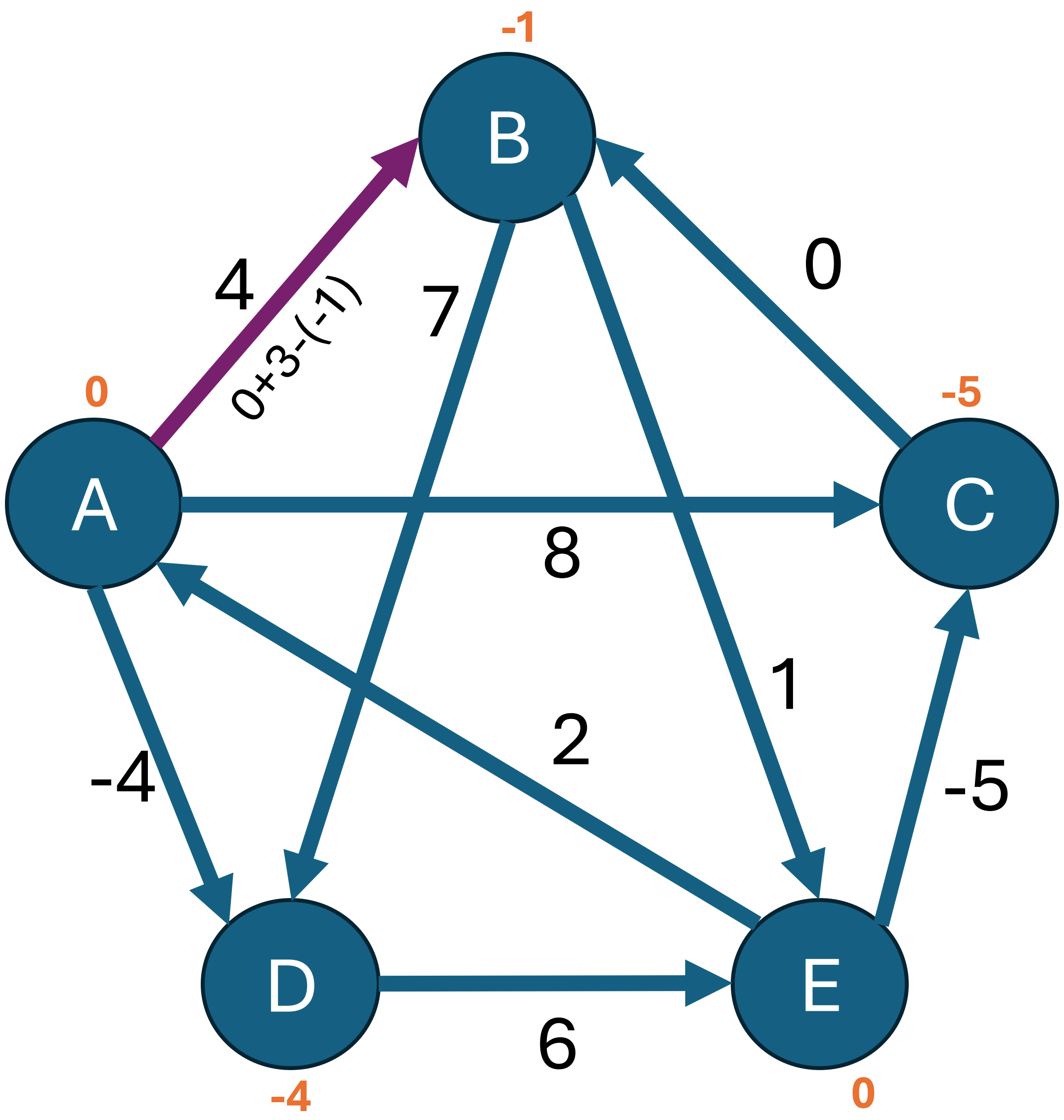


	Cost	Prev
S	0	-
A	0	S
B	-1	C
C	-5	E
D	-4	A
E	0	S

$$w_{new}(u,v) = w(u,v) + h(u) - h(v) >= 0$$

AB	AC	AD	BD	BE	CB	DE	EA	EC

3



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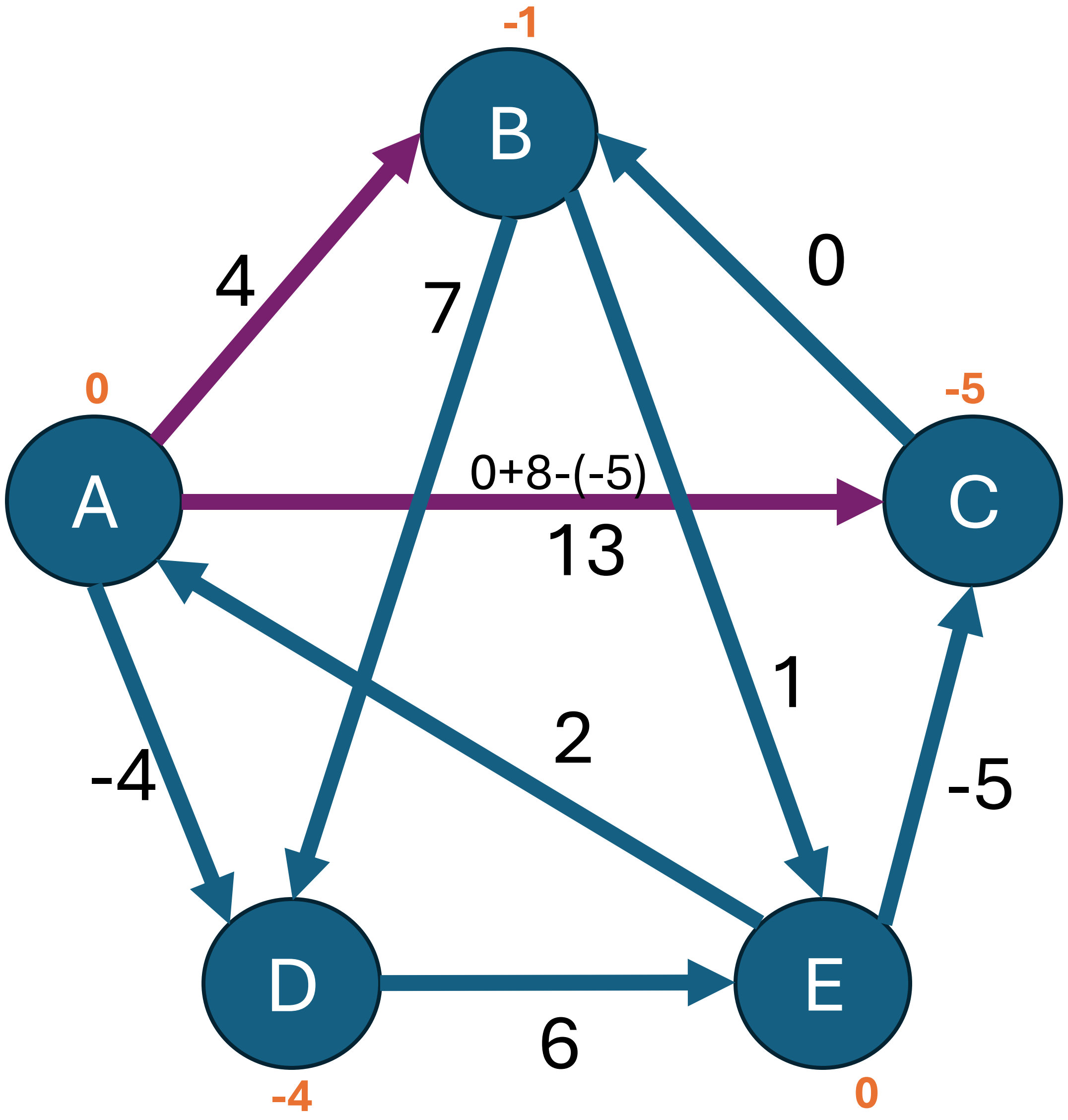
B	-1	C
C	-5	E
D	-4	A
E	0	S

AB	AC	AD	BD	BE	CB	DE	EA	EC

3



AB	AC	AD	BD	BE	CB	DE	EA	EC

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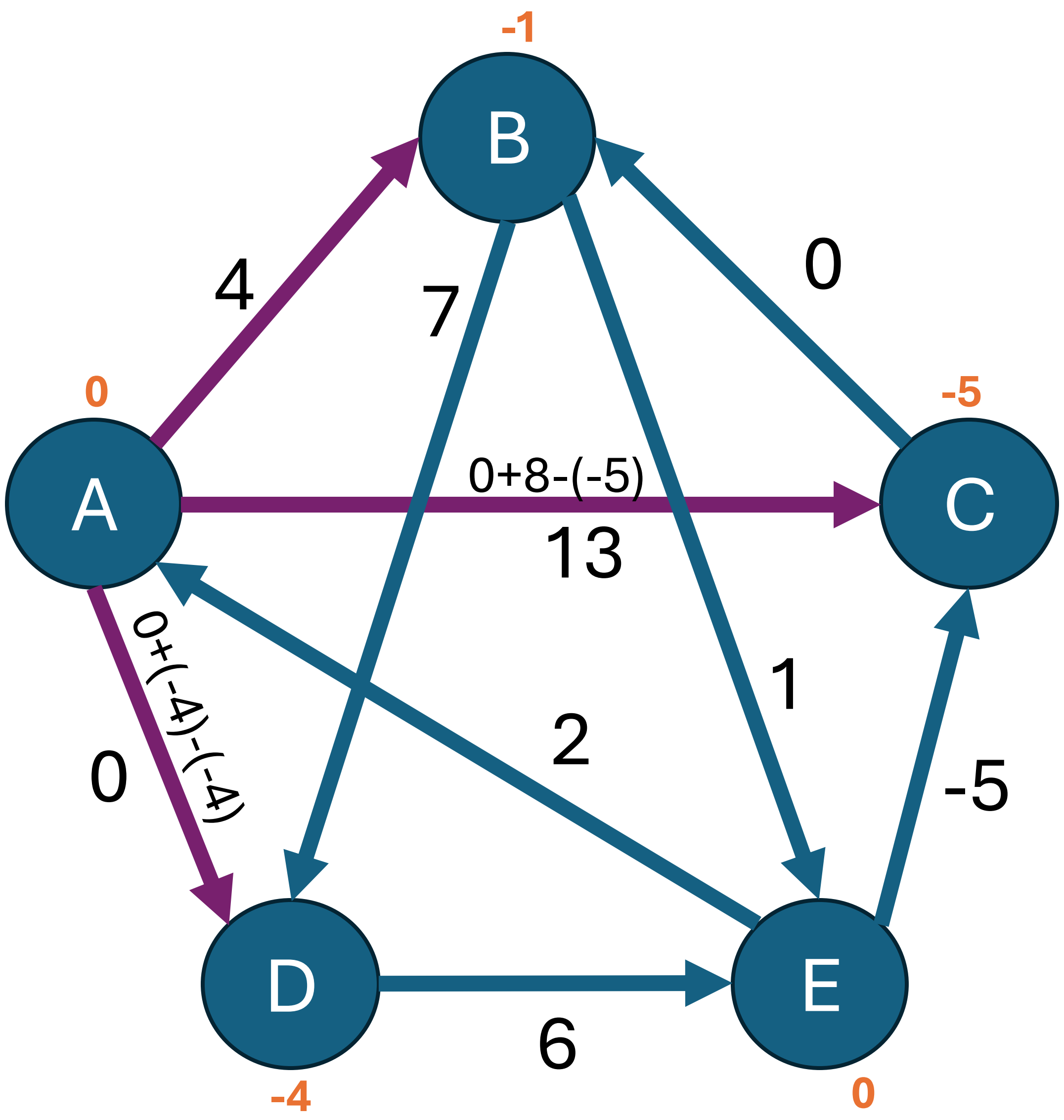
C	-5	E
D	-4	A
E	0	S

3



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AB	AC	AD	BD	BE	CB	DE	EA	EC

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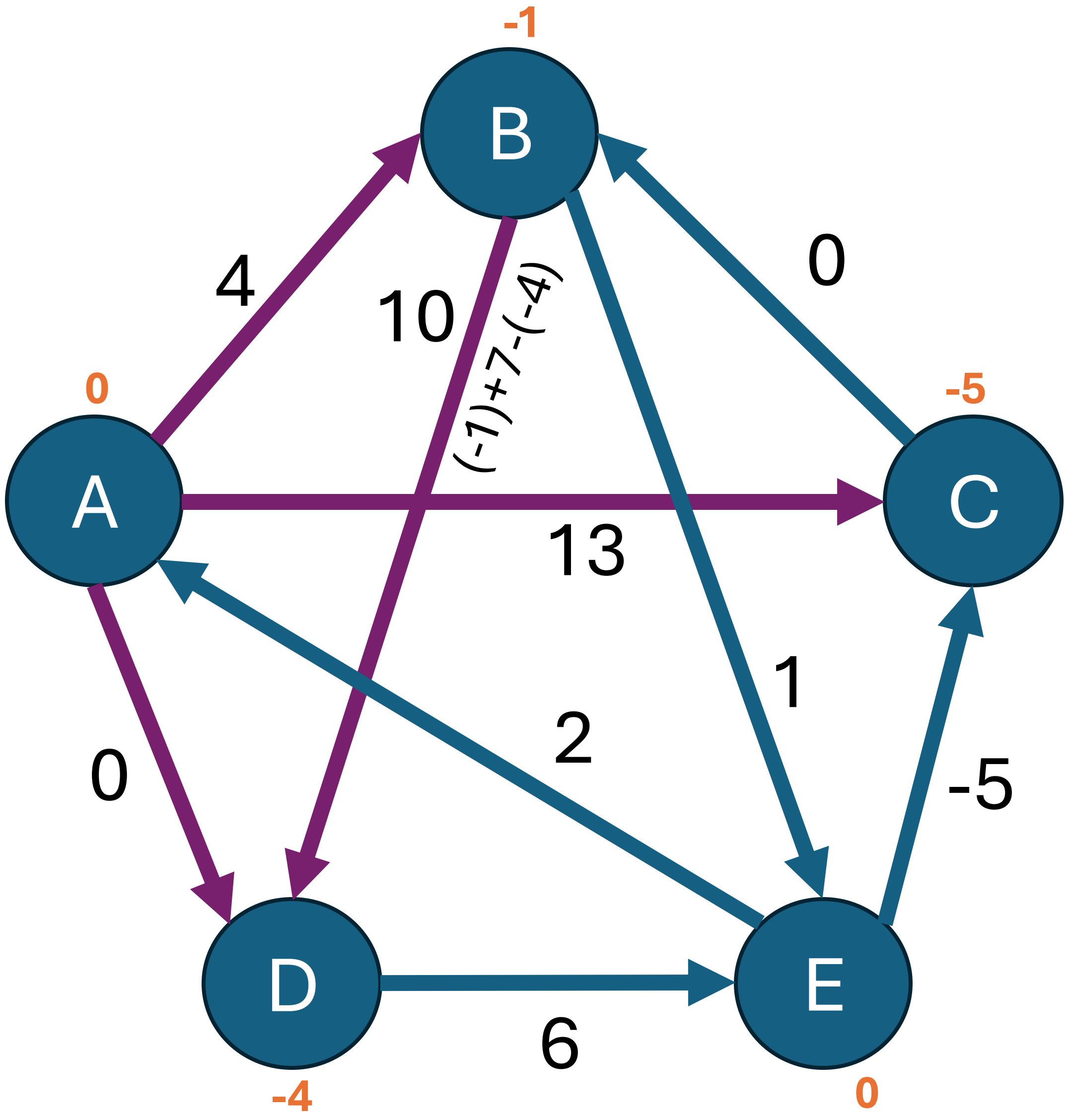

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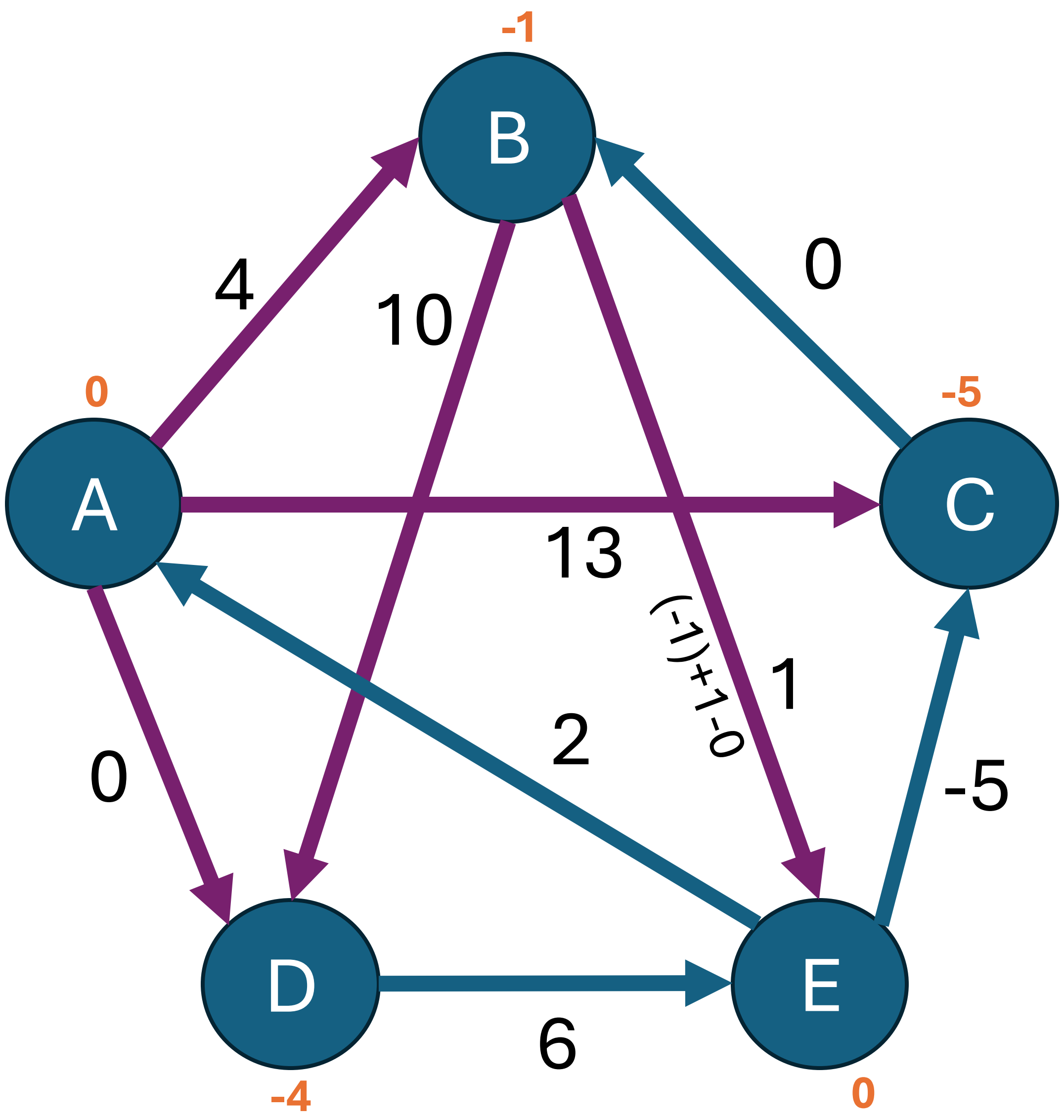

