An Efficient Insertion Operator in Dynamic Ridesharing Services

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Outline

- Background
- Problem Statement
- Partition-based Framework
- Segment-based DP Algorithm
- Experiments
- Conclusion

Dynamic Ridesharing Services

- Dynamic ridesharing: services that arrange one-time shared rides on short notice

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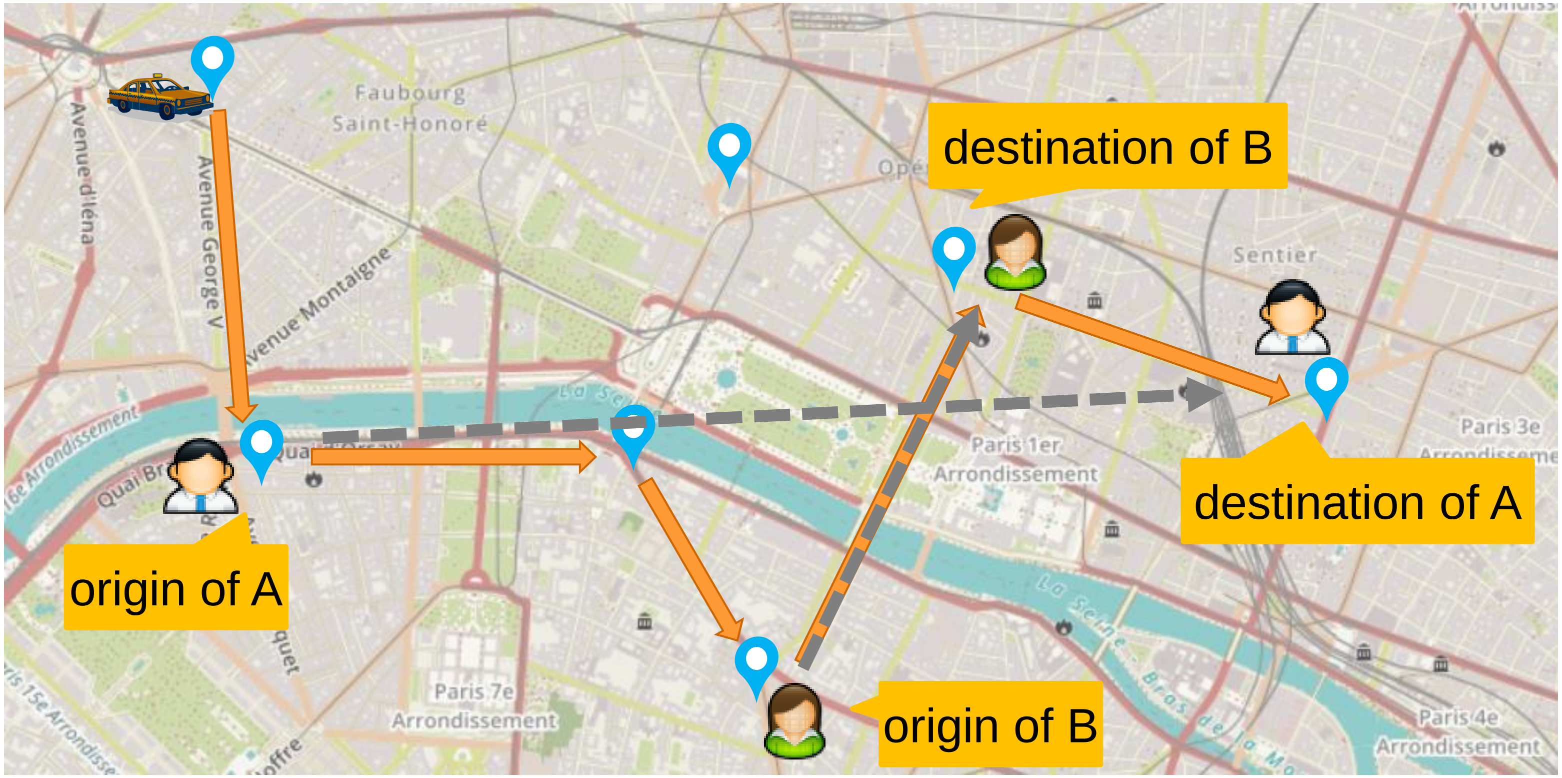
  - **Car-pooling**,



