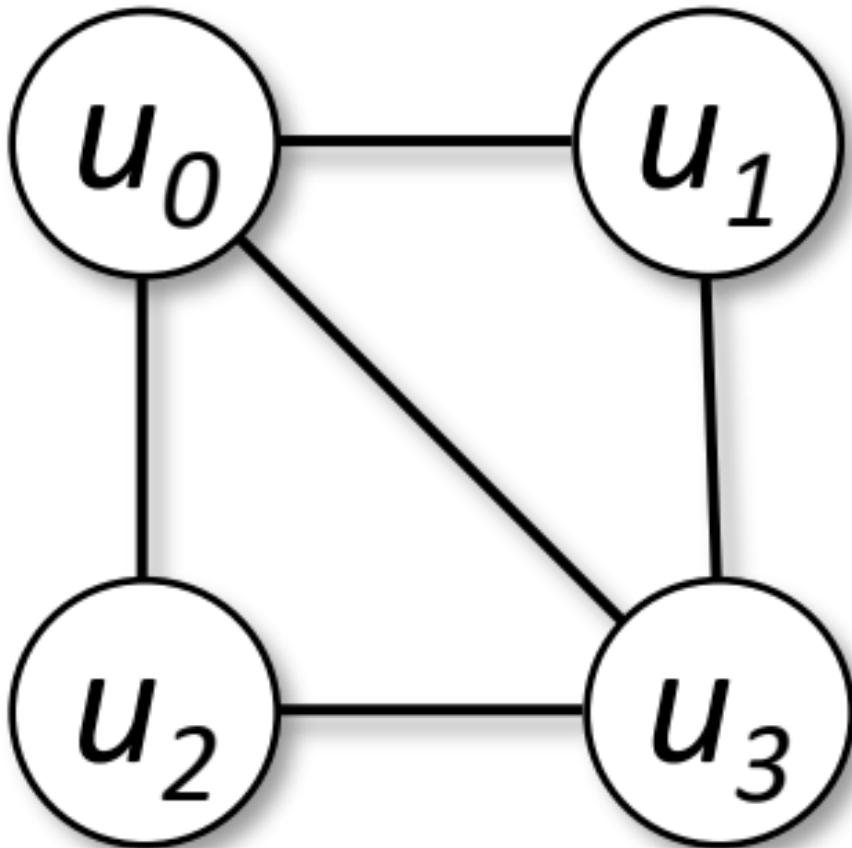
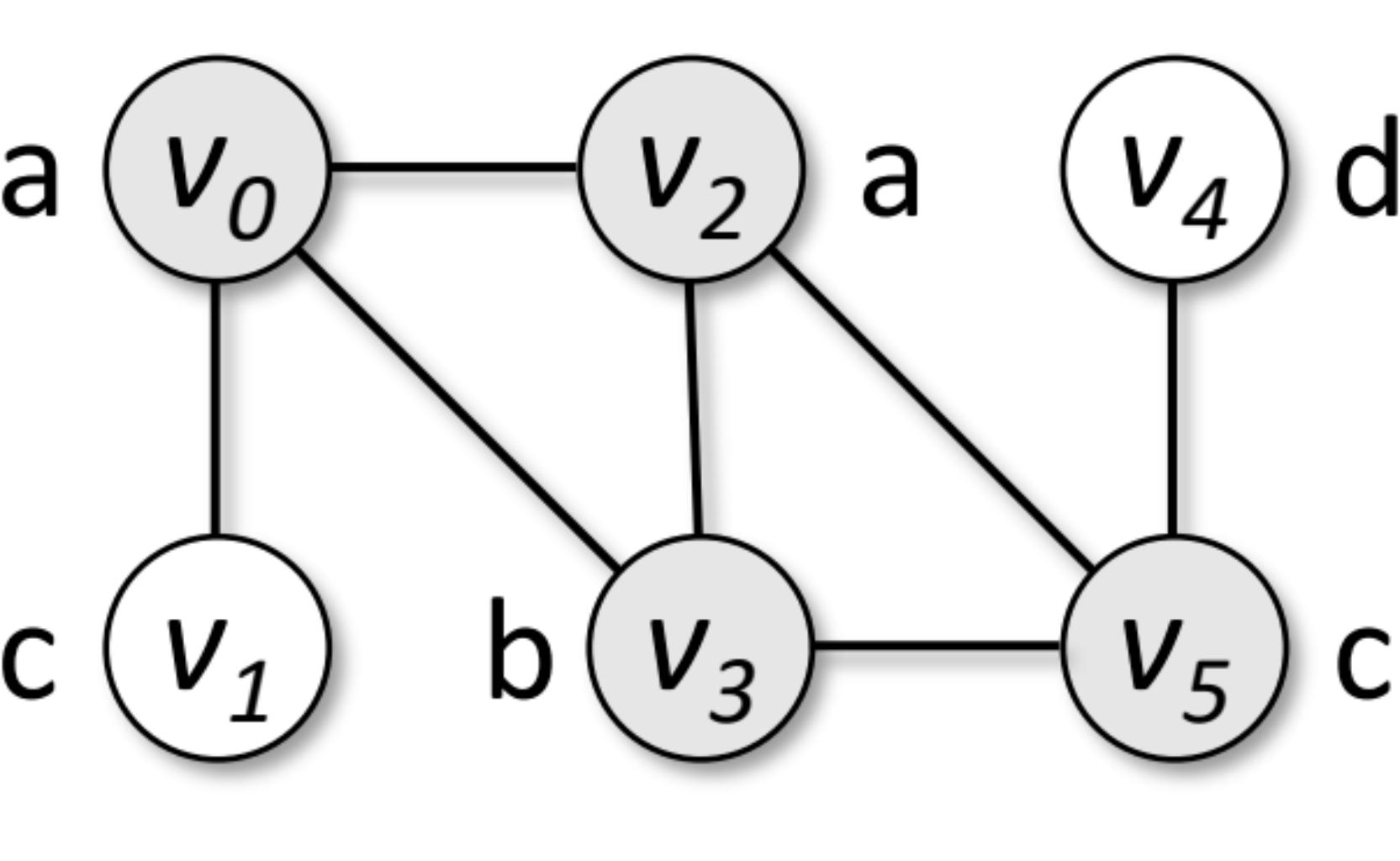