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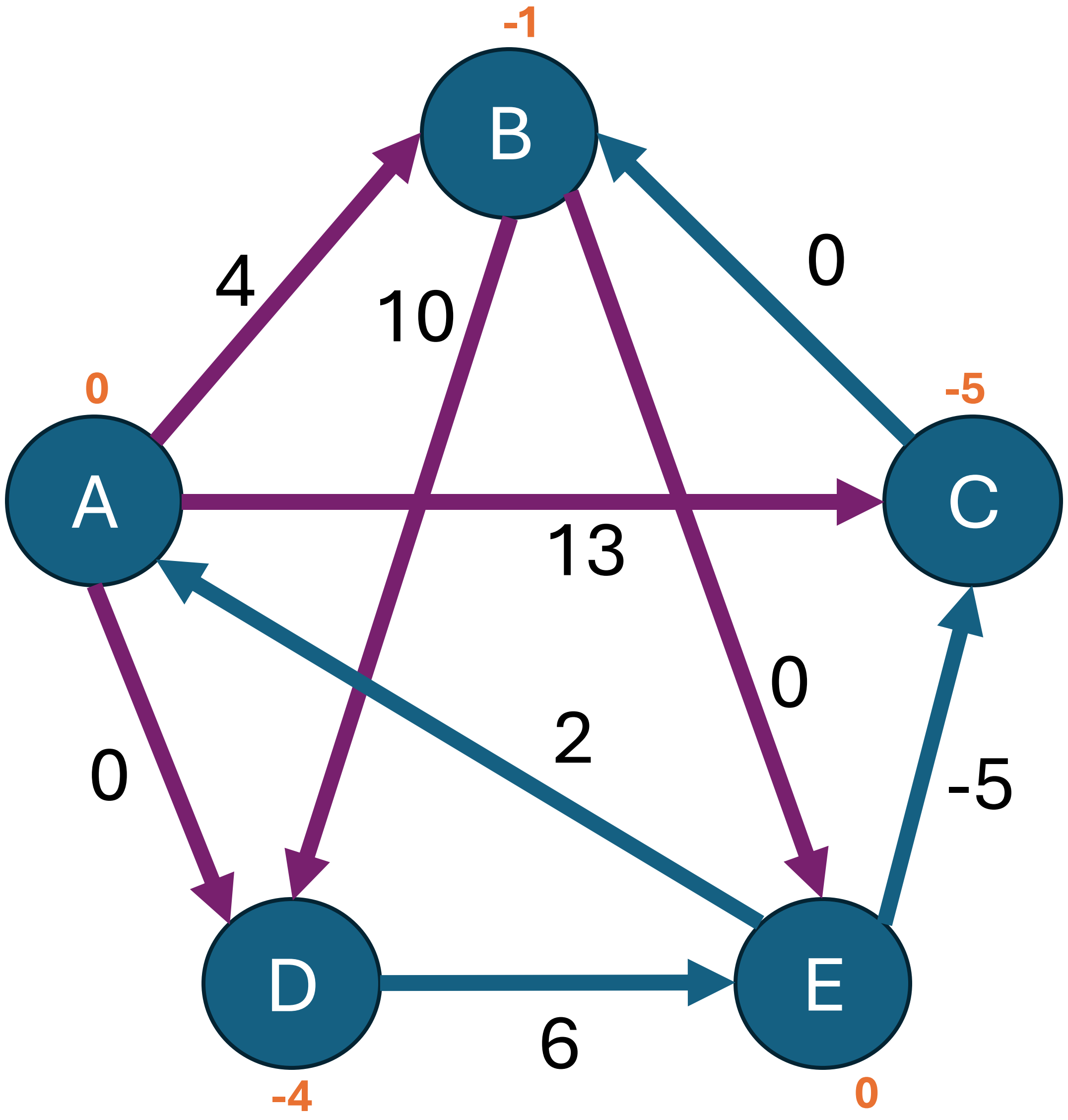

AB	AC	AD	BD	BE	CB	DE	EA	EC

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C	-5	E
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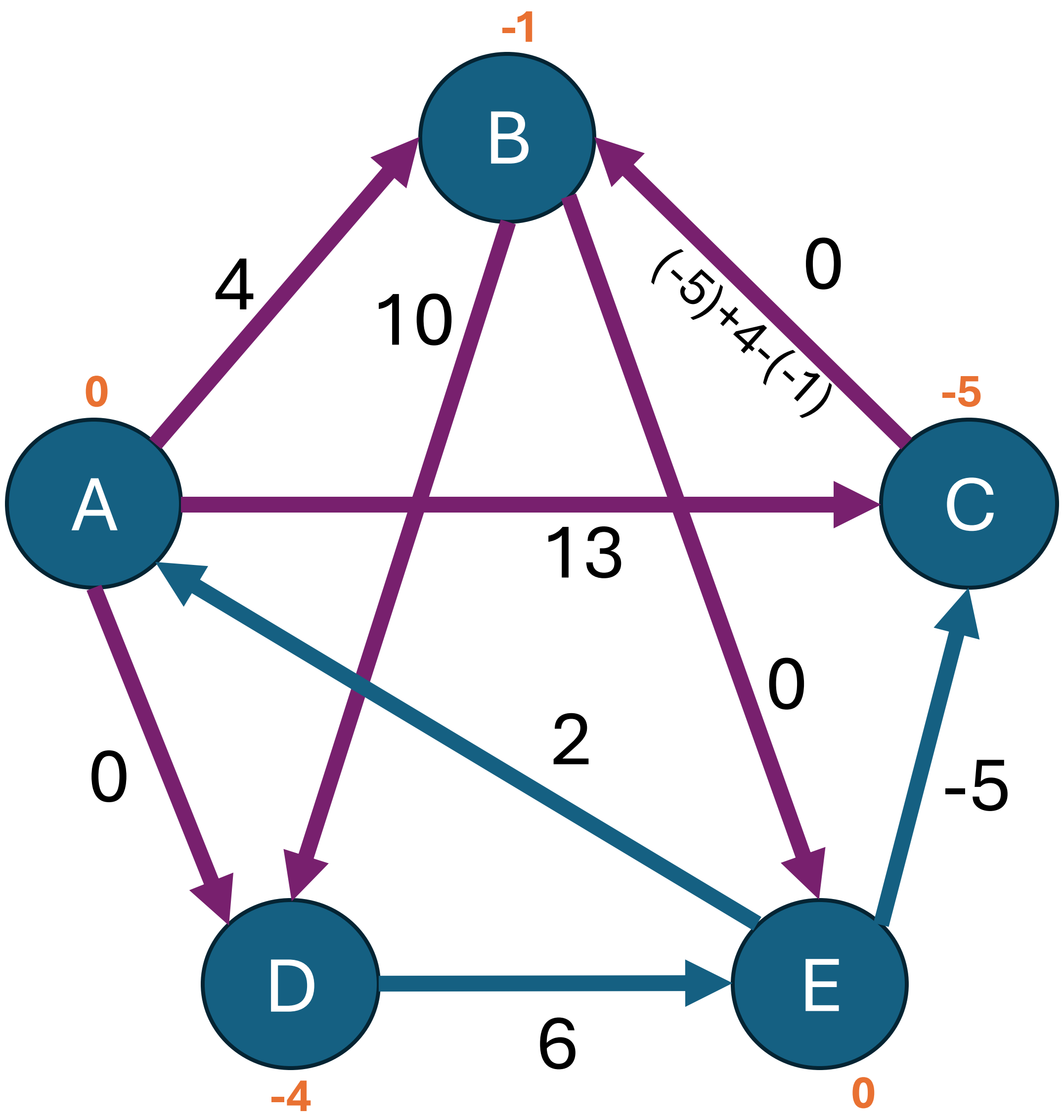
3



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AB	AC	AD	BD	BE	CB	DE	EA	EC

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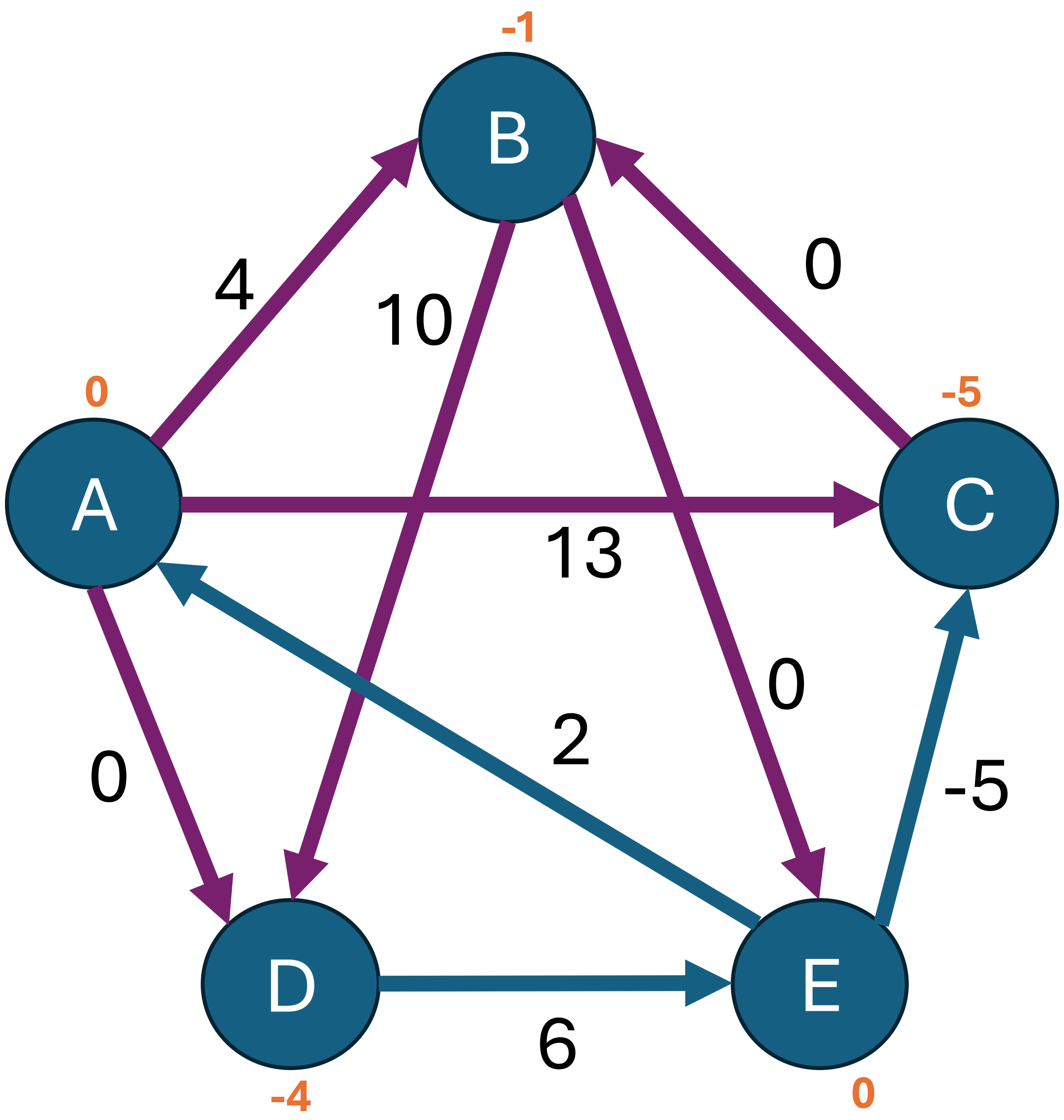

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AB	AC	AD	BD	BE	CB	DE	EA	EC

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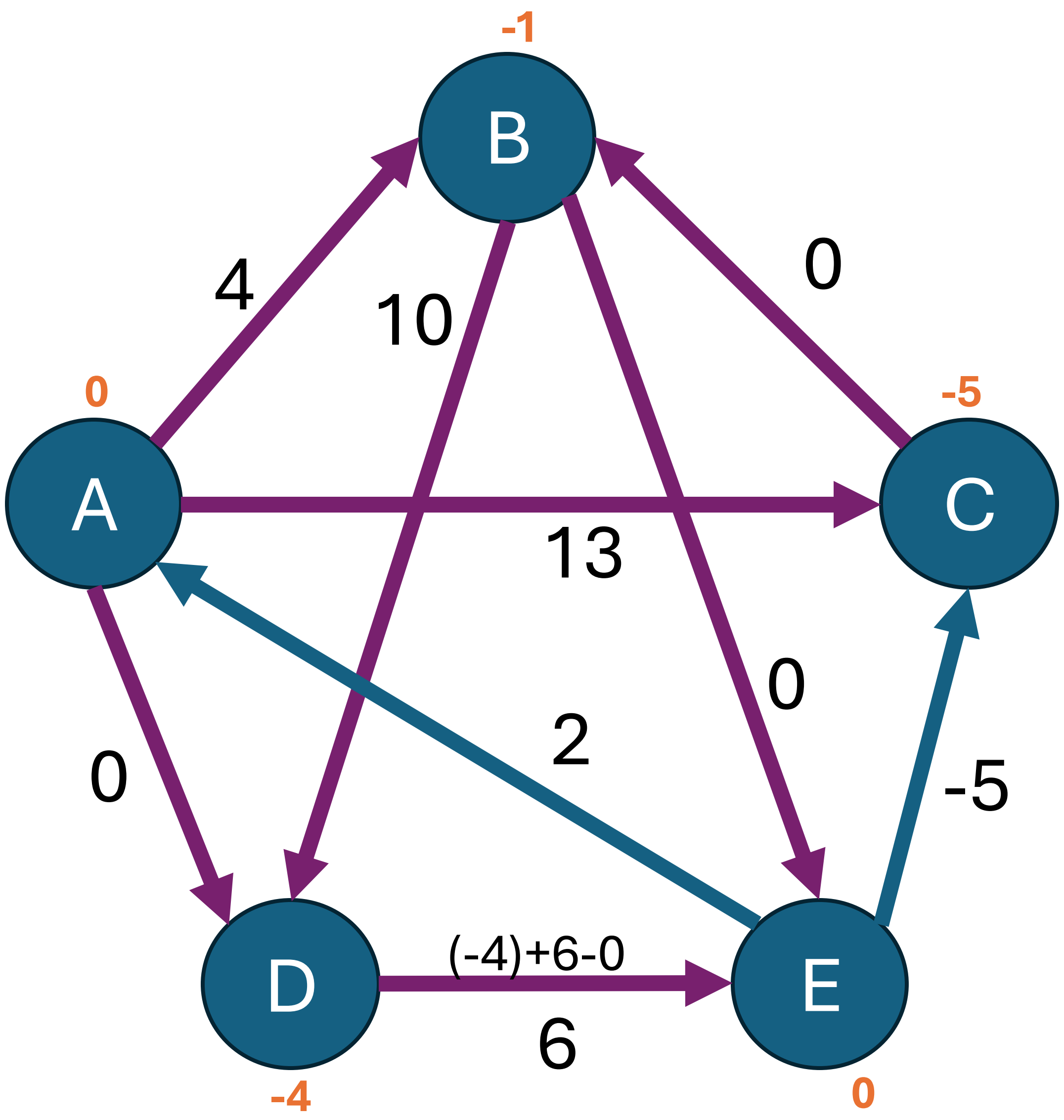

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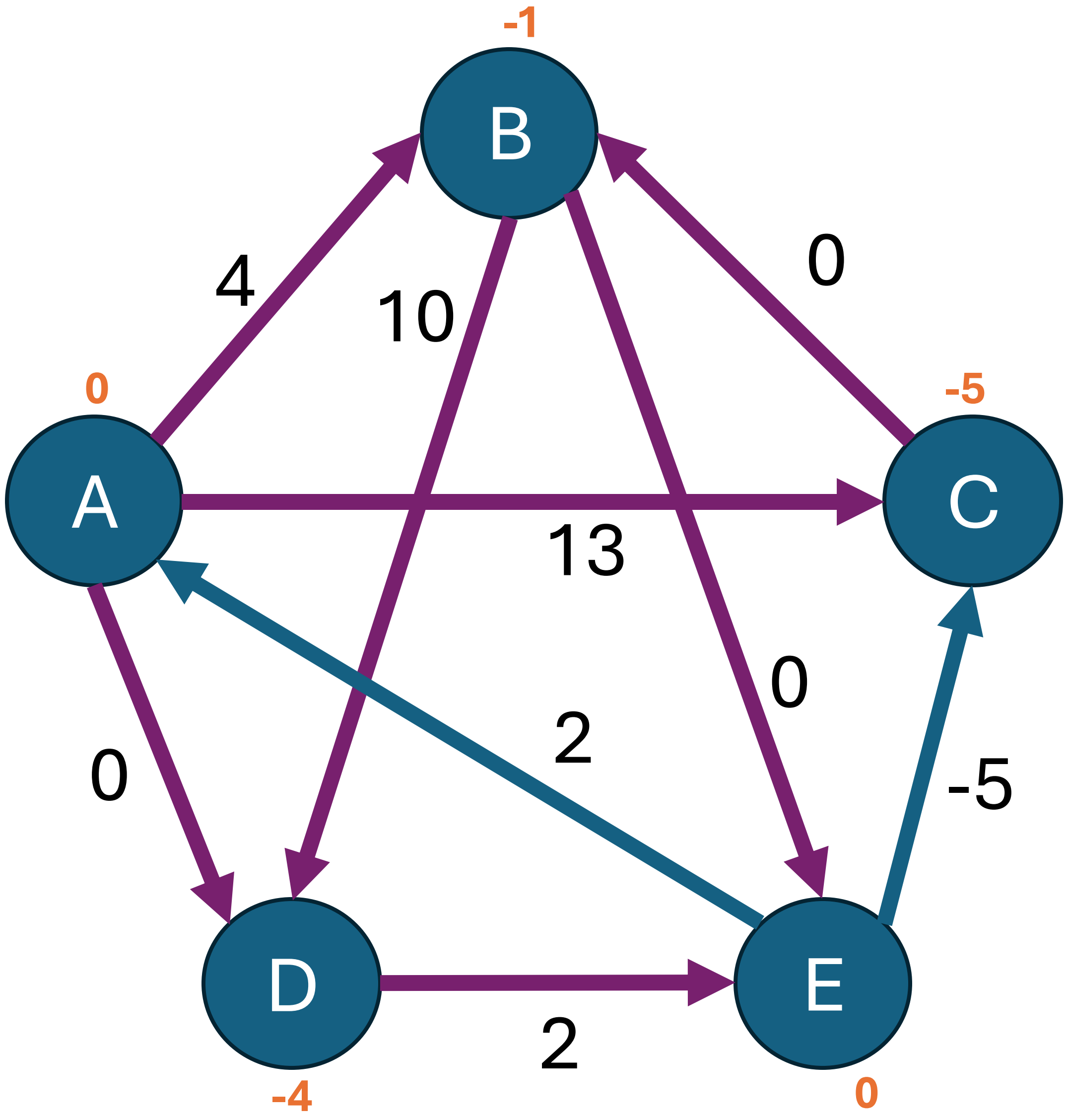