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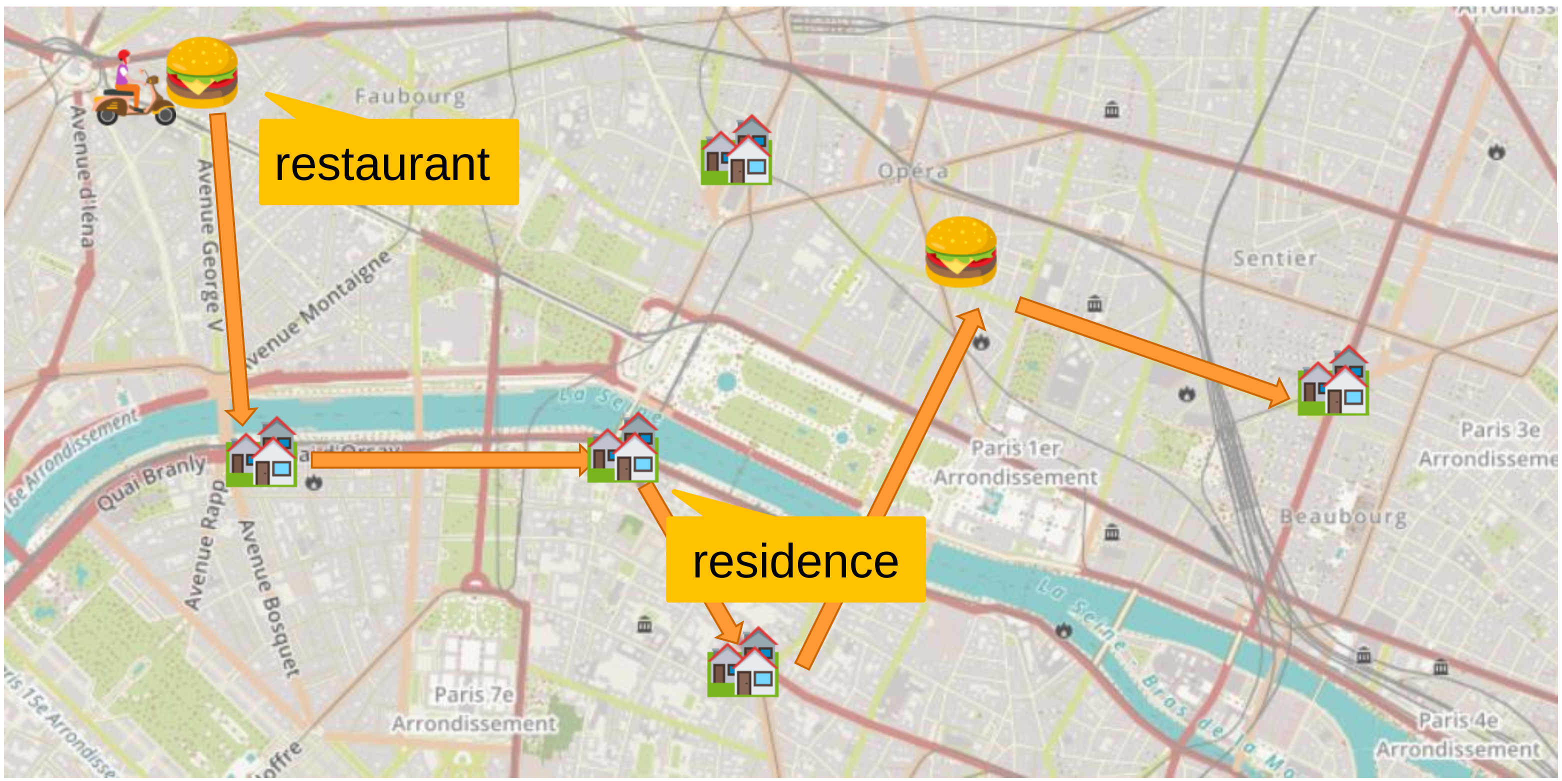
Dynamic Ridesharing Services

- Dynamic ridesharing: services that arrange one-time shared rides on short notice.
  - Car-pooling, **Food Delivery**,