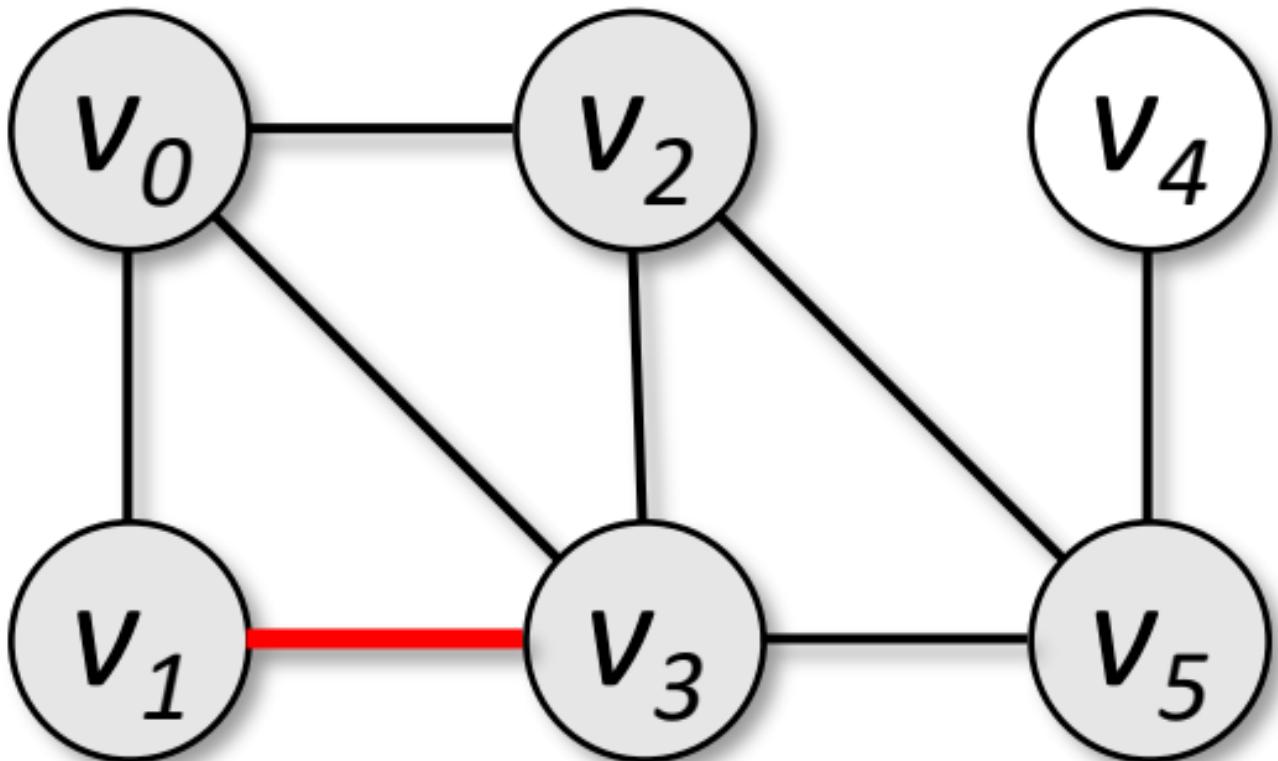