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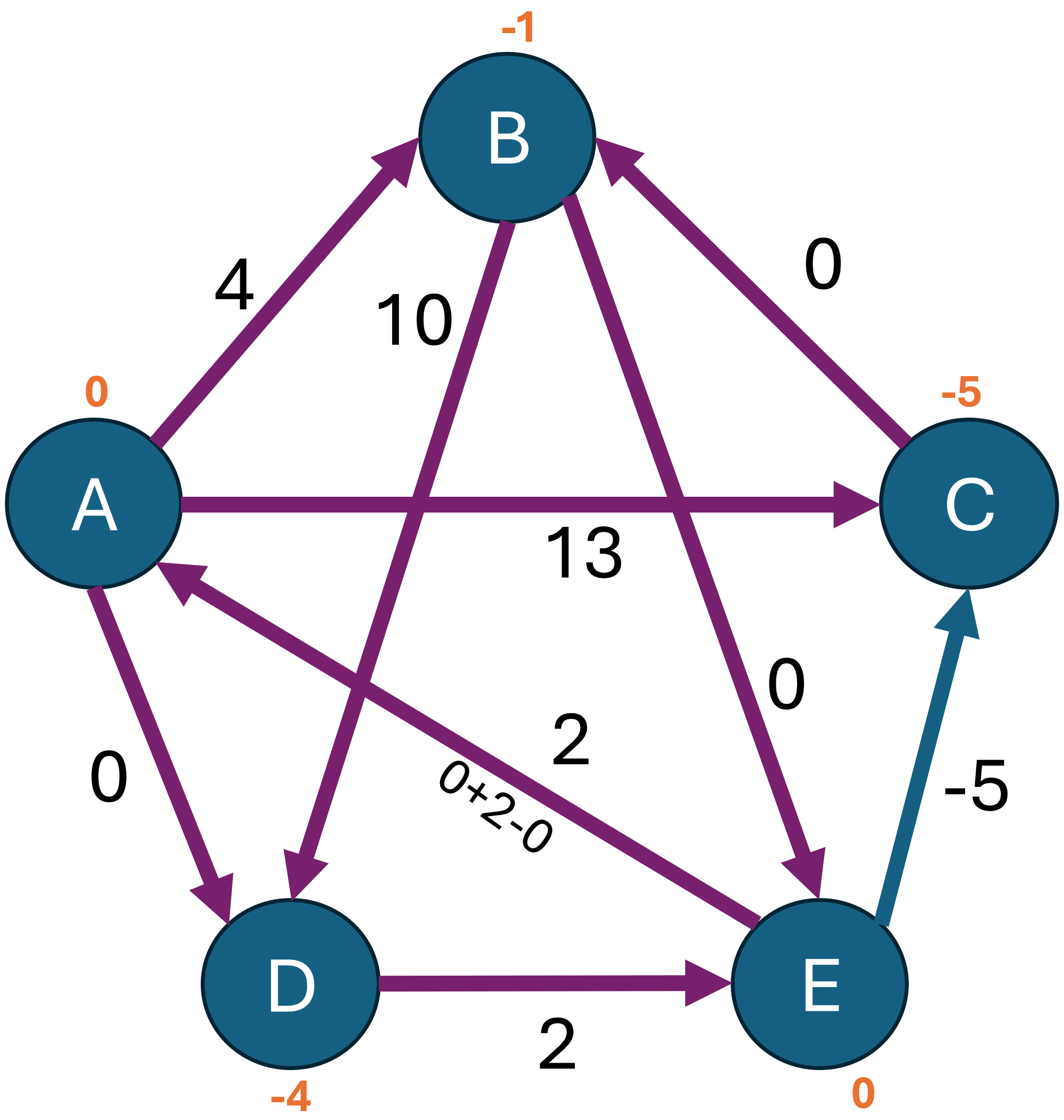

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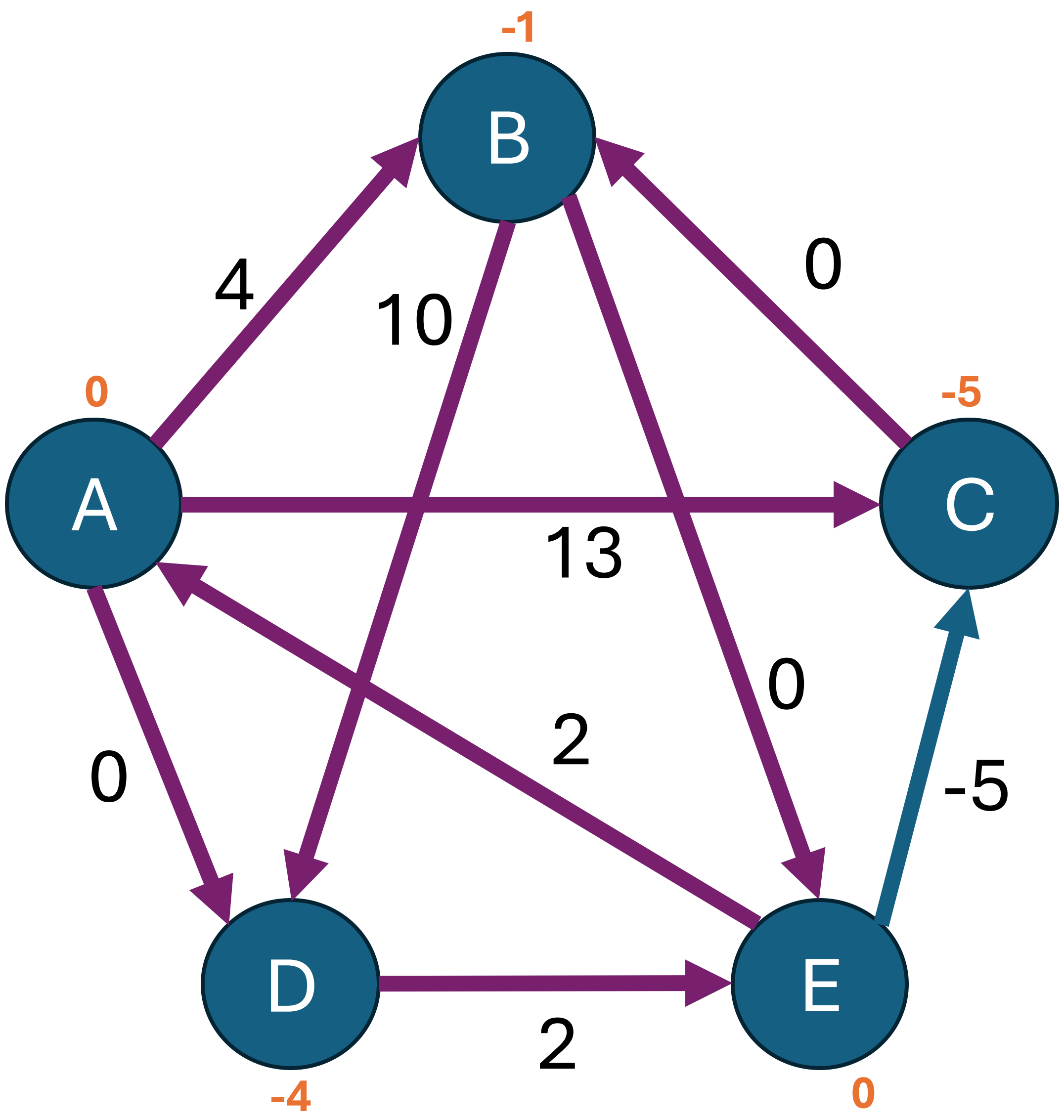

AB	AC	AD	BD	BE	CB	DE	EA	EC

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C	-5	E
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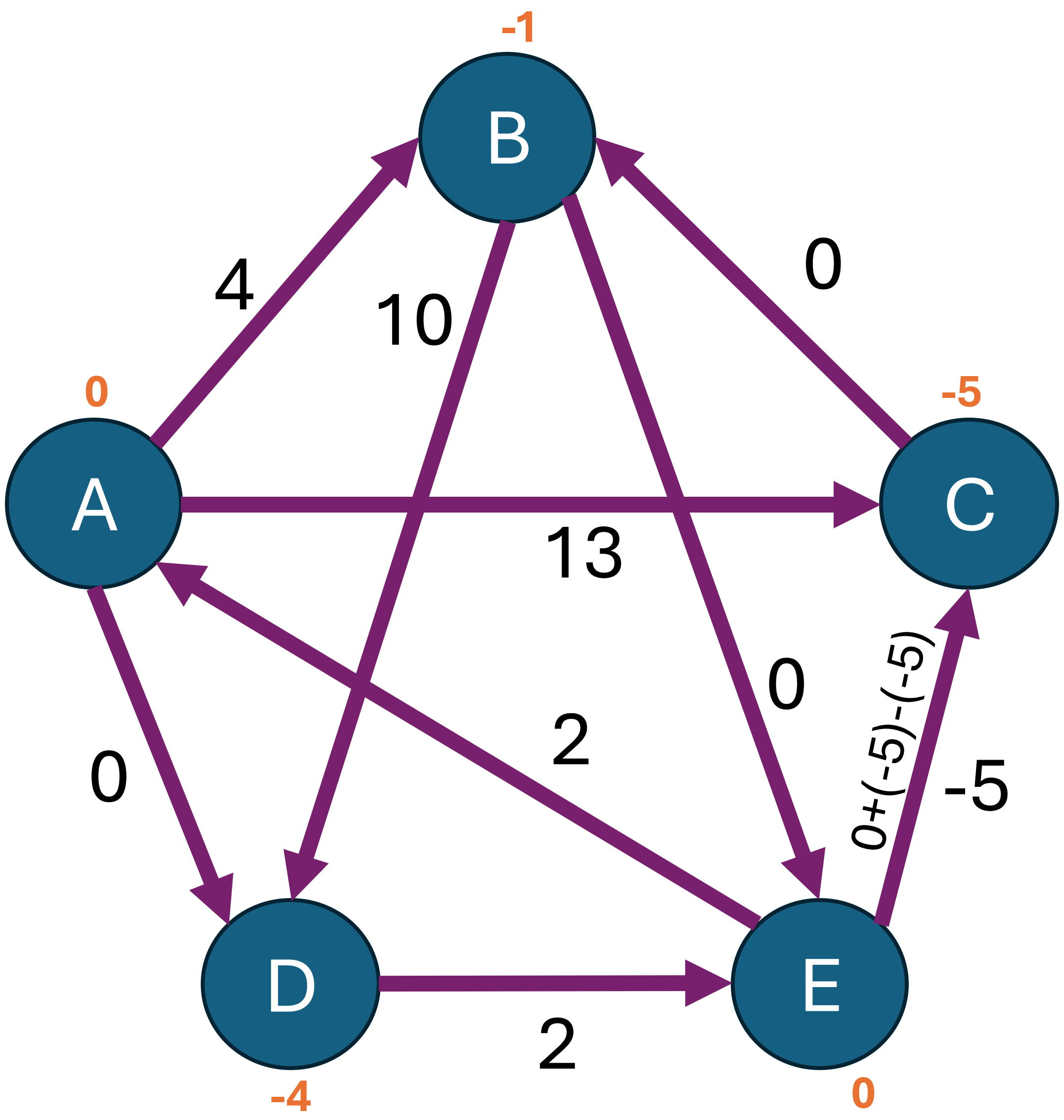
E	0	S



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S	0	-
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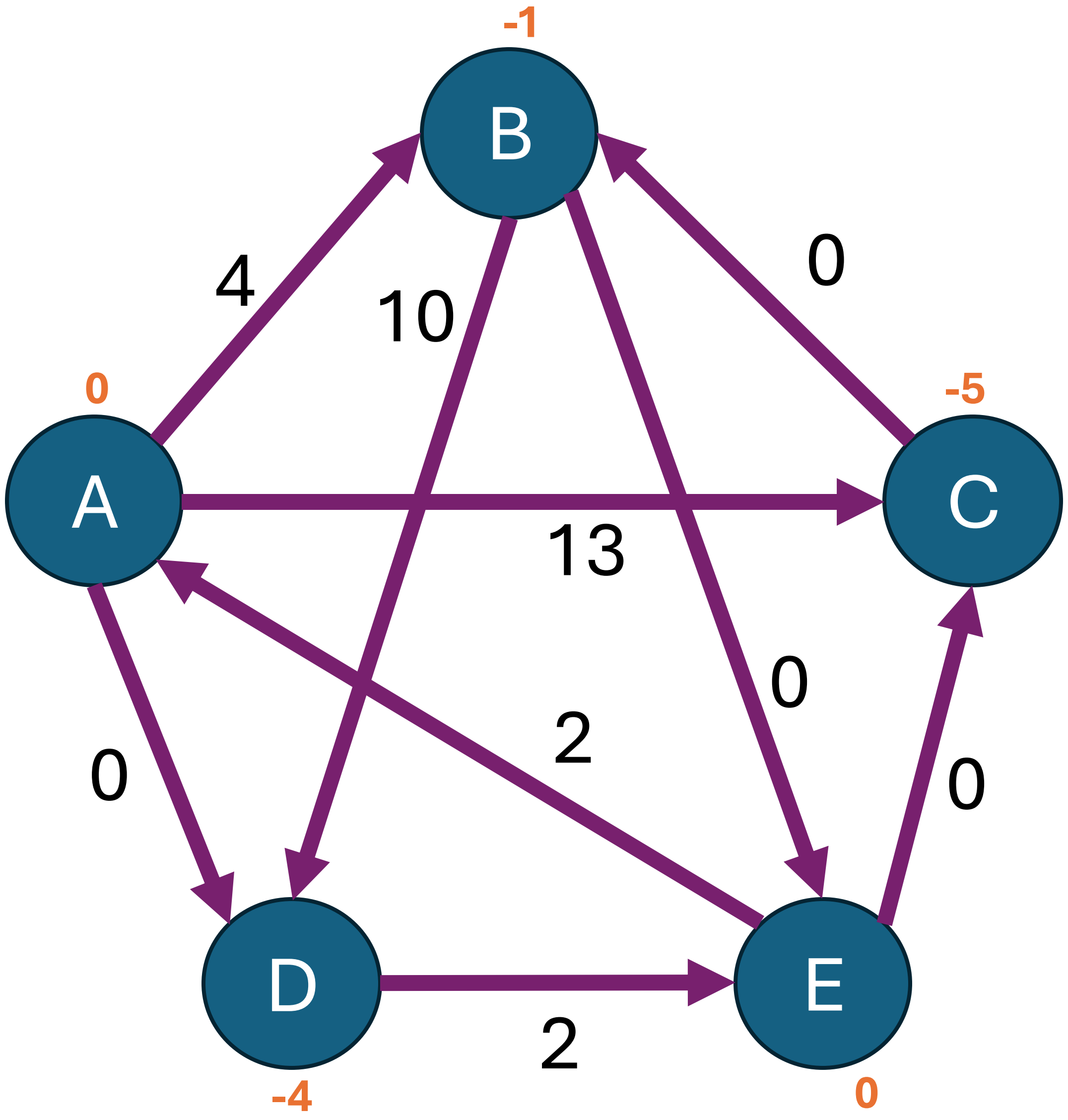
E	0	S