Delivery Hero

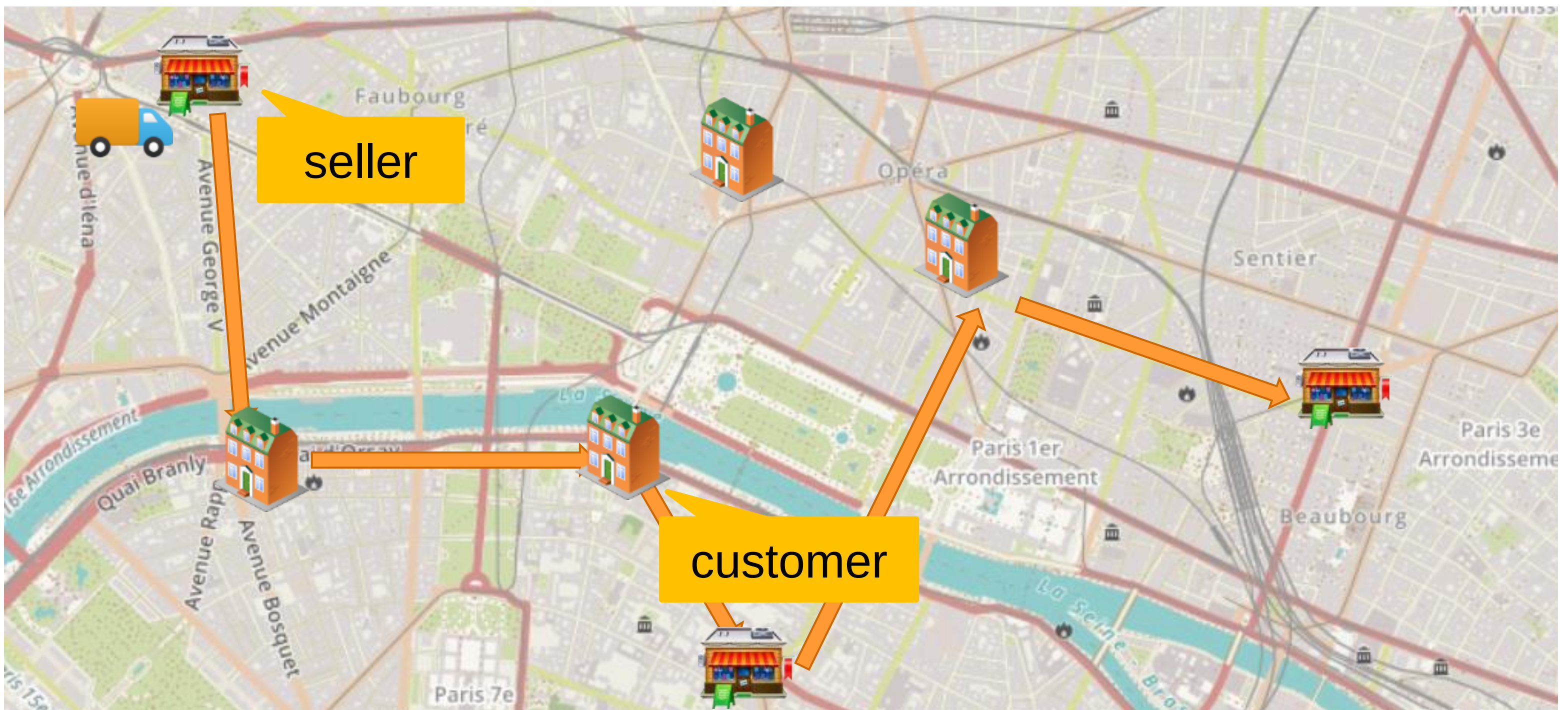
seamless

口碑 Koubei

美团 meituan.com

Dynamic Ridesharing Services

- Dynamic ridesharing: services that arrange one-time shared rides on short notice.
  - Car-pooling, Food Delivery, **Last-mile Logistics**

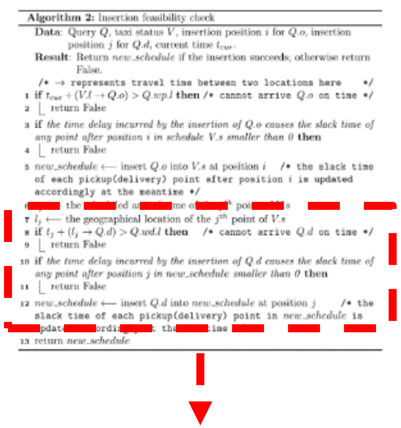


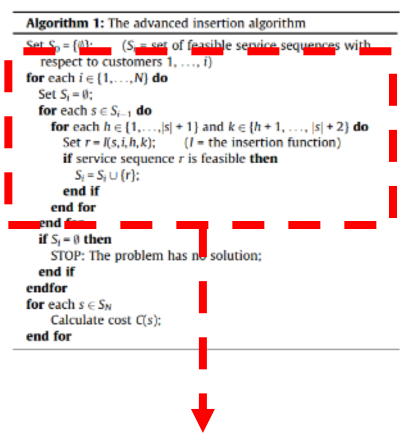
How to plan a route for the worker is central for DR