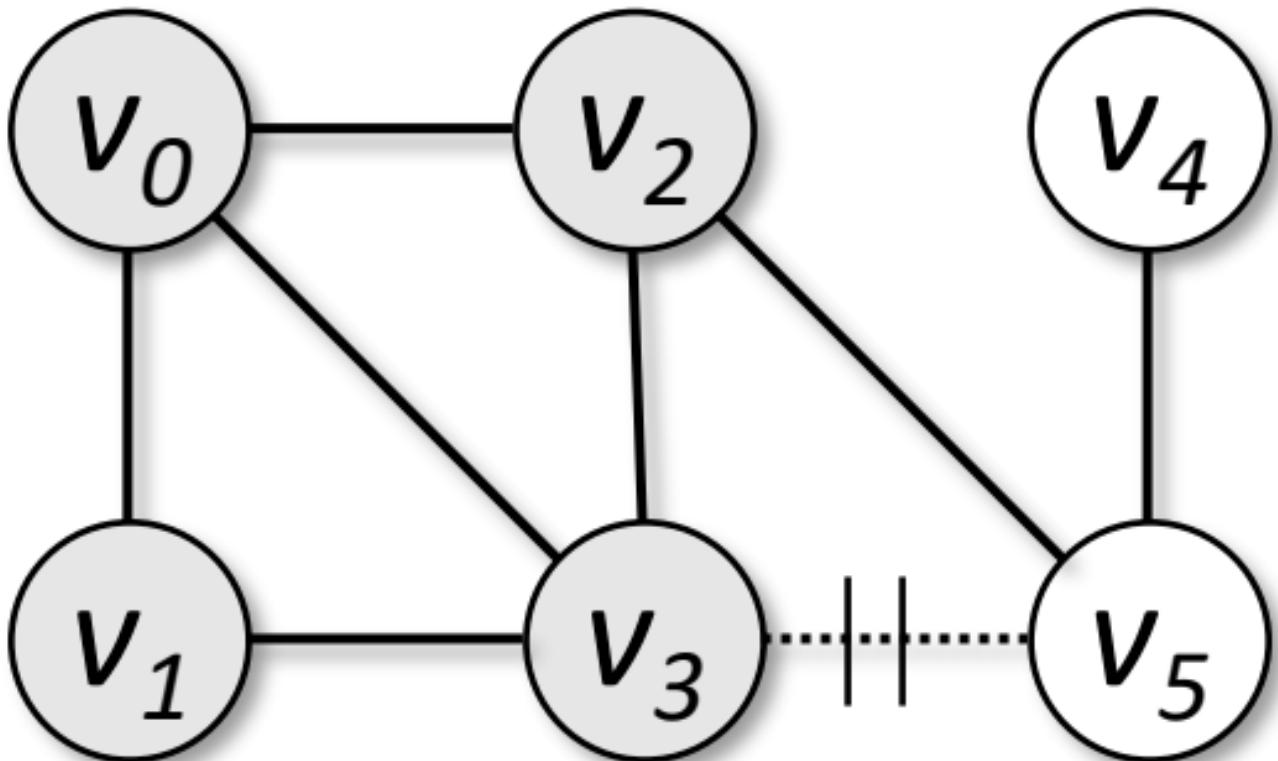
a a



c b

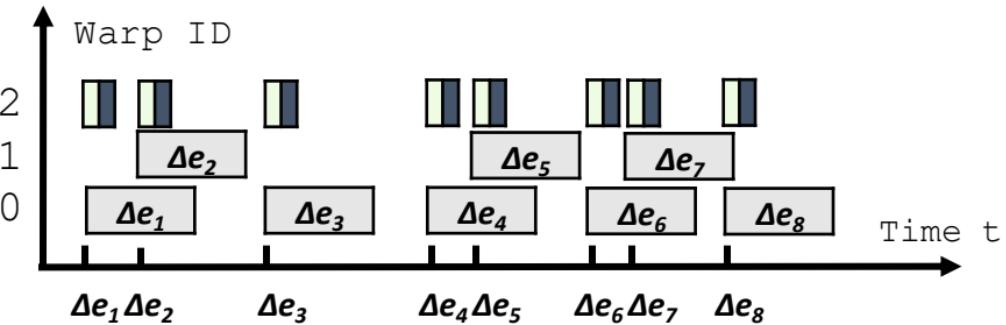
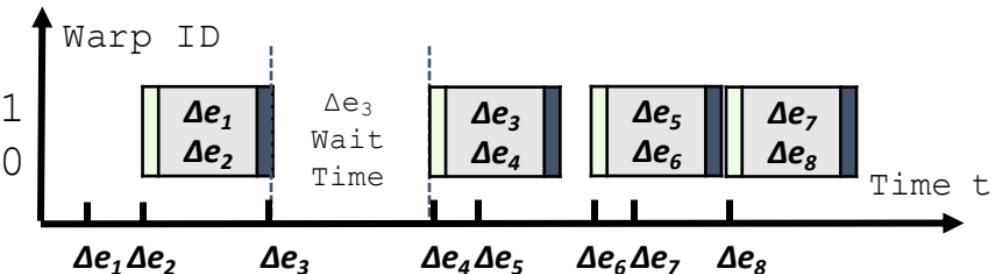
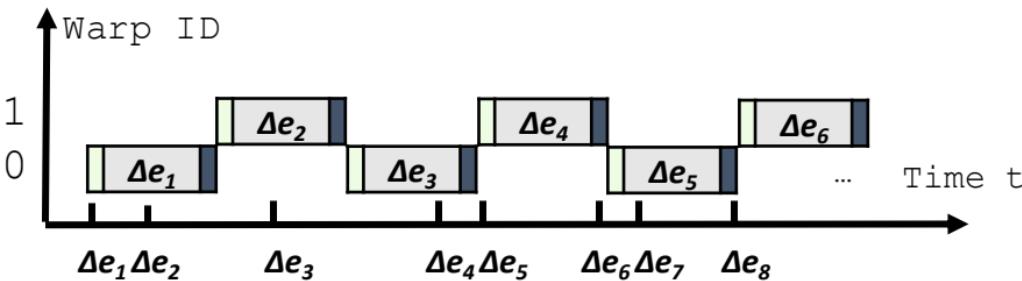