AB	AC	AD	BD	BE	CB	DE	EA	EC



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S	0	-
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B	-1	C
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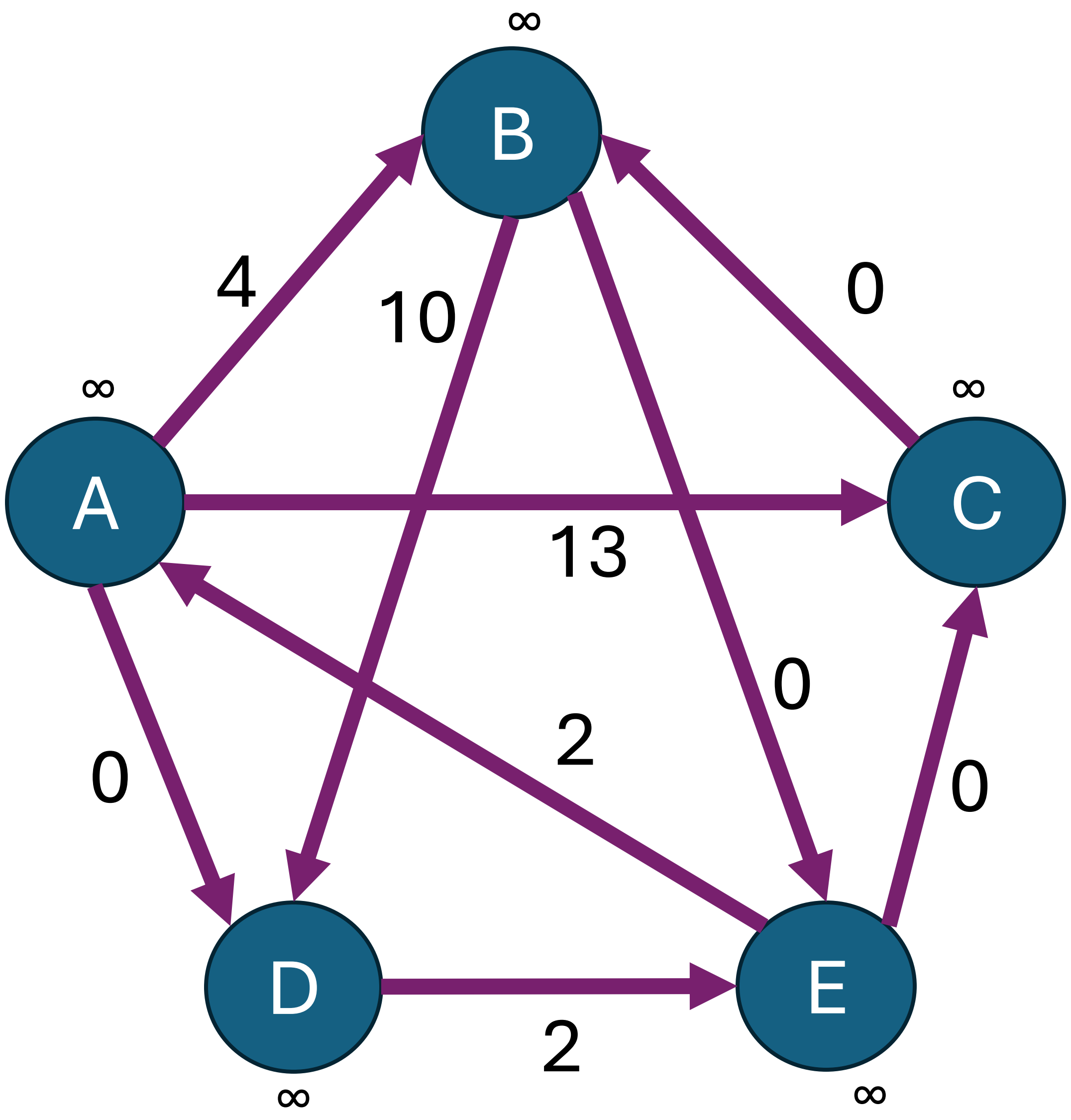
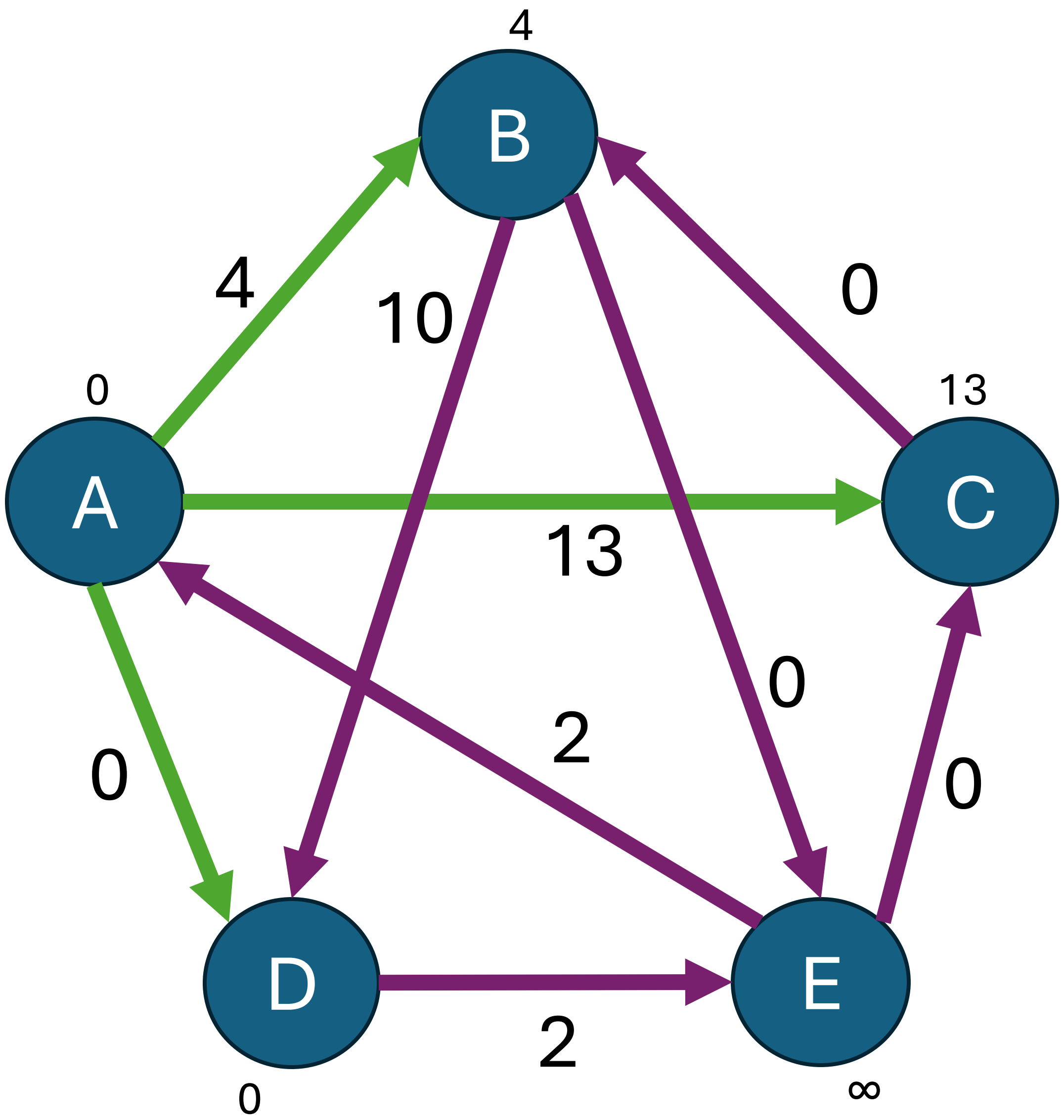
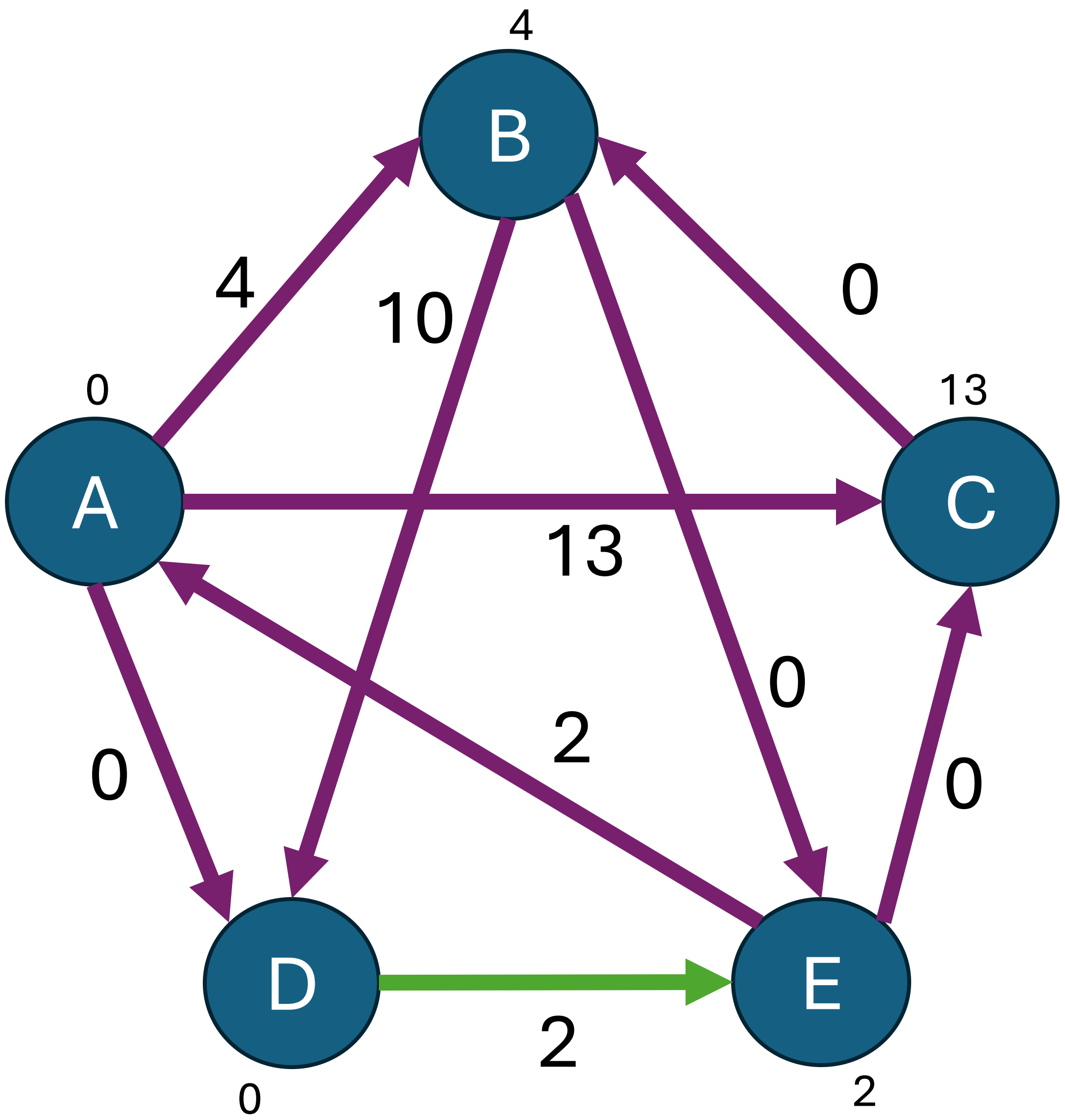
AB	AC	AD	BD	BE	CB	DE	EA	EC



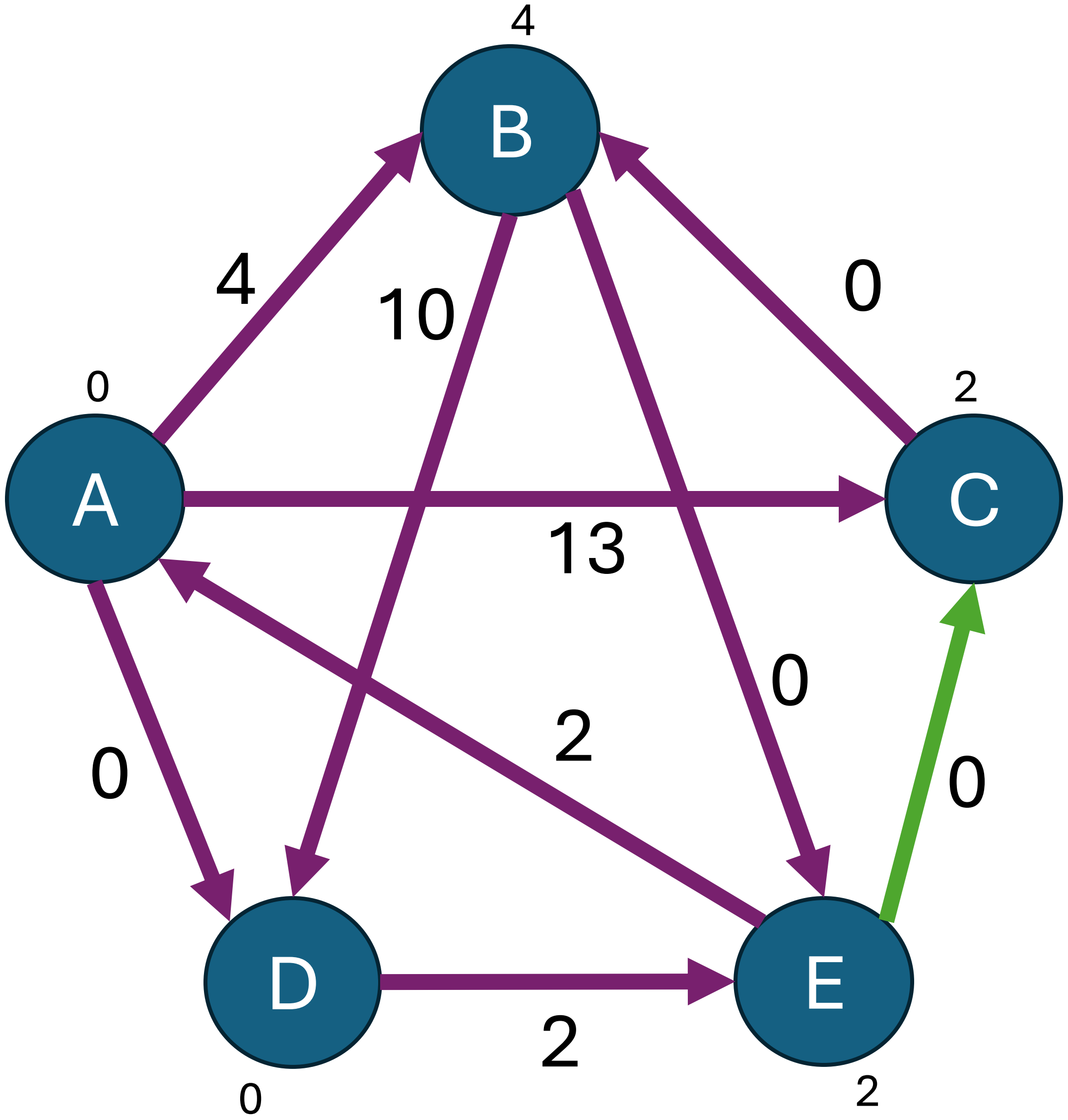
	A	B	C	D	E
A					



	A	B	C	D	E
A	0	4 A	13 A	0 A	



	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D



	A	B	C	D	E
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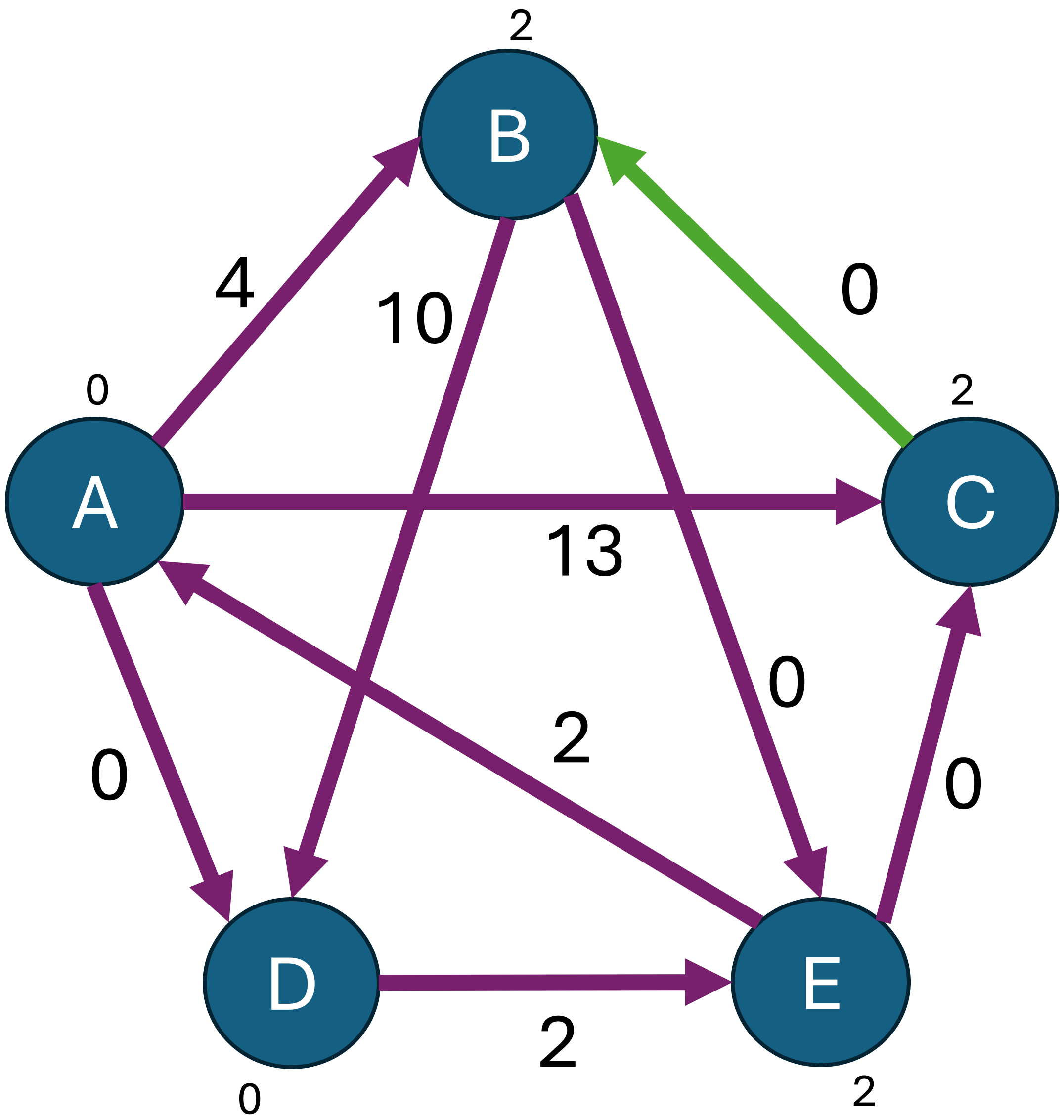
E	0	4 A	2 E	0 A	2 D



	A	B	C	D	E
A	0	4 A	13 A	0 A	
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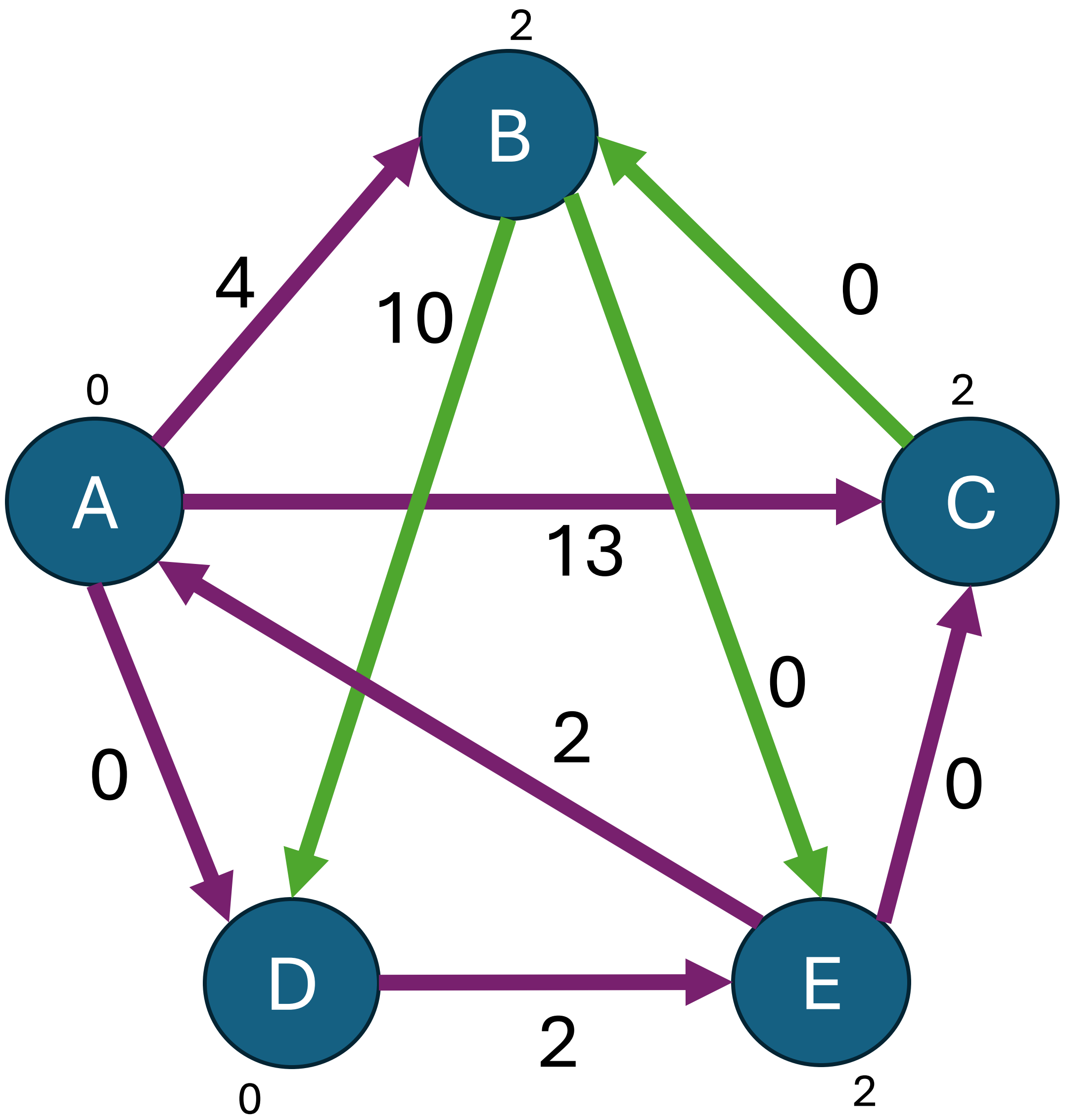
B	0	2 C	2 E	0 A	2 D