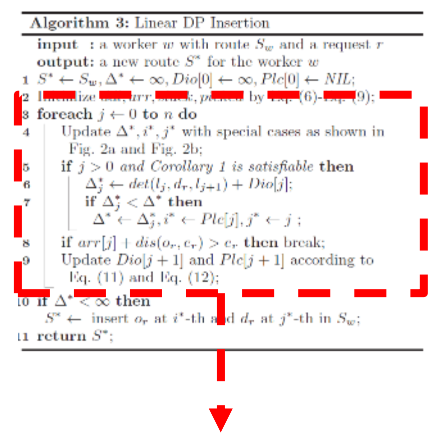
Dynamic Ridesharing Services

- The problem of route planning in dynamic ridesharing is very difficult and most existing solutions are heuristic

T-share	Adaptive insertion	Kinetic	Prune GreedyDP
[ICDE'13]	[EJOR'11]	[VLDB'14]	[VLDB'18]

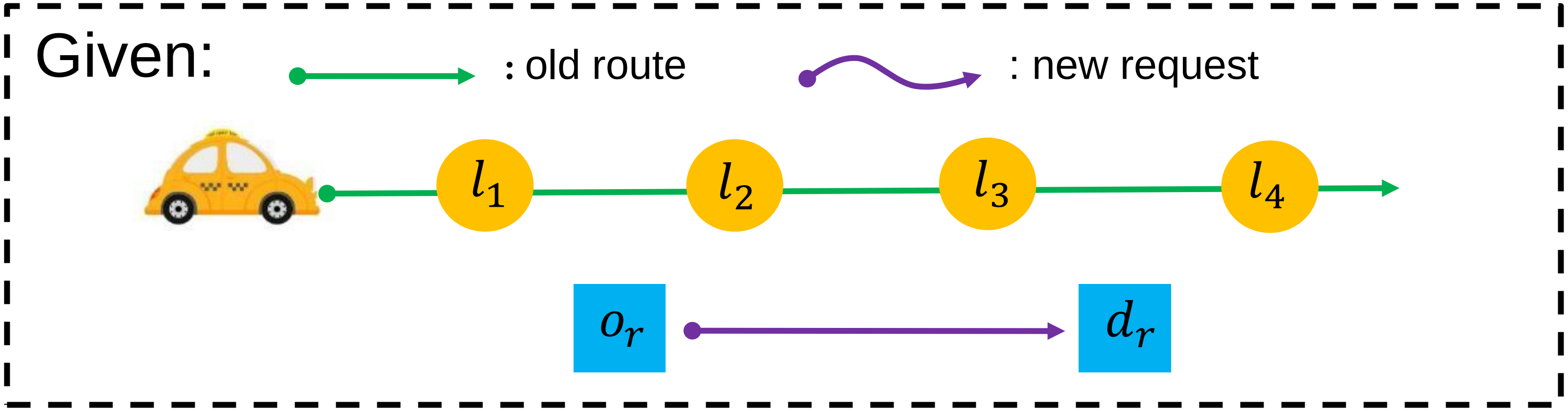




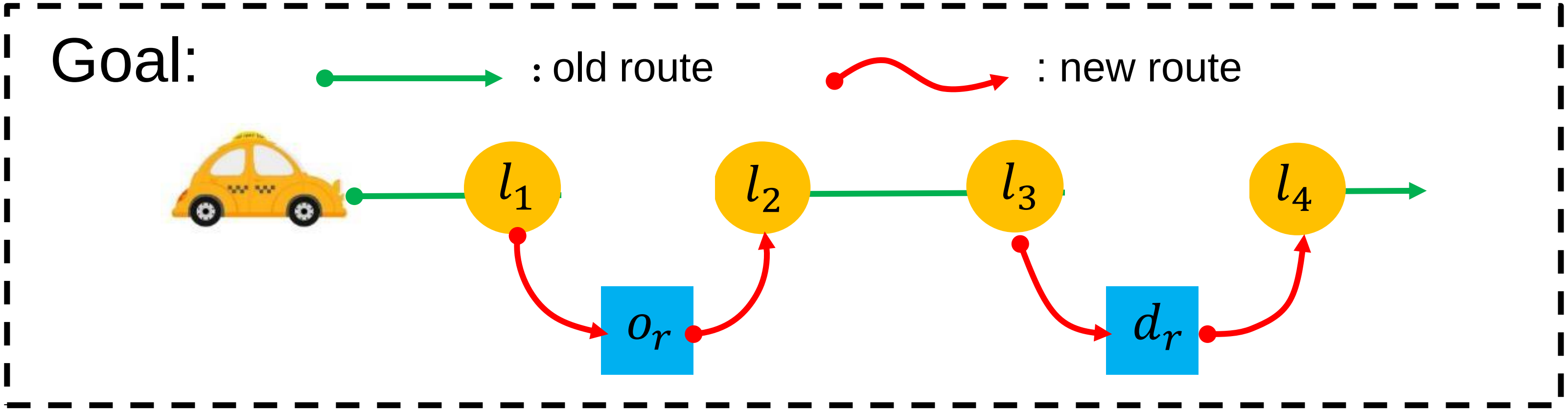


Insertion Operator: insert a new request into the current route