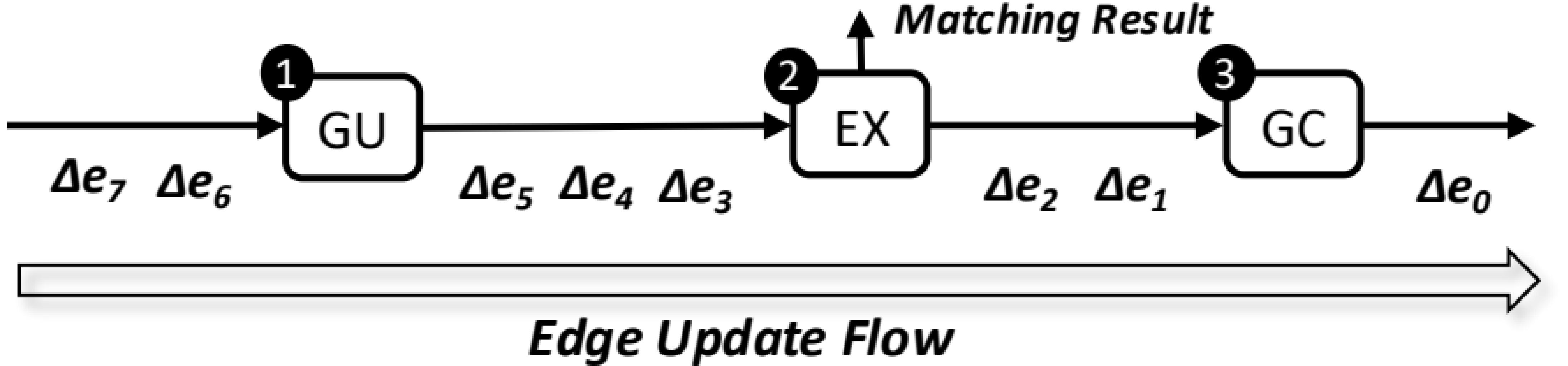

$$+(v_1, v_3)$$



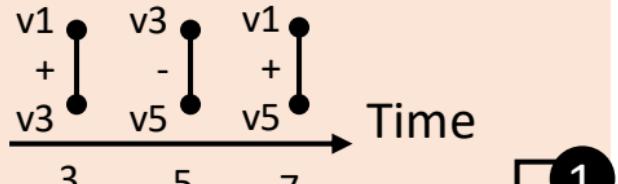
$-(v_3, v_5)$

Prepare Batch Graph
 Incremental Matching
 Update Data Graph





A Batch of Updates



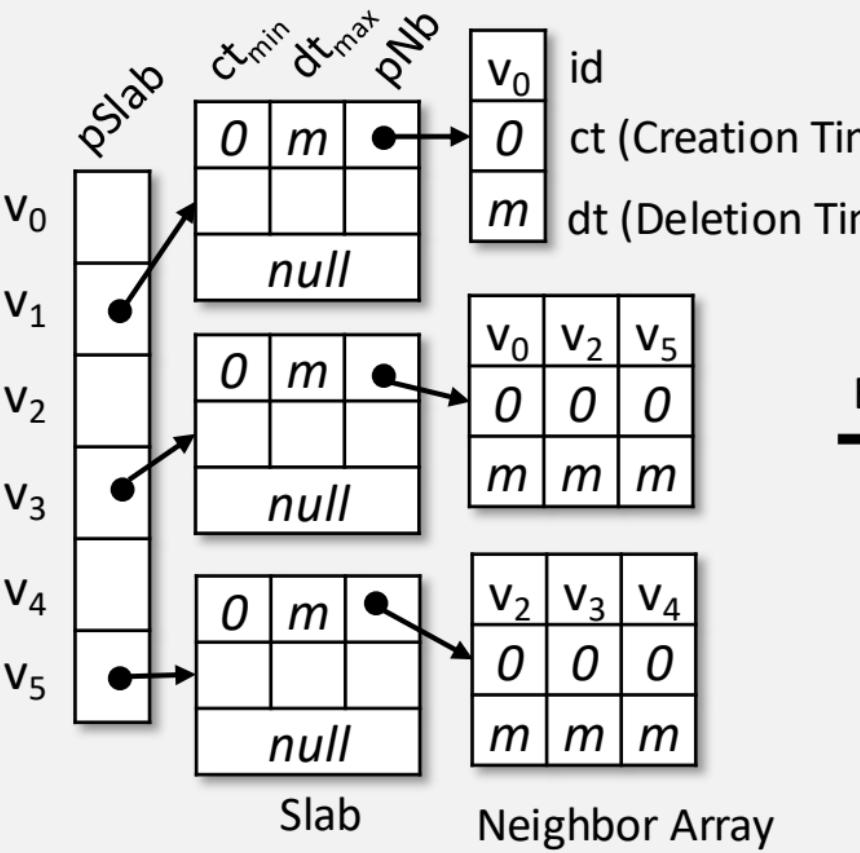
Batch Graph

	v1	v3	v5
v1	v1	v3	v5
v3	v3	v5	v5
v5	v5	v5	v5
	+ -	- +	+ +
Time	3	5	7
Type	ID	ID	Type