	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
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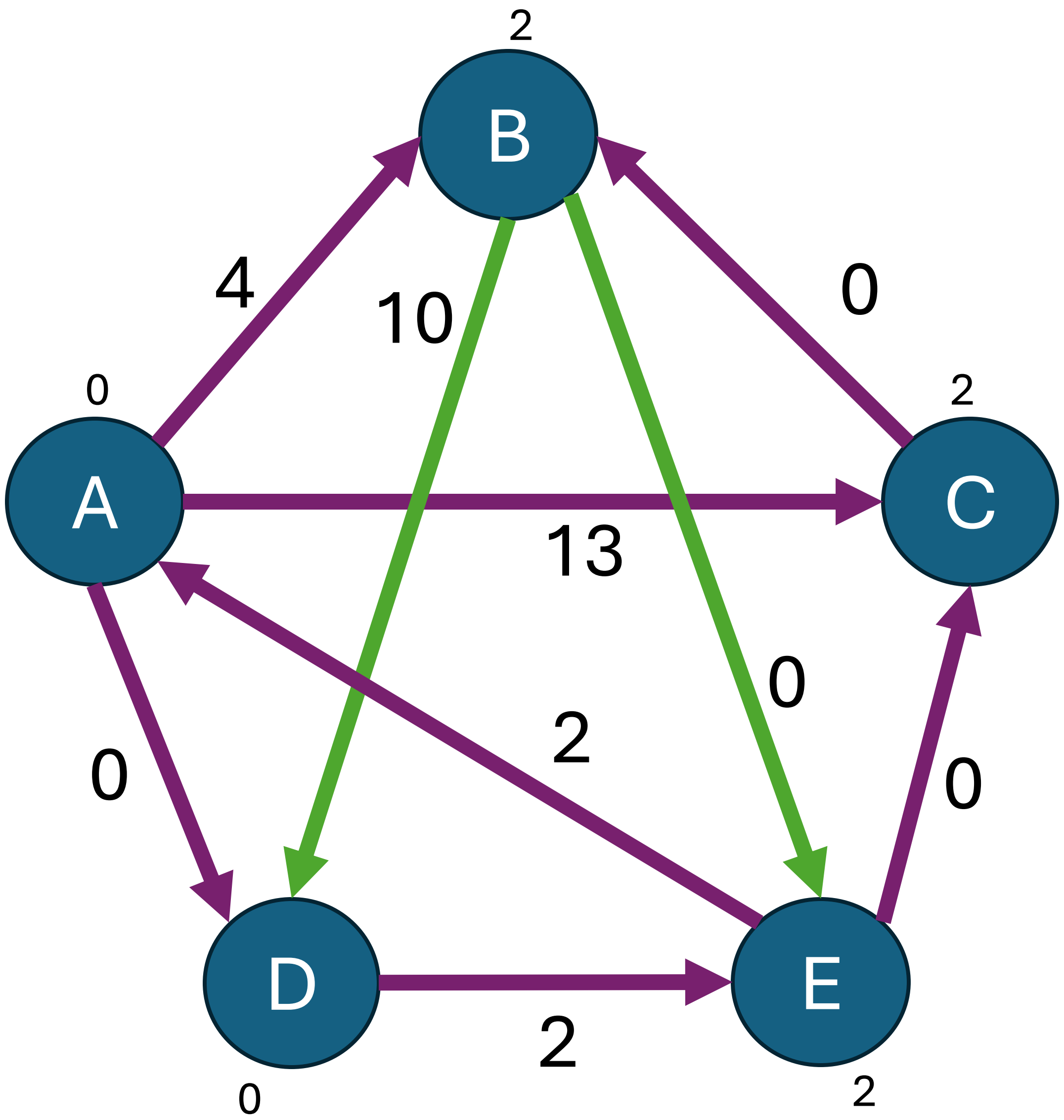

	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
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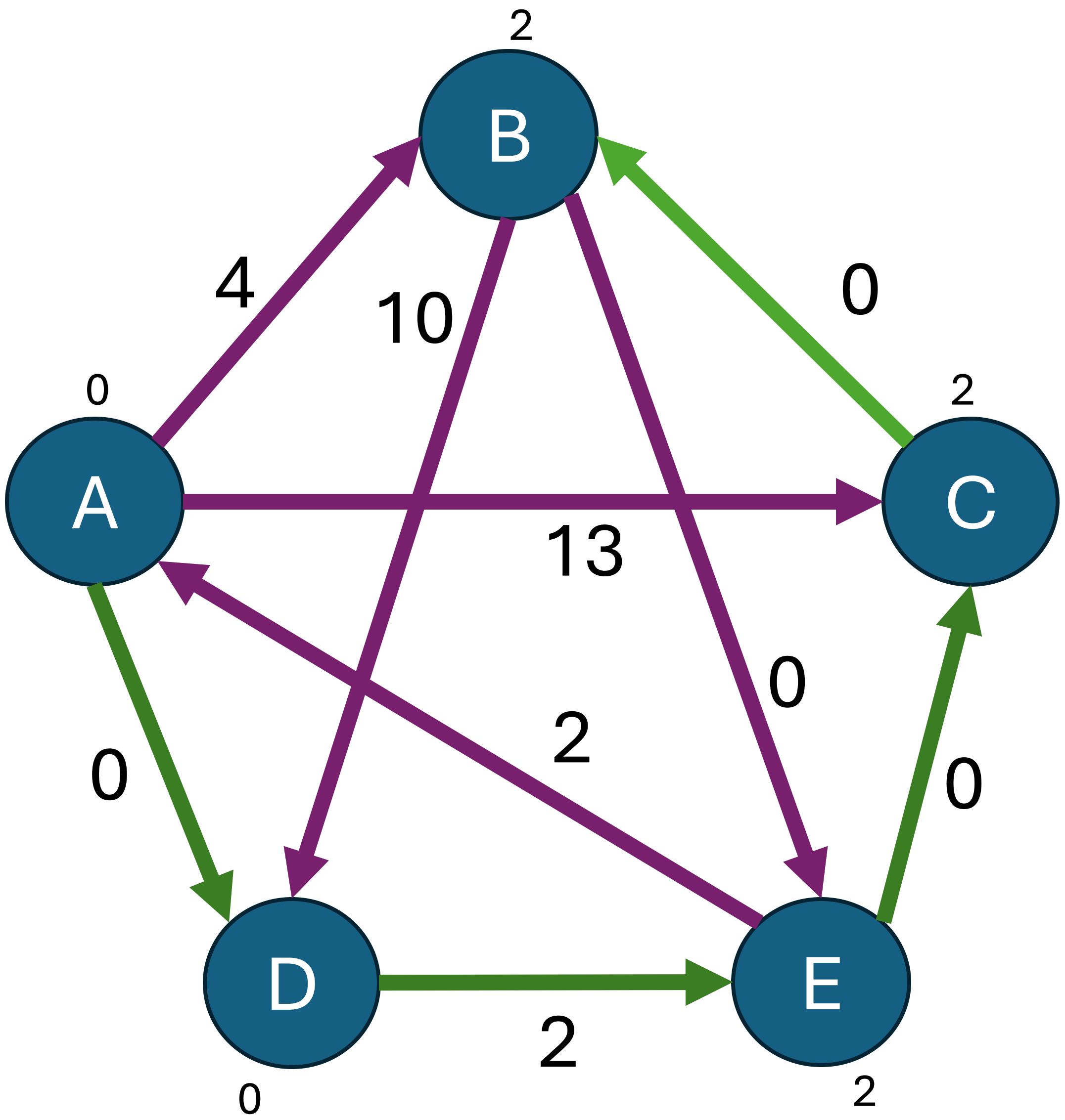
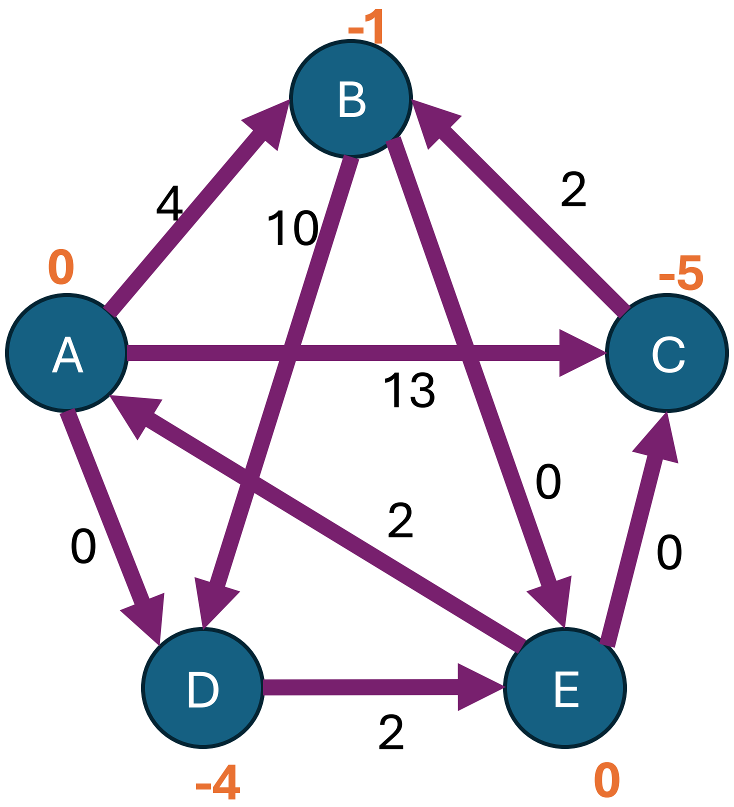


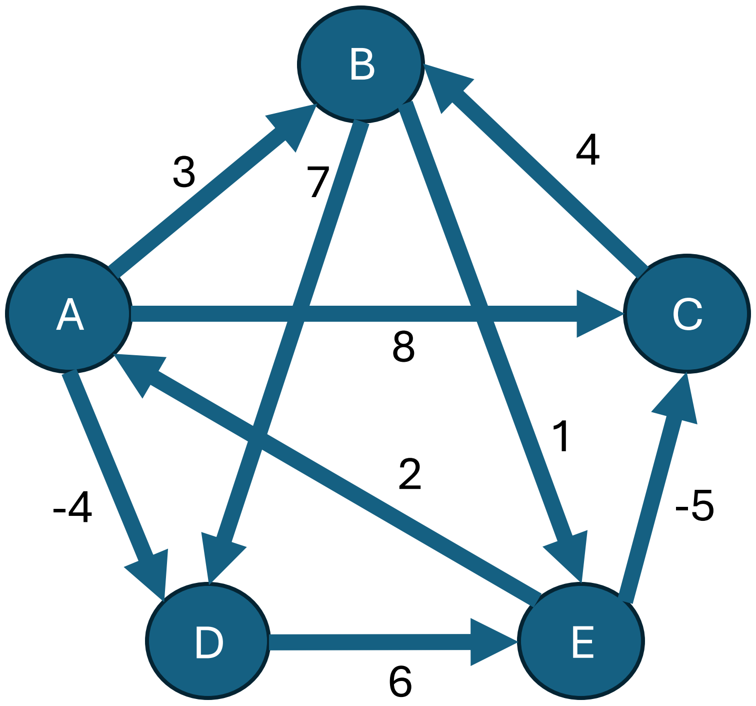
	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
E	0	4 A	2 E	0 A	2 D
C	0	2 C	2 E	0 A	2 D
B	0	2 C	2 E	0 A	2 D

Let us reweight the edges to retrieve the original weights

Graph computed by Bellman-Ford and reweighting



Original Graph



Distances from A to every other vertex

	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
E	0	4 A	2 E	0 A	2 D
C	0	2 C	2 E	0 A	2 D
B	0	2 C	2 E	0 A	2 D

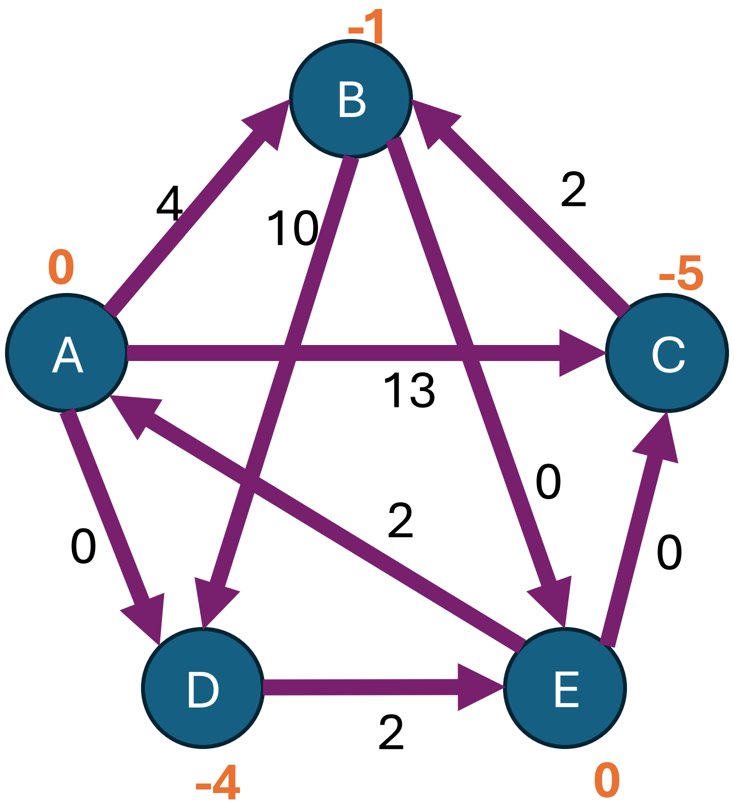
$d(u,v)=d'(u,v)-h(u)+h(v)$

$d(a,b) = 2-0+(-1) = 1$

$d(a,d) = 0-0+(-4) = -4$

$d(a,c) = 2-0+(-5) = -3$

Graph computed by Bellman-Ford and reweighting



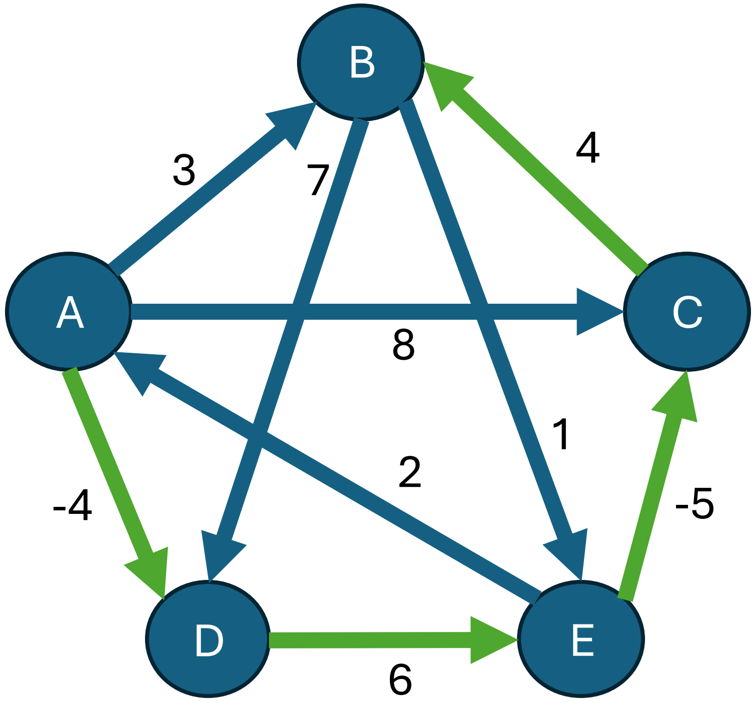
$d(u,v)=d'(u,v)-h(u)+h(v)$

$d(a,b) = 2-0+(-1) = 1$

$d(a,d) = 0-0+(-4) = -4$

$d(a,c) = 2-0+(-5) = -3$

Original Graph

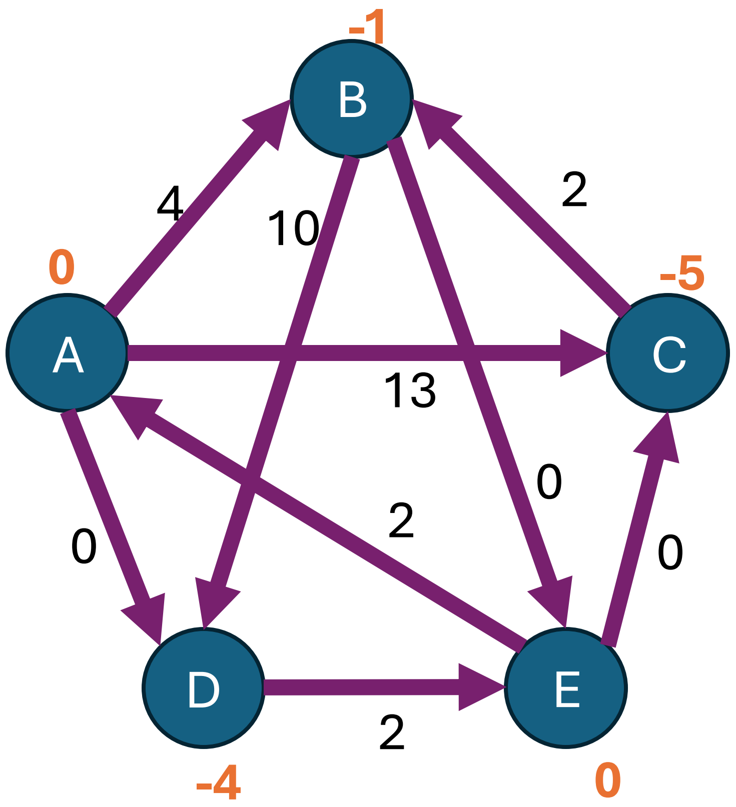


Total is 1!

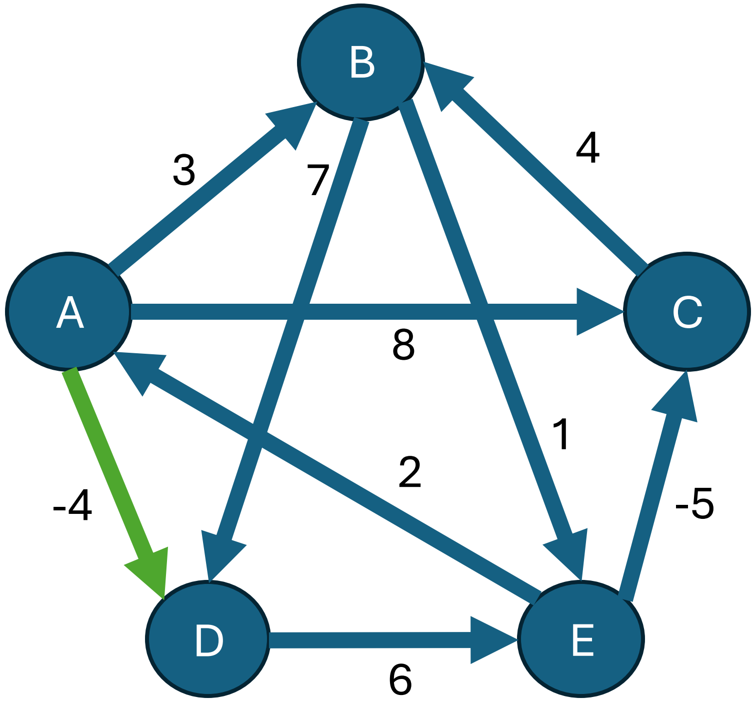
Distances from A to every other vertex

	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
E	0	4 A	2 E	0 A	2 D
C	0	2 C	2 E	0 A	2 D
B	0	2 C	2 E	0 A	2 D

Graph computed by Bellman-Ford and reweighting



Original Graph



Total is -4!