Insertion Operator



Insertion:
finding the appropriate location to
Insert the new request



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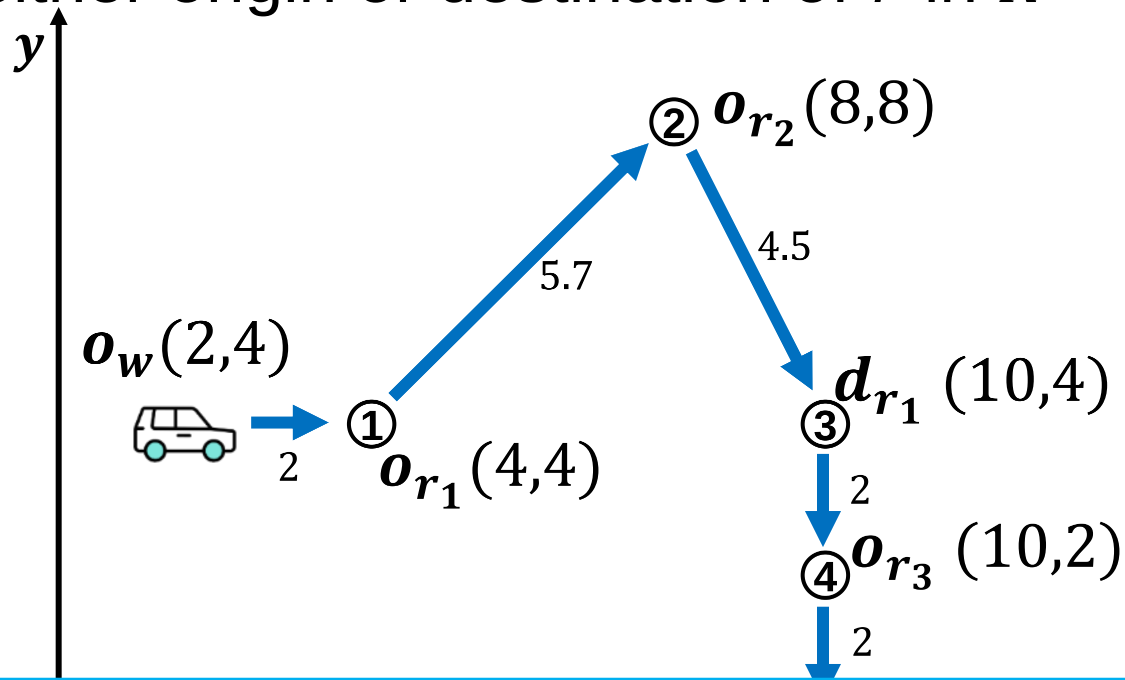
Worker

- Worker: $w = \langle o_w, c_w \rangle$
  - o_w: current location
  - c_w: capacity
  - Capacity constraint: the number of passengers he takes at the same time is less than his capacity.