Prepare

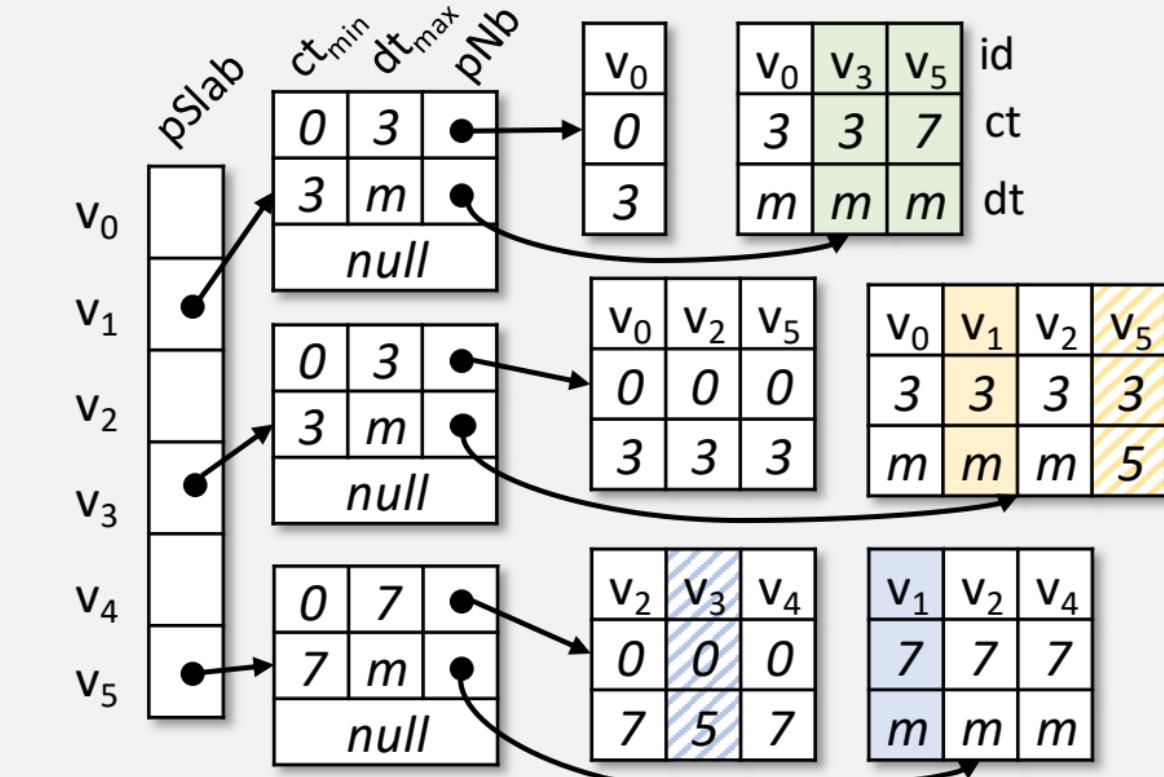
Update

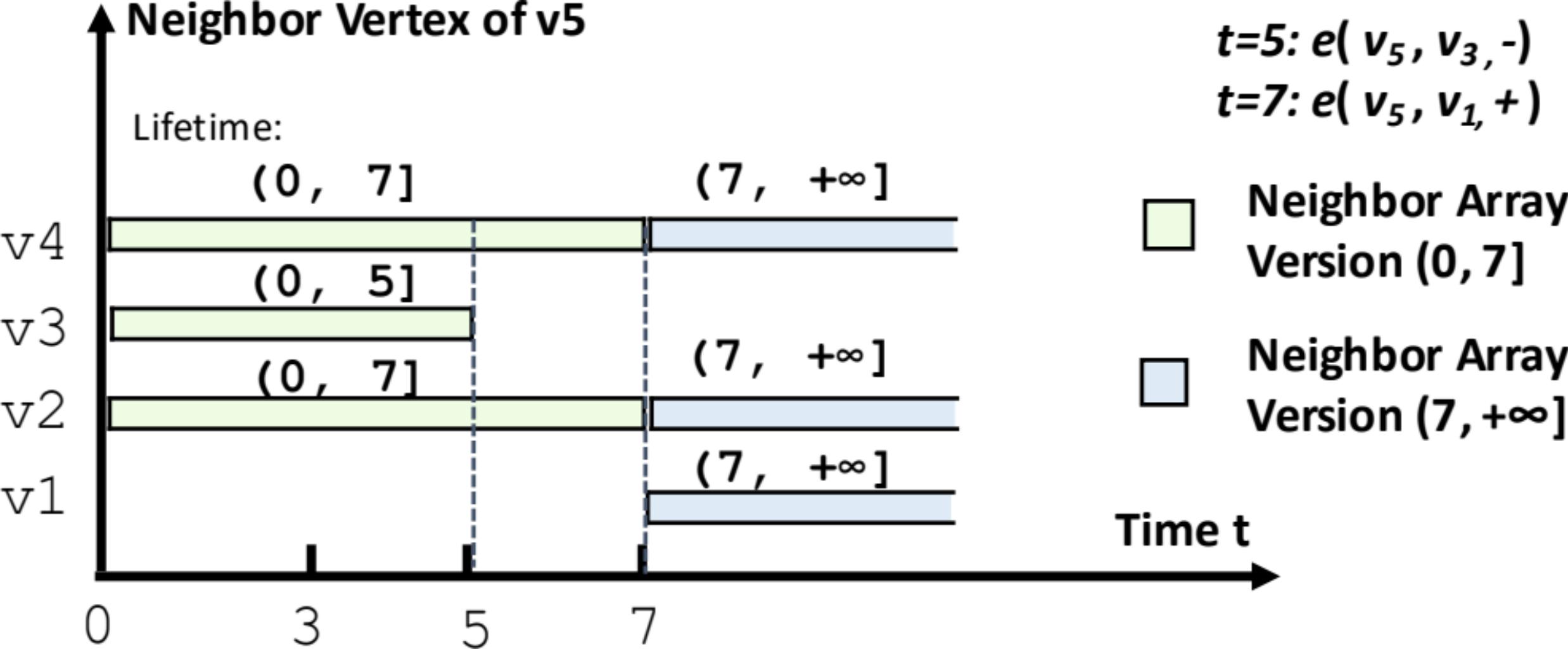
Multi-Version Graph Before Update



Become

Multi-Version Graph After Update





bps

0	1	1	1	4	4	4	
---	---	---	---	---	---	---	--

ps ↑ ② Broadcast

0	1	4	7				
---	---	---	---	--	--	--	--

size ↑ ① Prefix Sum

1	3	3					
---	---	---	--	--	--	--	--

np

*V ₁	*V ₃	*V ₅					
-----------------	-----------------	-----------------	--	--	--	--	--

bnp ↓ ② Broadcast

*V ₁	*V ₃	*V ₃	*V ₃	*V ₅	*V ₅	*V ₅	
-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	--

↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑
0 1 2 3 4 5 6 7

thread id

dst

V ₀	V ₀	V ₂	V ₅	V ₂	V ₃	V ₄	
----------------	----------------	----------------	----------------	----------------	----------------	----------------	--

src ↑ ④ Async Copy

V ₀	V ₀	V ₂	V ₅	V ₂	V ₃	V ₄	
----------------	----------------	----------------	----------------	----------------	----------------	----------------	--

bnp ||

*V ₁	*V ₃	*V ₃	*V ₃	*V ₅	*V ₅	*V ₅	
-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	-----------------	--