Distances from A to every other vertex

	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
E	0	4 A	2 E	0 A	2 D
C	0	2 C	2 E	0 A	2 D
B	0	2 C	2 E	0 A	2 D

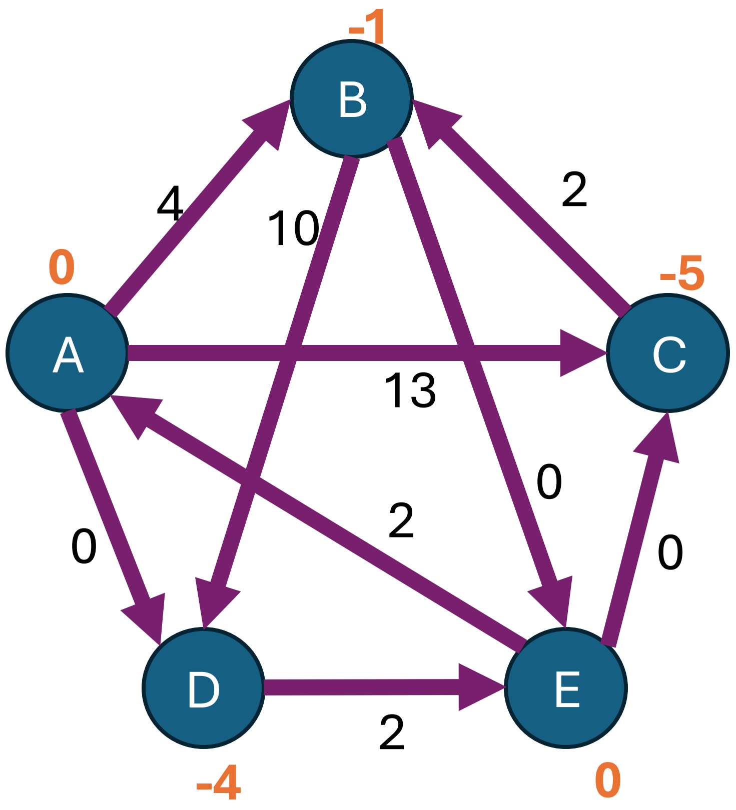
d(u,v)=d'(u,v)−h(u)+h(v)

d(a,b) = 2-0+(-1) = 1

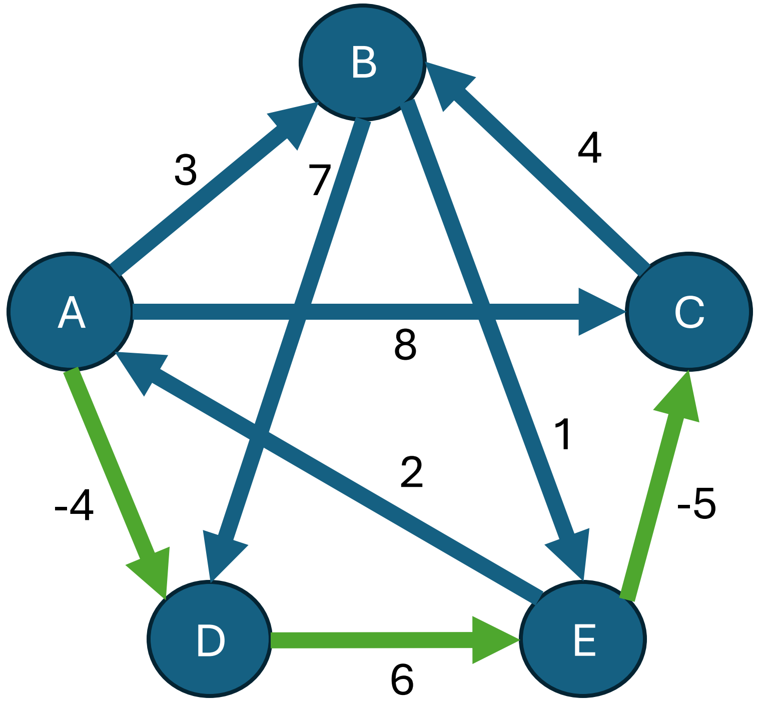
d(a,d) = 0-0+(-4) = -4

d(a,c) = 2-0+(-5) = -3

Graph computed by Bellman-Ford and reweighting



Original Graph



Total is -3!