- Request: $r = \langle o_r, d_r, t_r, e_r, c_r \rangle$
  - o_r, d_r : origin and destination
  - t_r, e_r : release time and deadline
  - c_r: occupation
  - Deadline constraint: the request is delivered before the deadline.

Route

- Route: $S_R = \langle l_0, l_1, \cdots, l_n \rangle$
  - R: a set of requests
  - l_0: the current location of worker
  - l_i: either origin or destination of r in R



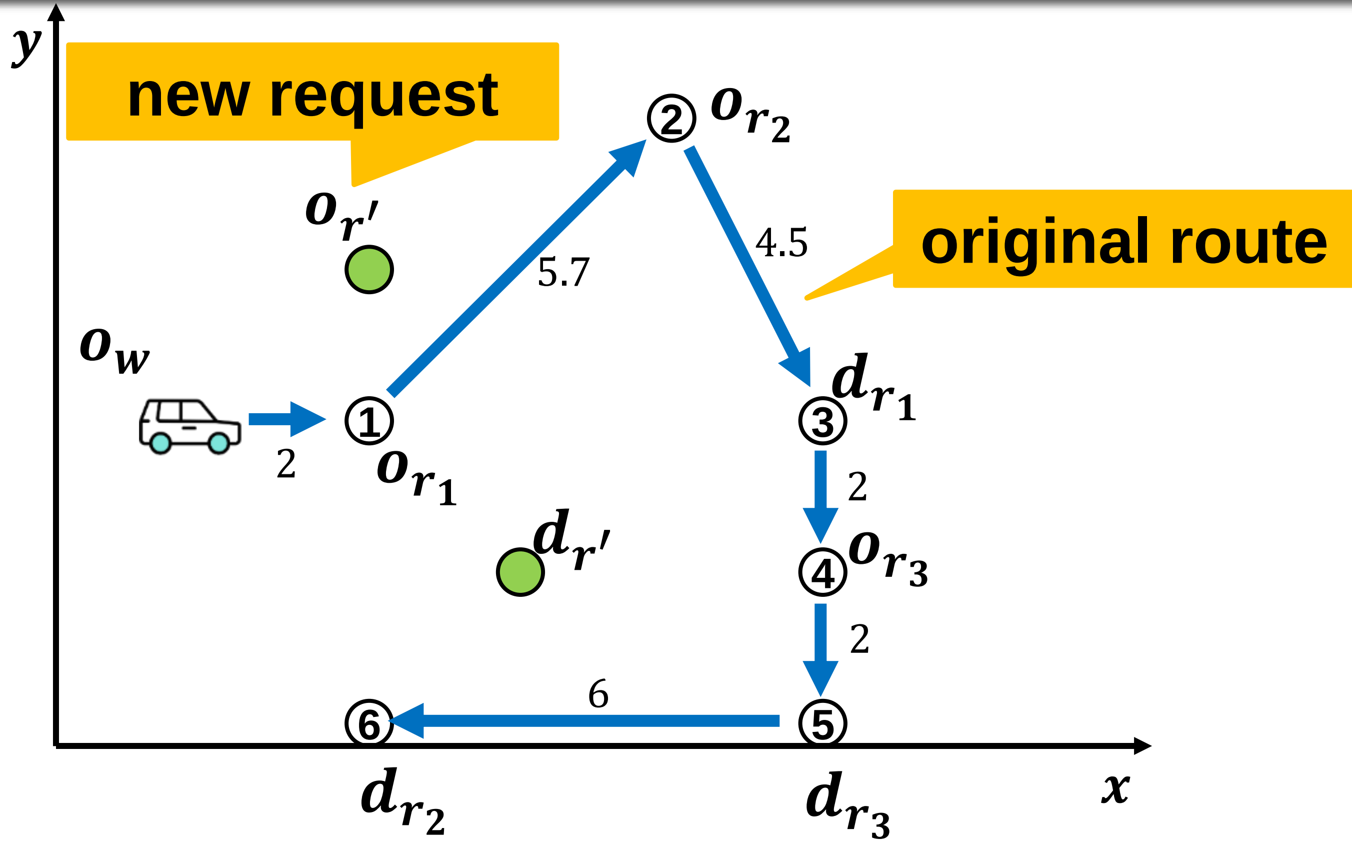
Feasible: (1) Capacity constraint; (2) Deadline constraint