idx + ③ Add

0	0	1	2	0	1	2	
---	---	---	---	---	---	---	--

↑ ↑ ↑ ↑ ↑ ↑ ↑ ↑
0 1 2 3 4 5 6 7

thread id

$$\Delta e_0 = (v1, v3 +), \quad T(\Delta e_0) = 3$$

$$\Delta e_1 = (v2, v5, -), \quad T(\Delta e_1) = 5$$

$$\Delta e_2 = (v1, v5, +), \quad T(\Delta e_2) = 7$$

Δe_2 t=7

Δe_1 t=5

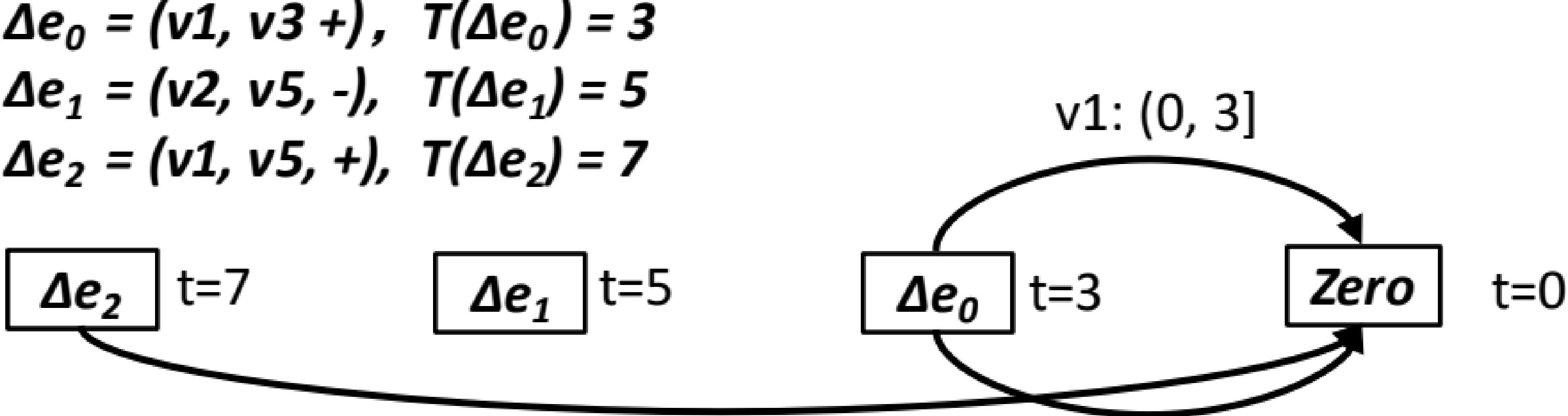
Δe_0 t=3

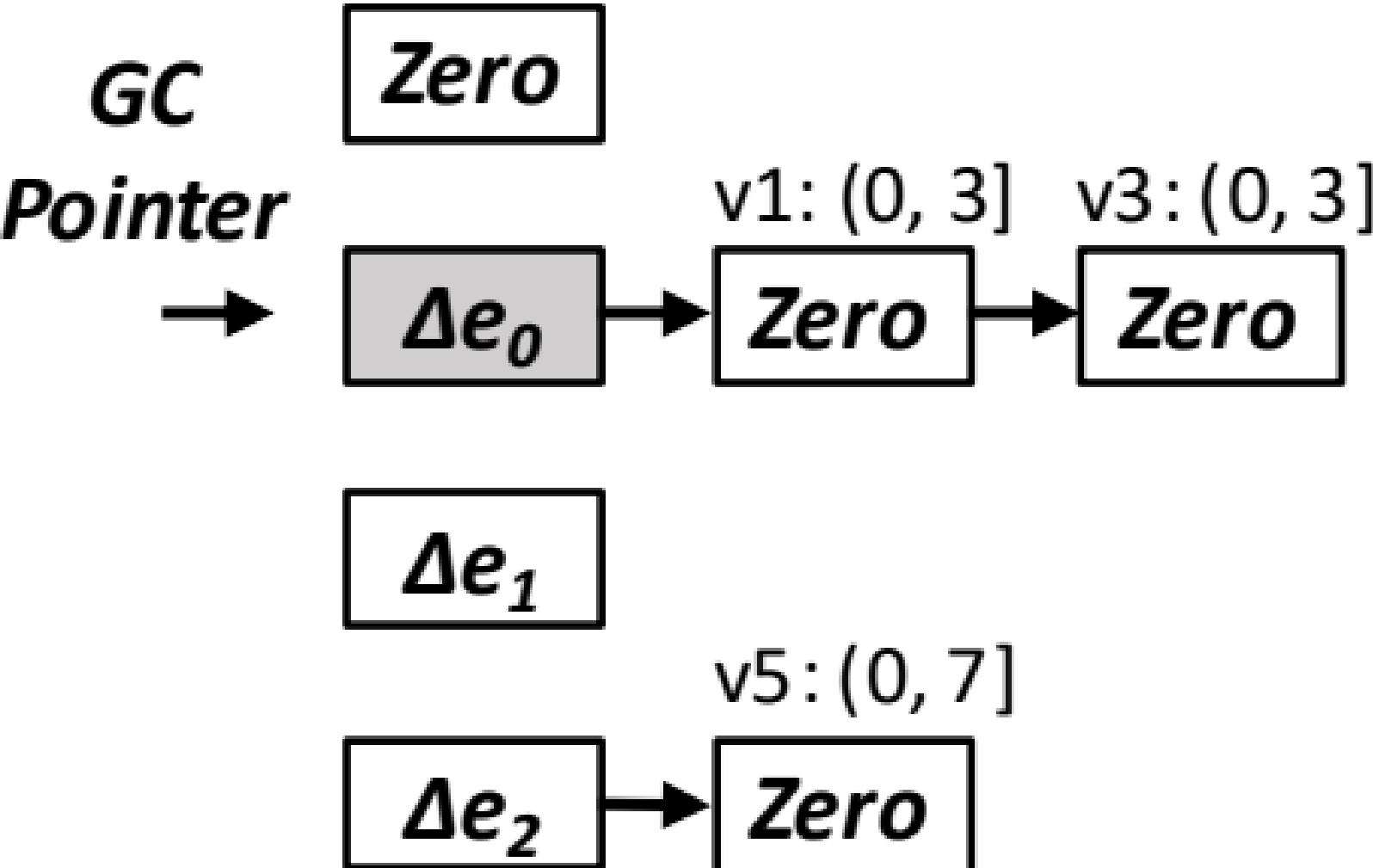
Zero t=0

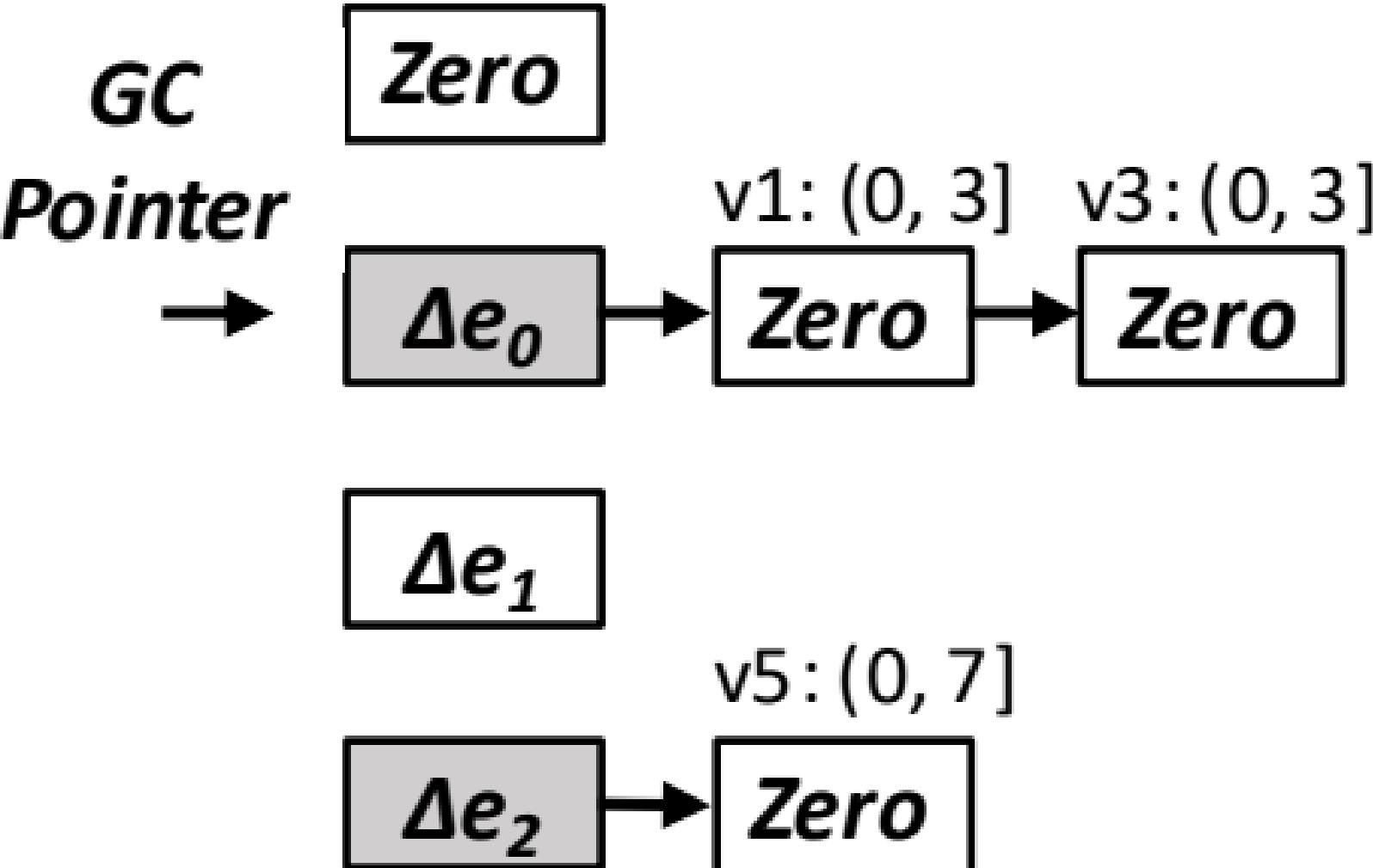
v5: (0, 7]

v3: (0, 3]

v1: (0, 3]







Zero

v1: (0, 3] v3: (0, 3]

Δe_0

Zero

Zero

GC

Δe_1

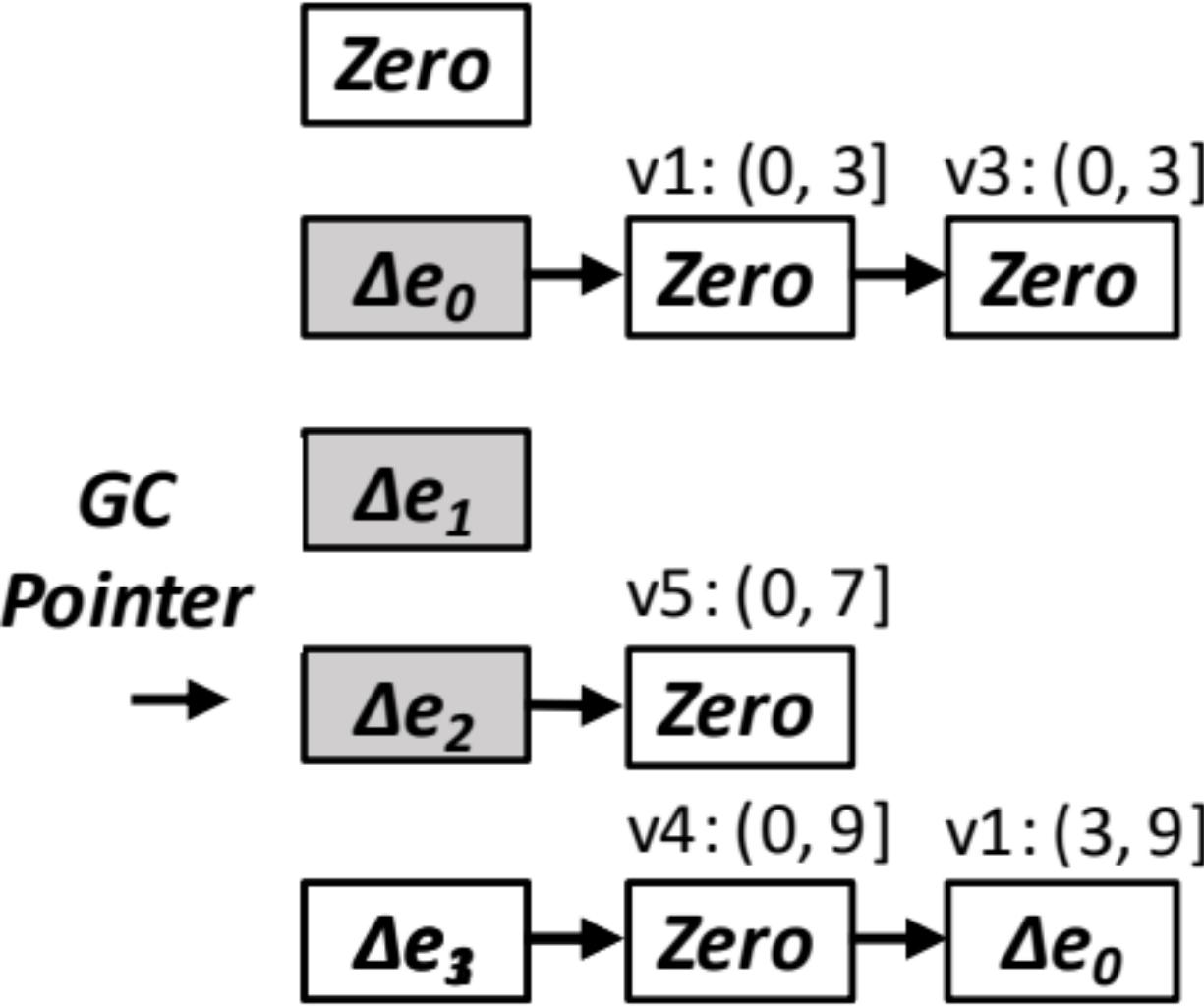
v5: (0, 7]