Distances from A to every other vertex

	A	B	C	D	E
A	0	4 A	13 A	0 A	
D	0	4 A	13 A	0 A	2 D
E	0	4 A	2 E	0 A	2 D
C	0	2 C	2 E	0 A	2 D
B	0	2 C	2 E	0 A	2 D

$d(u,v)=d'(u,v)-h(u)+h(v)$

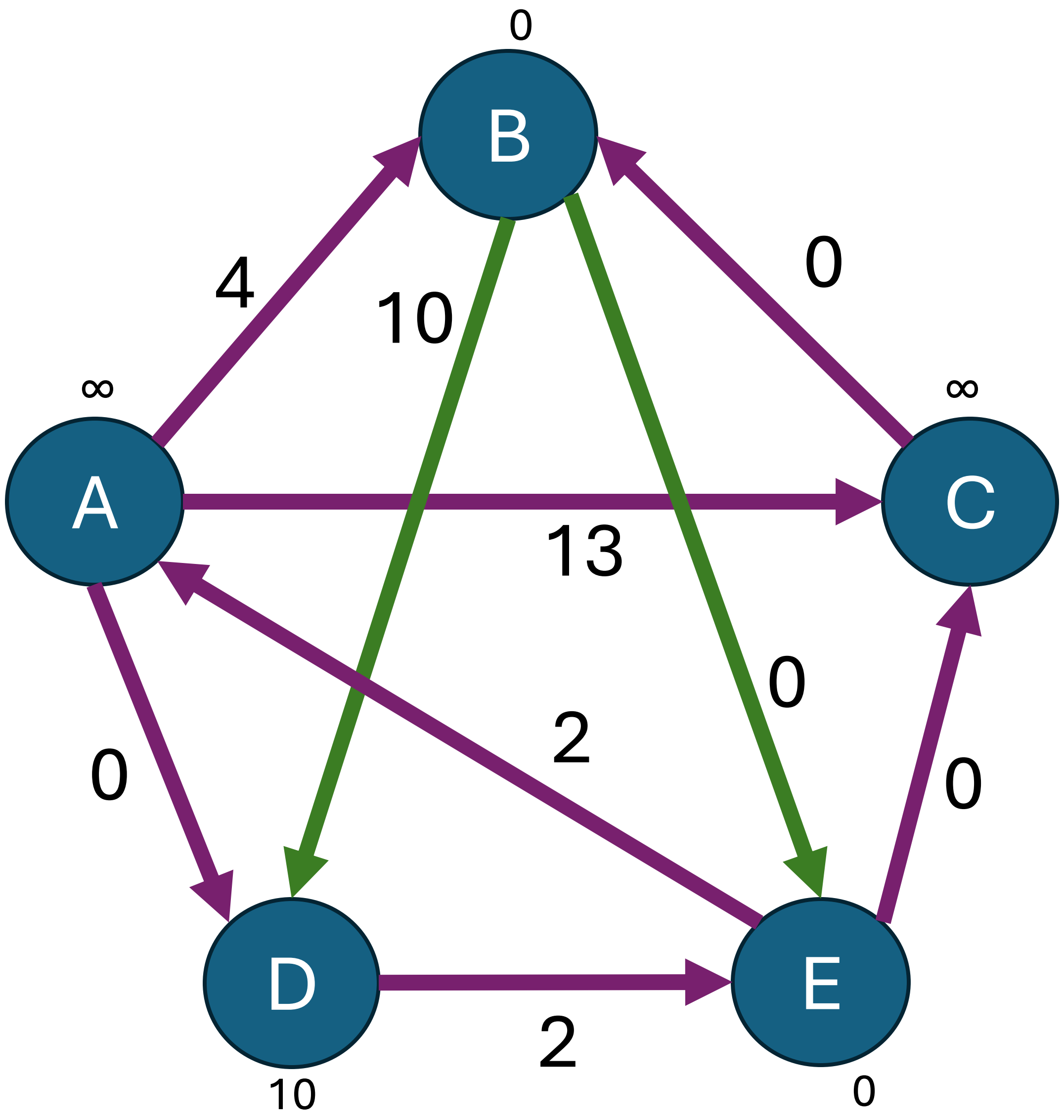
$d(a,b) = 2-0+(-1) = 1$

$d(a,d) = 0-0+(-4) = -4$

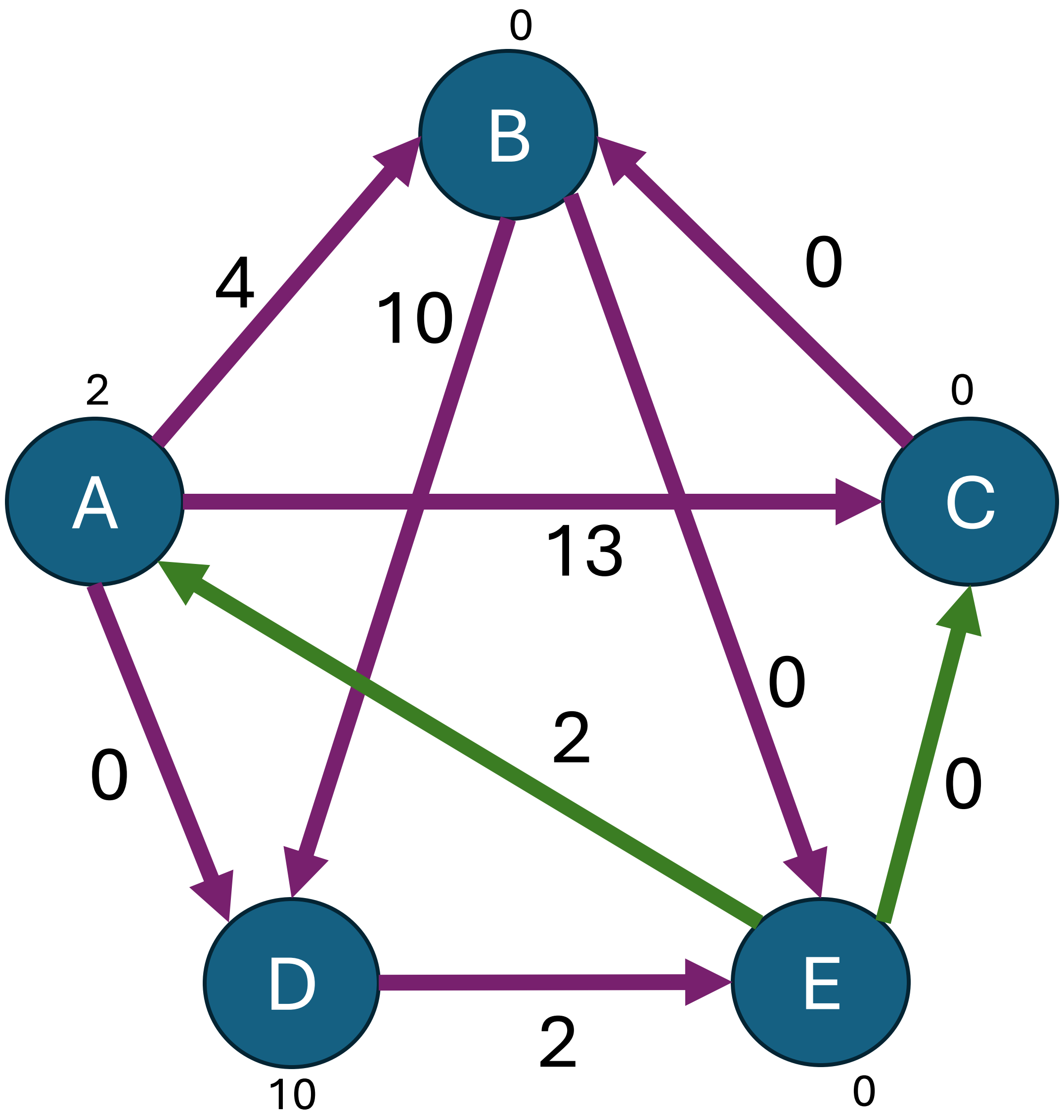
$\mathbf{d(a,c) = 2-0+(-5) = -3}$

Perform Dijkstra on every other vertex in the graph

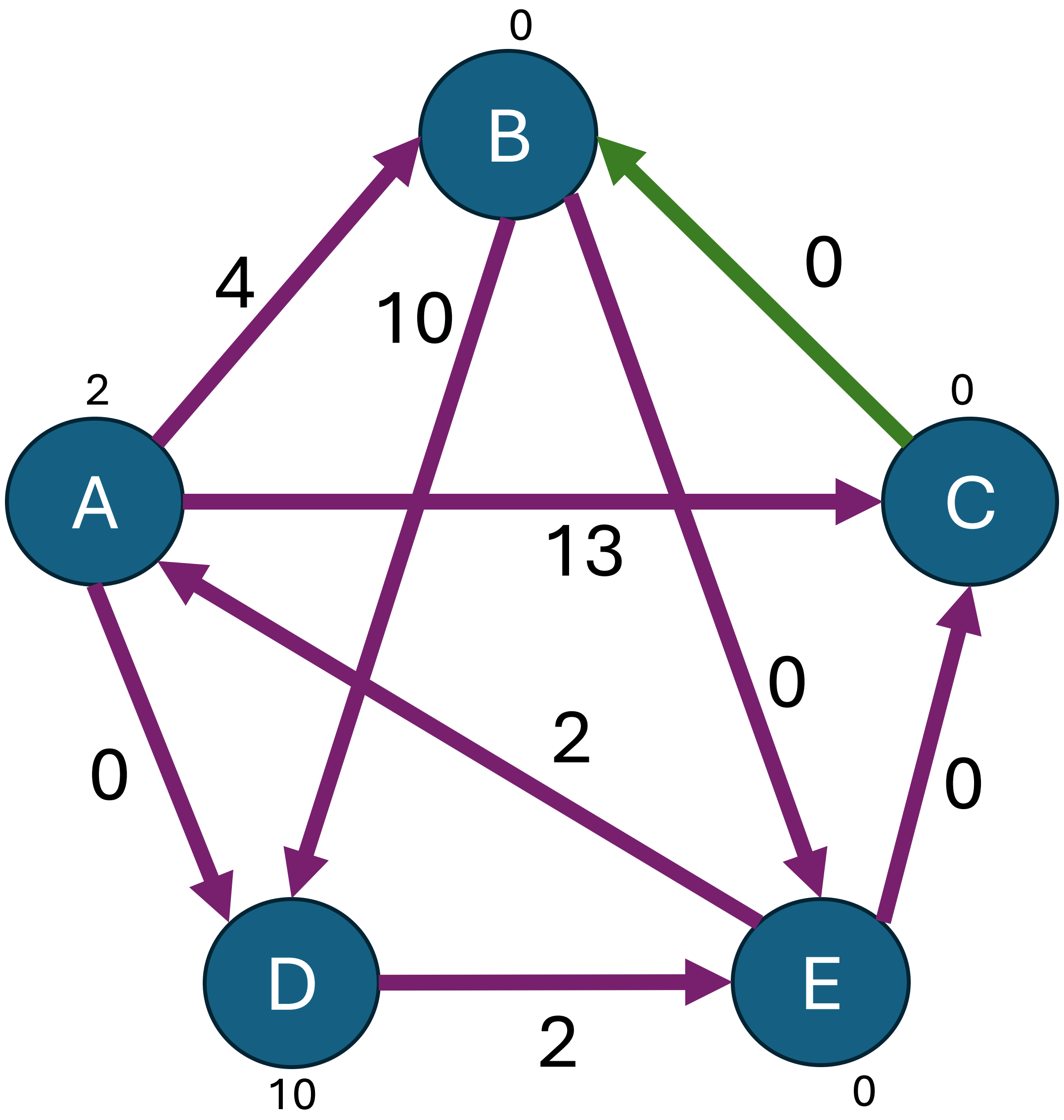
Perform Dijkstra on vertex B



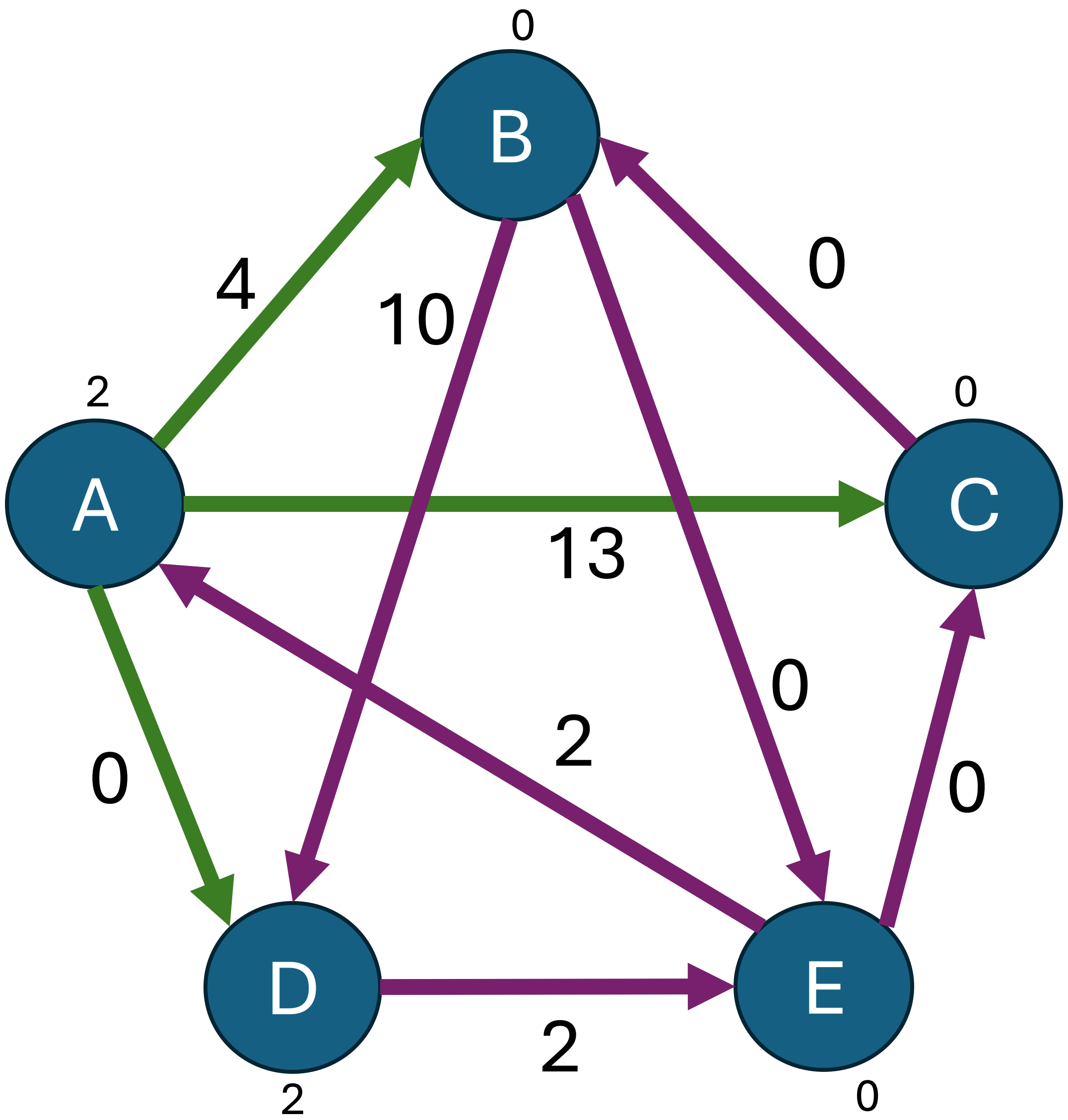
	B	A	C	D	E
B	0			10 B	0 B



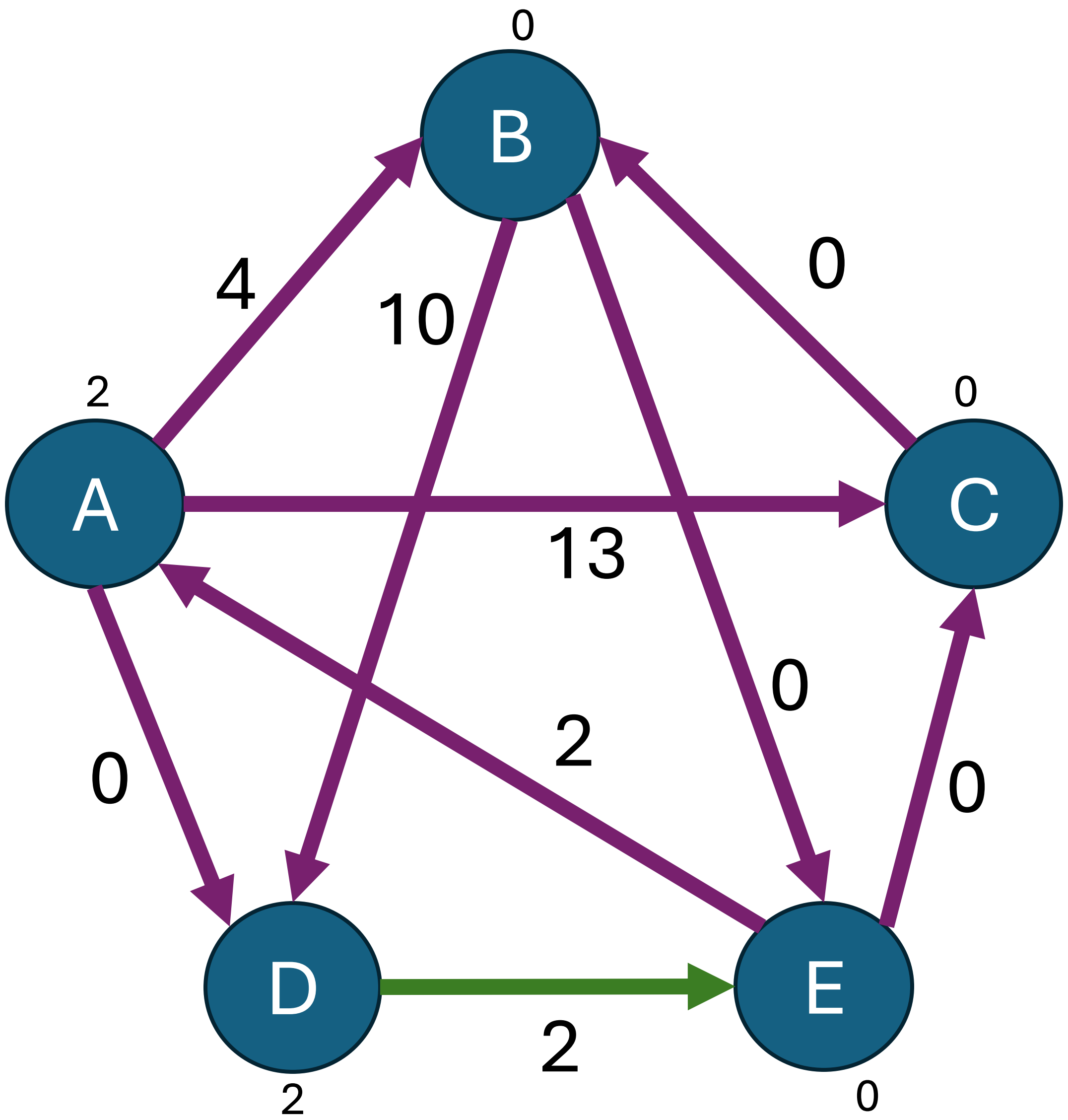
	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B



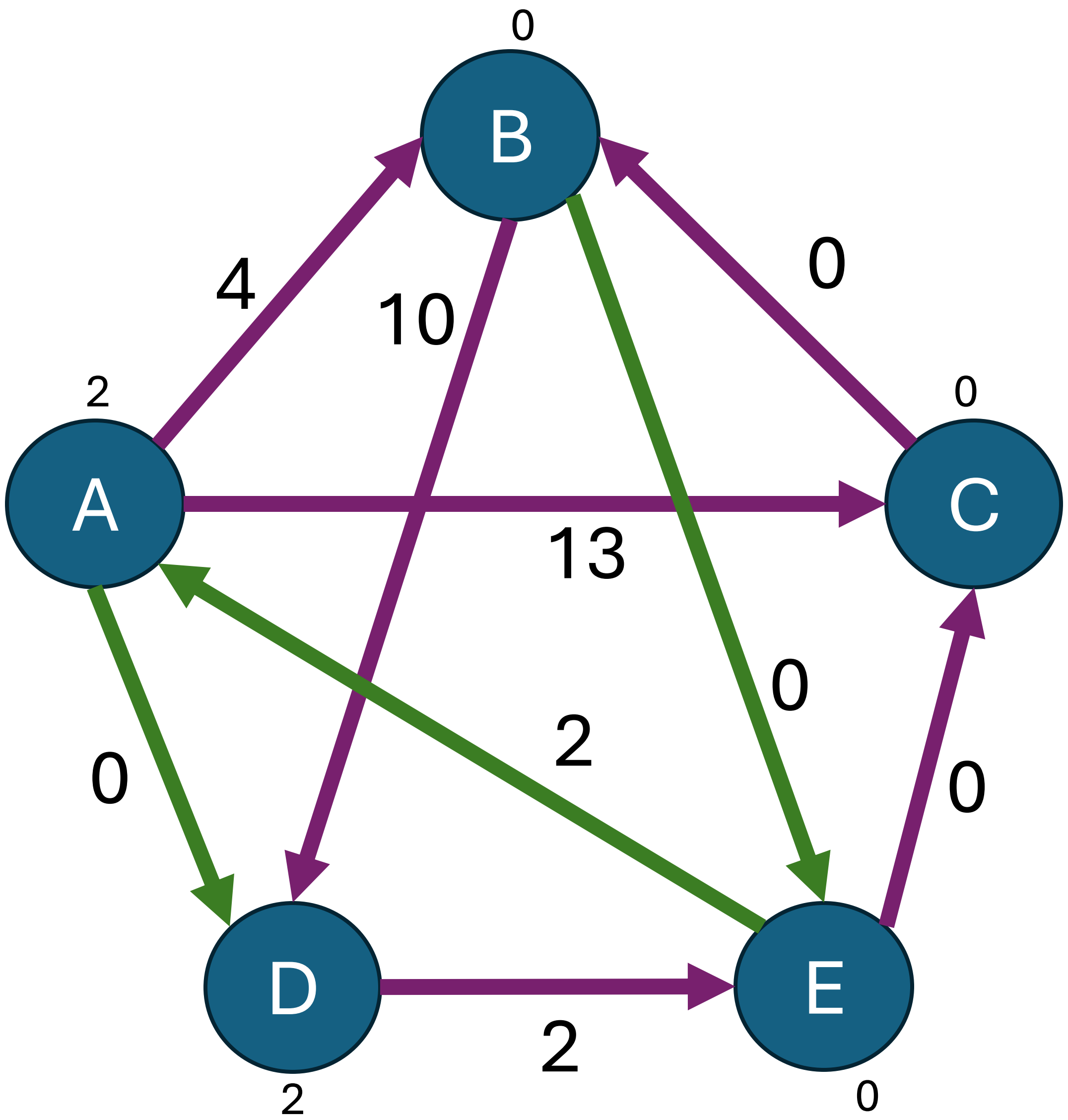
	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B
C	0	2 E	0 E	10 B	0 B



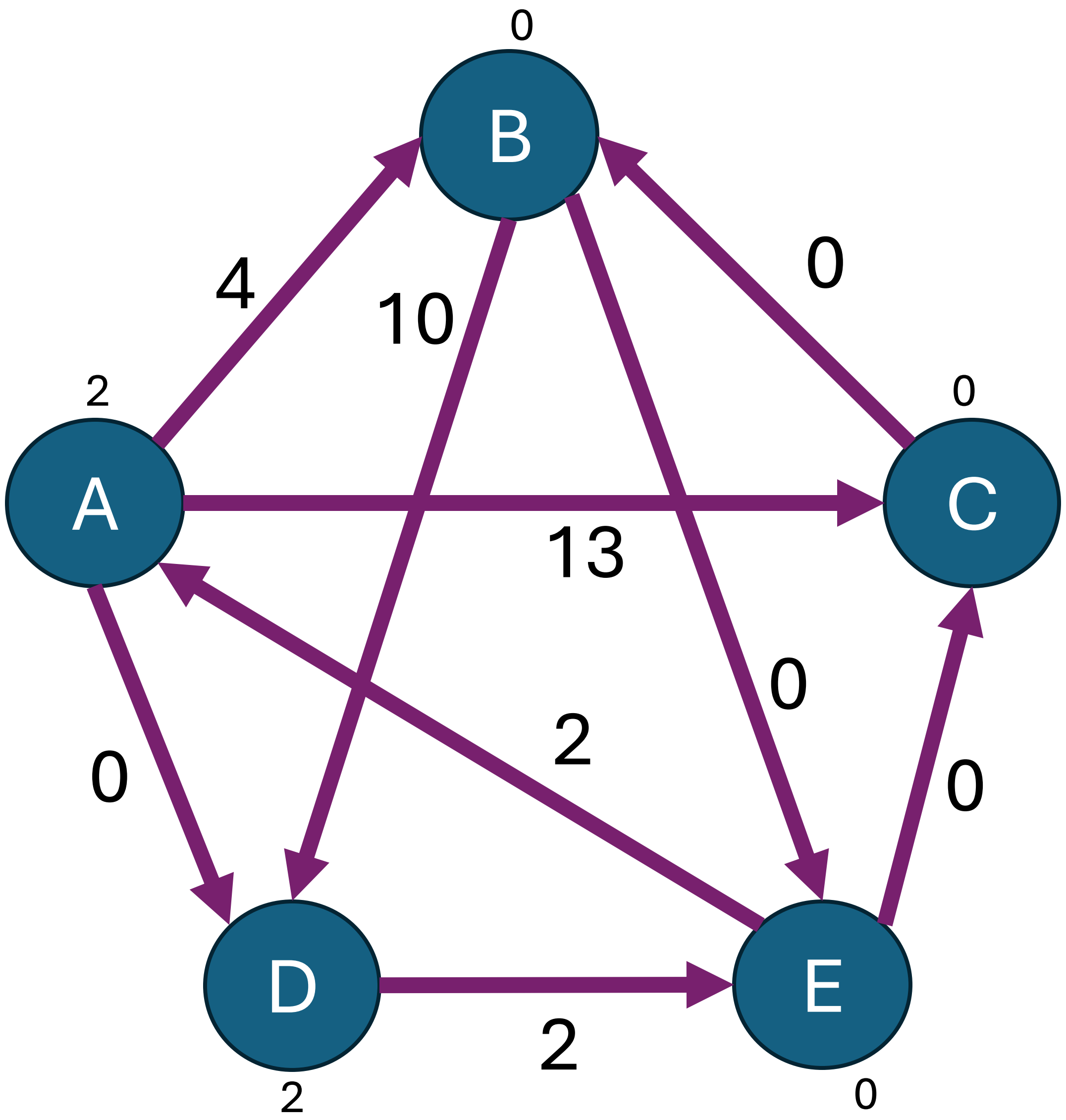
	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B
C	0	2 E	0 E	10 B	0 B
A	0	2 E	0 E	2 A	0 B



	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B
C	0	2 E	0 E	10 B	0 B
A	0	2 E	0 E	2 A	0 B
D	0	2 E	0 E	2 A	0 B

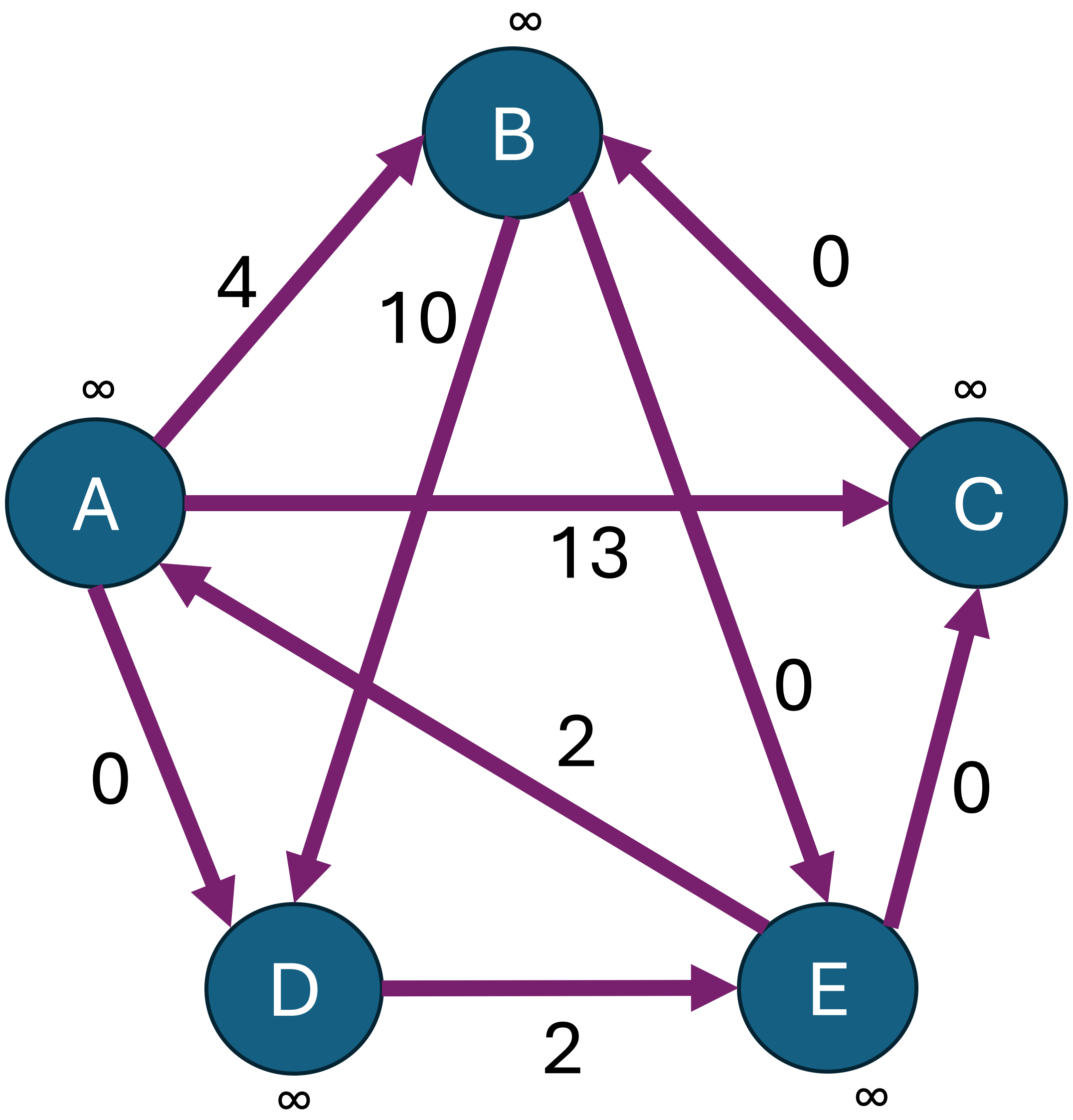


	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B
C	0	2 E	0 E	10 B	0 B
A	0	2 E	0 E	2 A	0 B
D	0	2 E	0 E	2 A	0 B

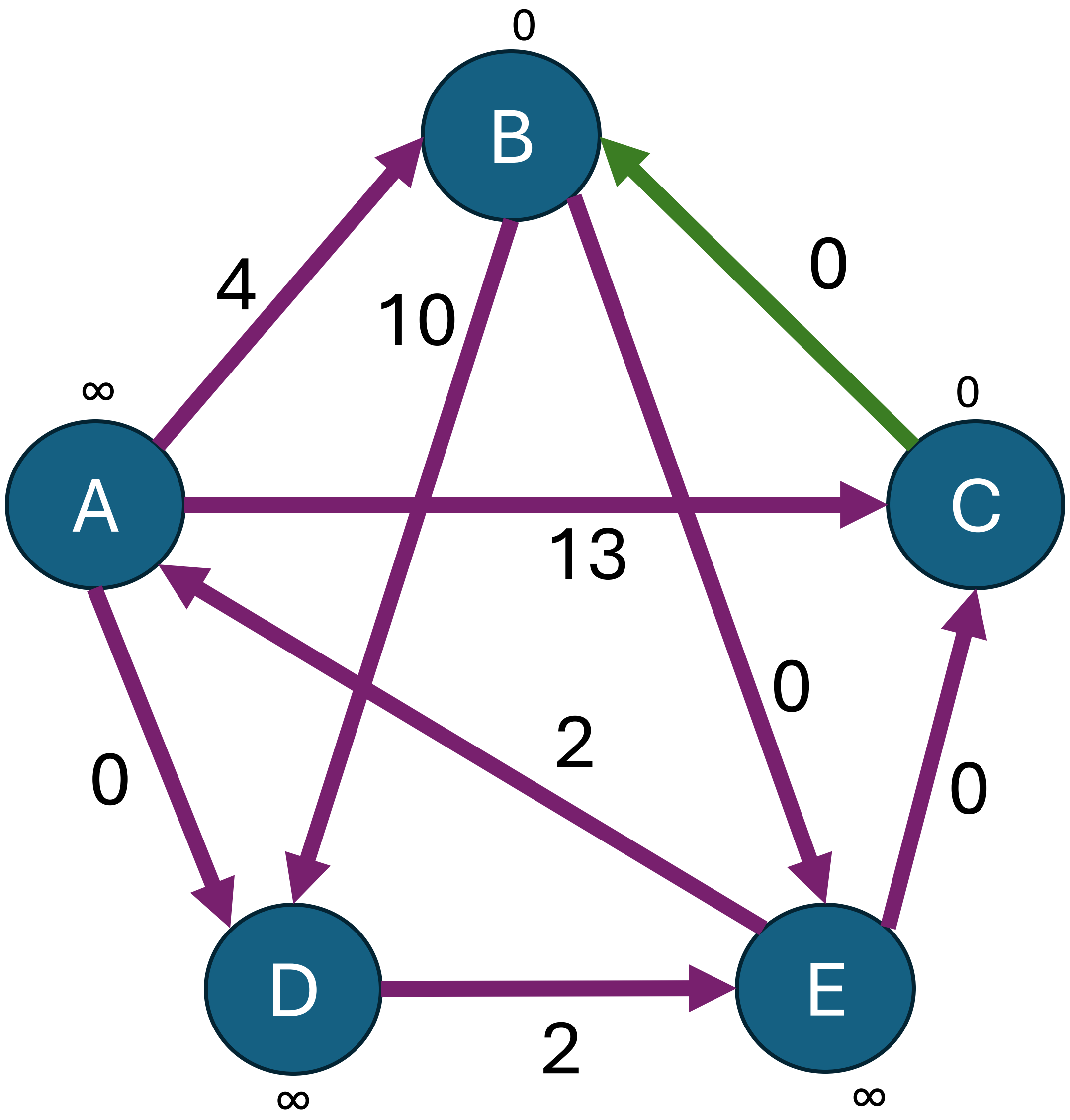


	B	A	C	D	E
B	0			10 B	0 B
E	0	2 E	0 E	10 B	0 B
C	0	2 E	0 E	10 B	0 B
A	0	2 E	0 E	2 A	0 B
D	0	2 E	0 E	2 A	0 B

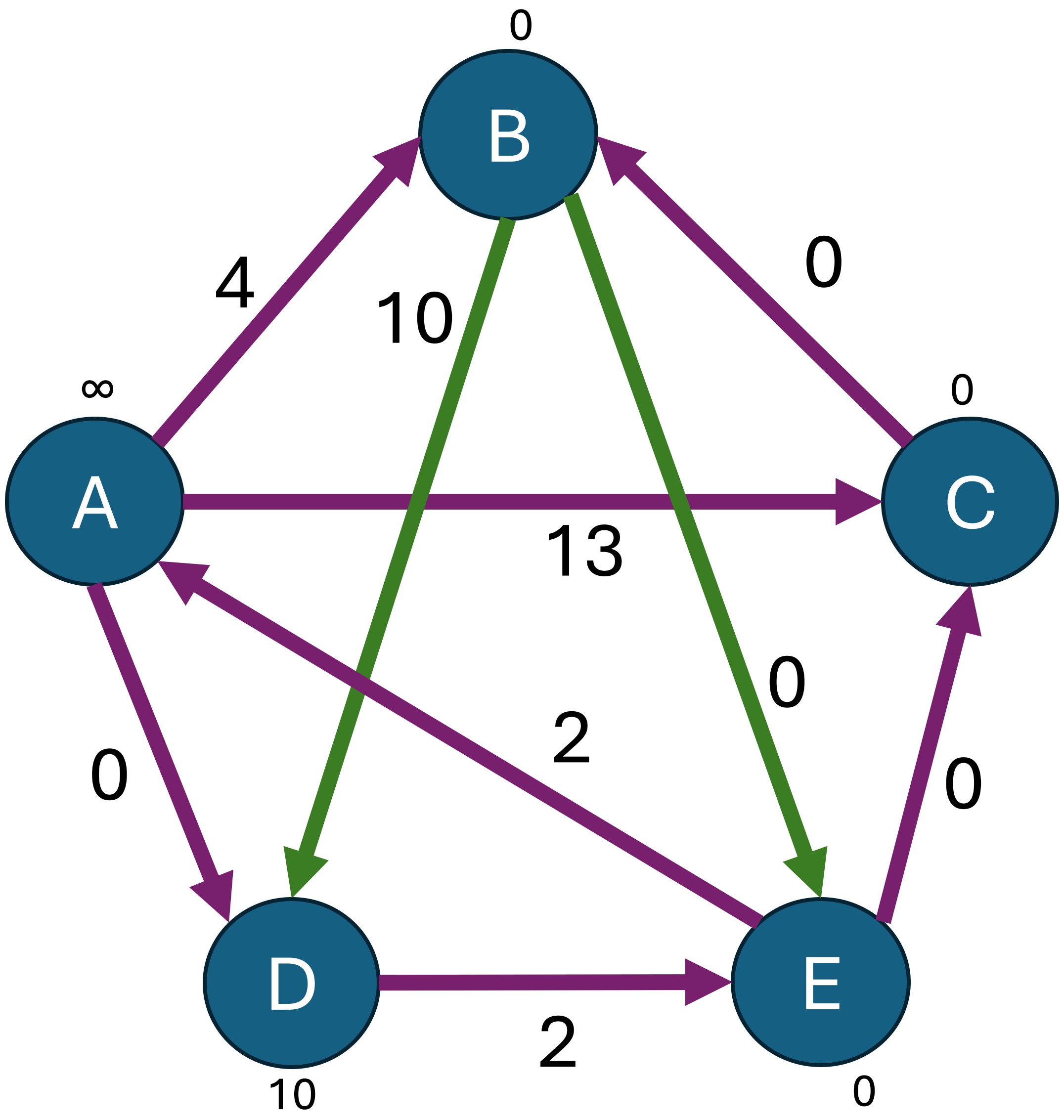
Perform Dijkstra on vertex C



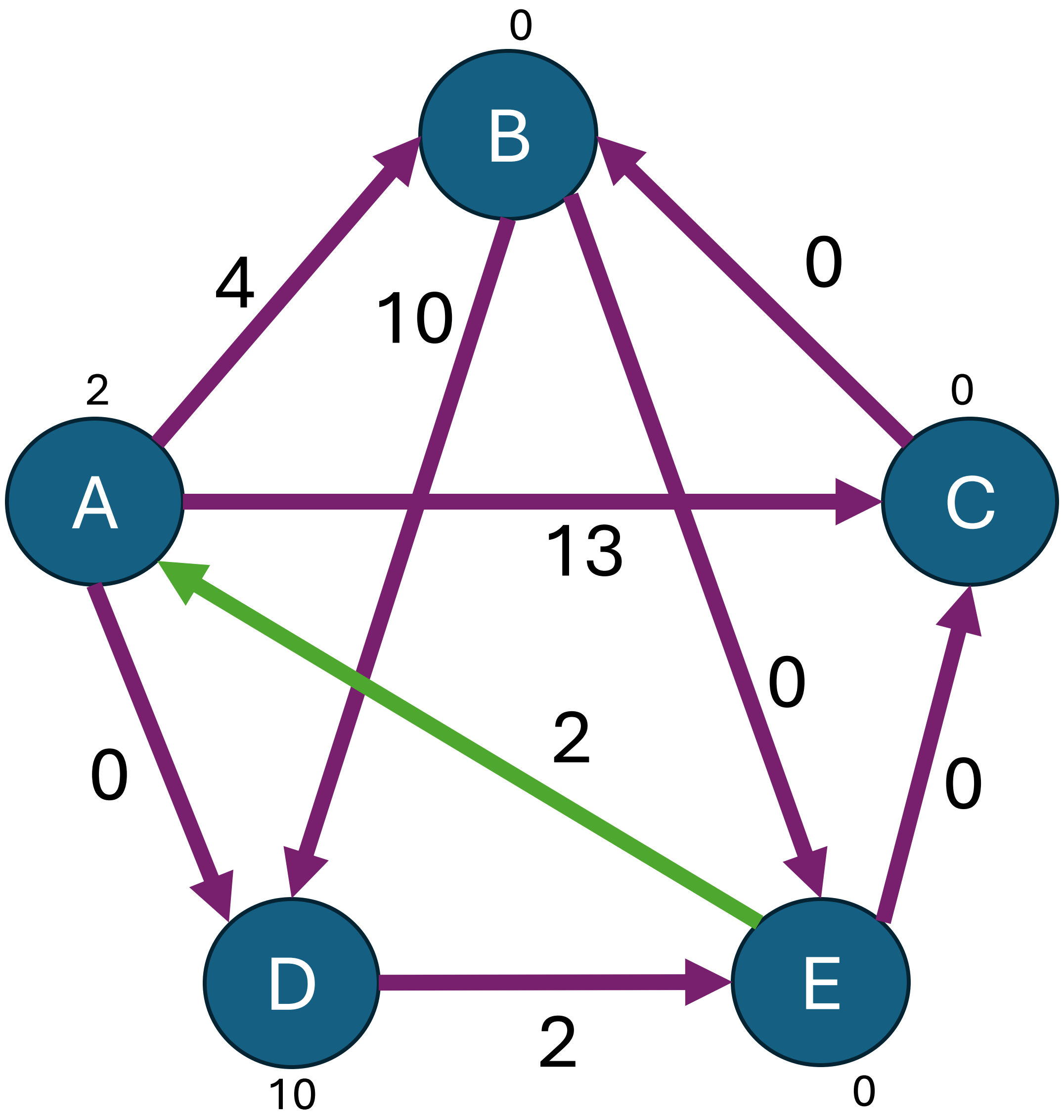
	C	A	B	D	E
C					



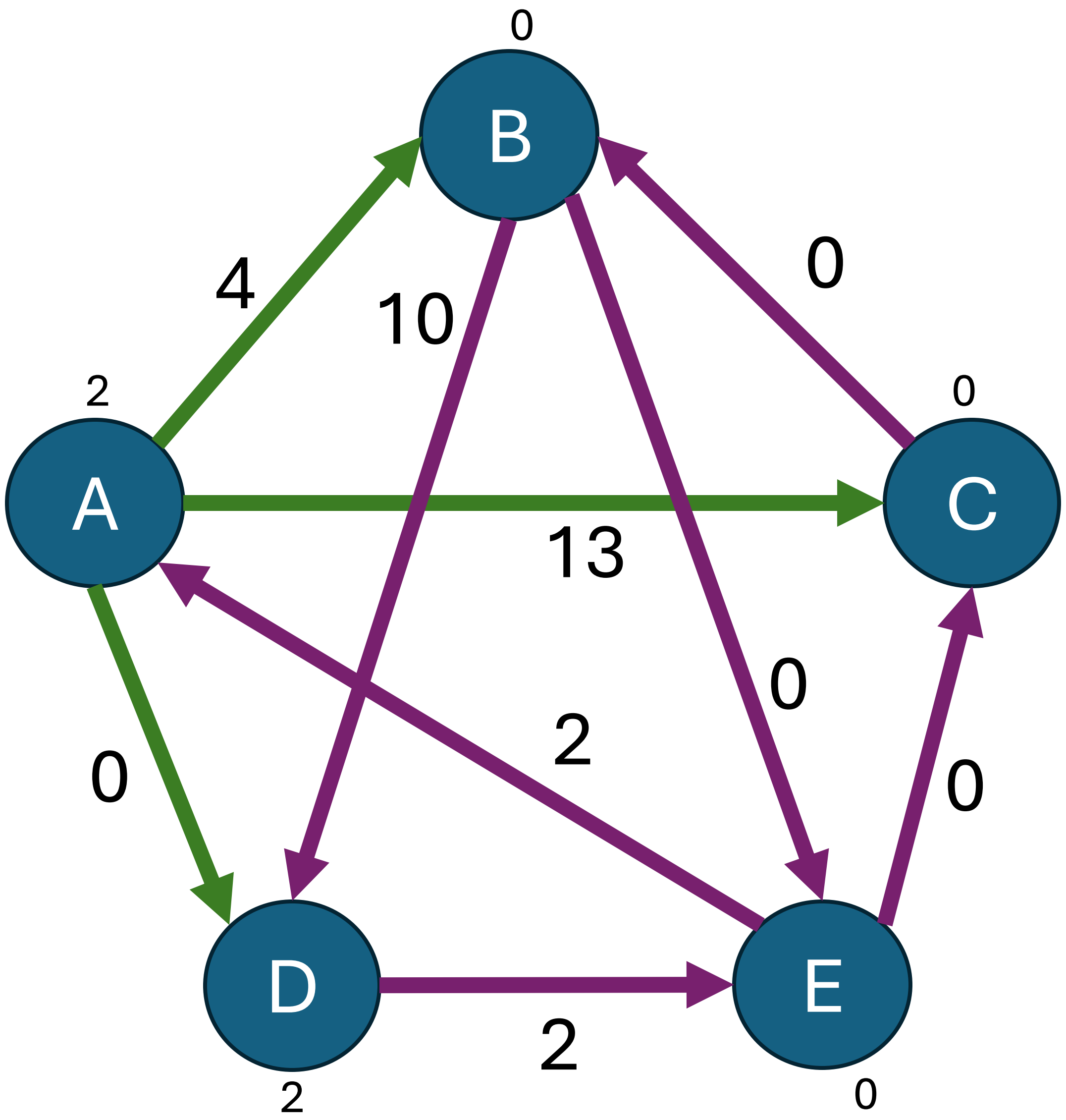
	C	A	B	D	E
C	0		0 C		



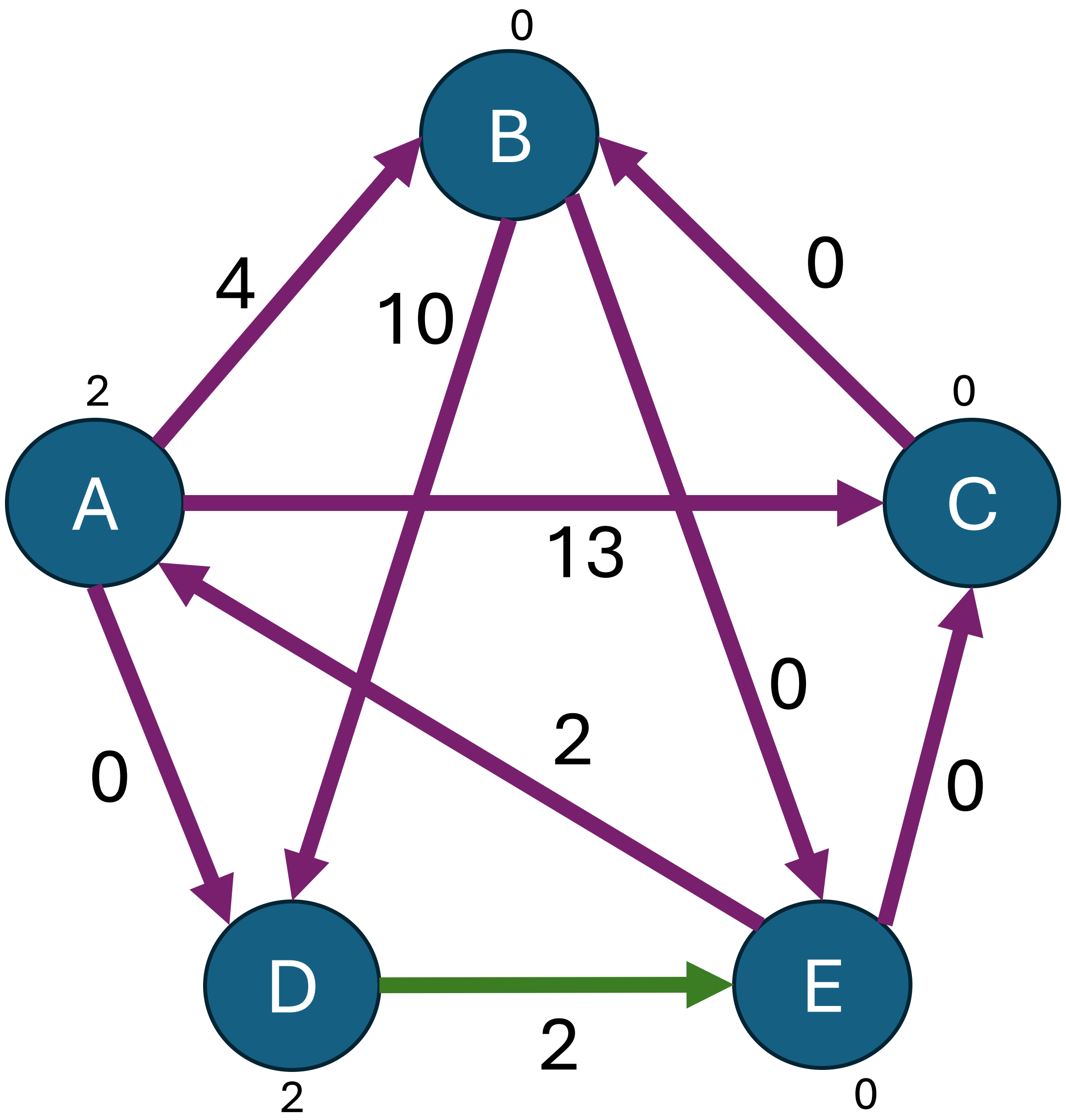
	C	A	B	D	E
C	0		0 C		
B	0		0 C	10 B	0 B



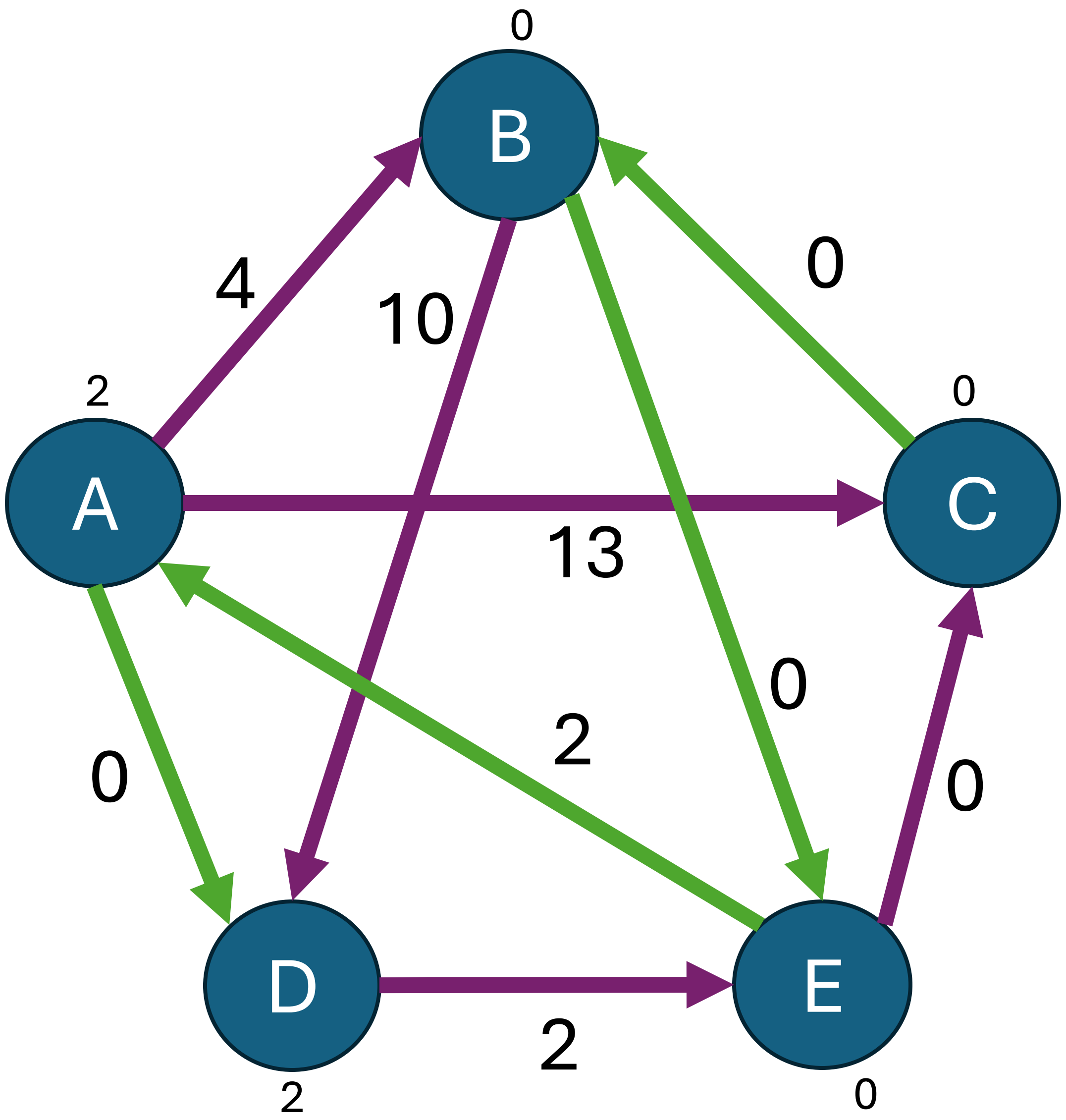
	C	A	B	D	E
C	0		0 C		
B	0		0 C	10 B	0 B
E	0	2 E	0 C	10 B	0 B



	C	A	B	D	E
C	0		0 C		
B	0		0 C	10 B	0 B
E	0	2 E	0 C	10 B	0 B
A	0	2 E	0 C	2 A	0 B



	C	A	B	D	E
C	0		0 C		
B	0		0 C	10 B	0 B
E	0	2 E	0 C	10 B	0 B
A	0	2 E	0 C	2 A	0 B
D	0	2 E	0 C	2 A	0 B



	C	A	B	D	E
C	0		0 C		
B	0		0 C	10 B	0 B
E	0	2 E	0 C	10 B	0 B
A	0	2 E	0 C	2 A	0 B
D	0	2 E	0 C	2 A	0 B