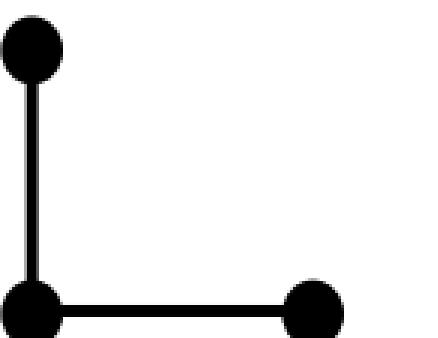
Pointer



Δe_2

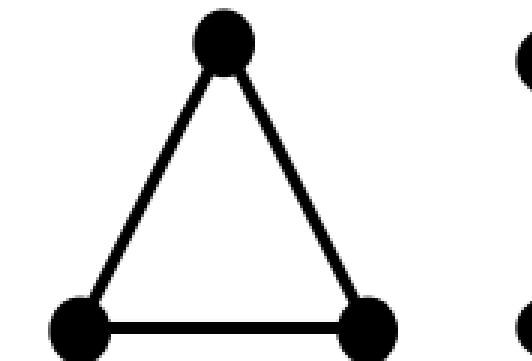
Zero





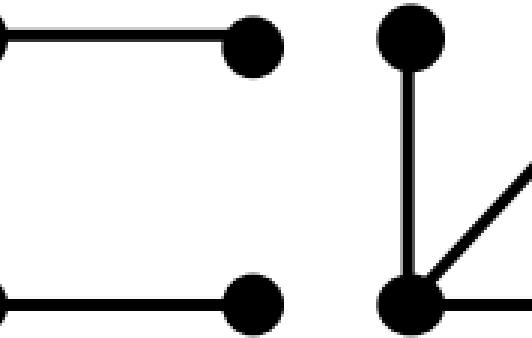
wedge

Q1



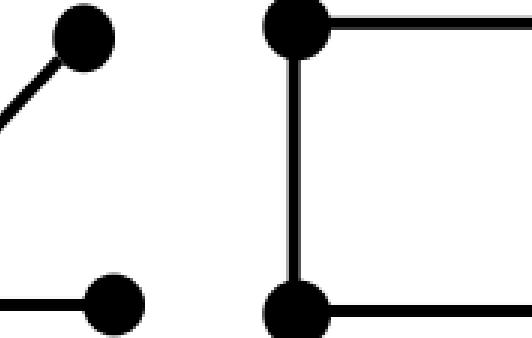
triangle

Q2



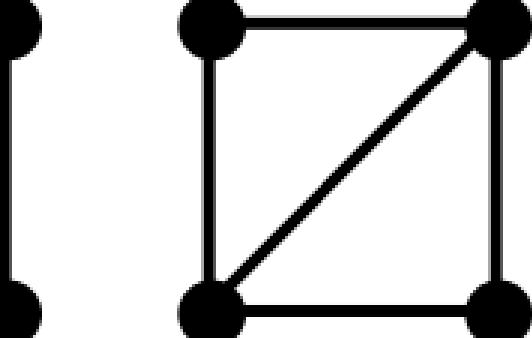
4-path

Q3



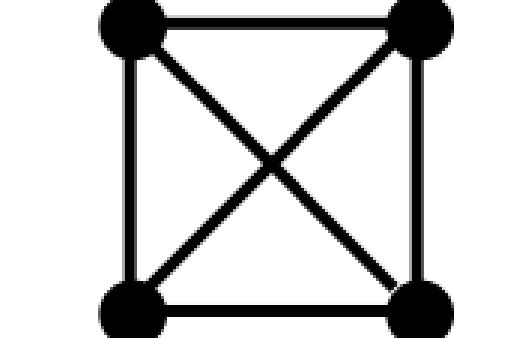
3-star

Q4



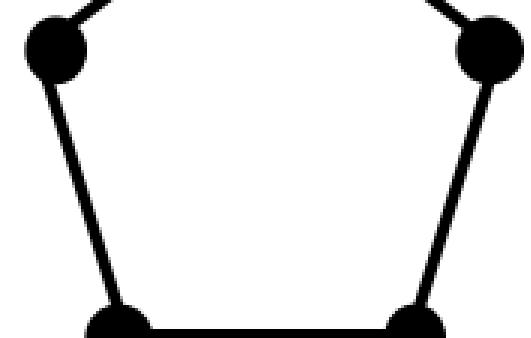
4-cycle

Q5



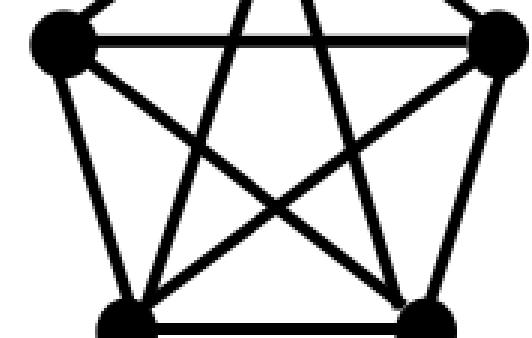
diamond

Q6



4-clique

Q7



5-cycle

Q8



5-clique

Q9