Problem Formulation

- Insertion Operator
  - Given:
    - Worker w, feasible original route S_R, new request r'
  - Goal:
    - Inserts r' into S_R to obtain a new feasible route with:
      - **Minimizing maximum flow time** of all requests: i.e., minimizing maximum waiting time of all requests (waiting time = delivery time - release time)
      - **Minimizing total travel time** of the worker, i.e., the delivery time of the last request for the worker

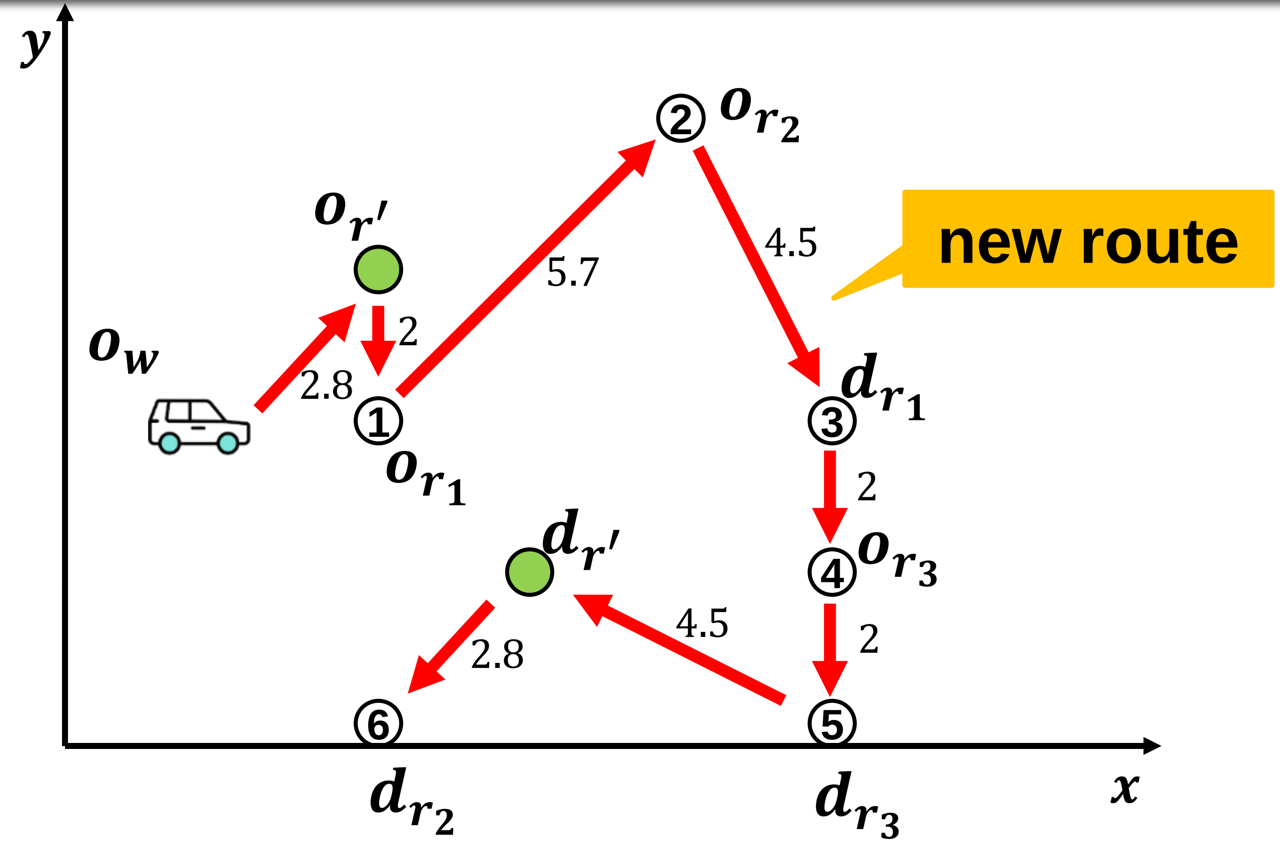
Focus of This talk.

Example



	t_r	e_r	o_r	d_r	c_r
r_1	0	25	(4,4)	(10,4)	1
r_2	0	37	(8,8)	(4,0)	2
r_3	0	33	(10,2)	(10,0)	1
r'	0	26	(4,6)	(6,2)	1

Example



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r'	0	26	(4,6)	(6,2)	1

Problem

Time complexity: $O(n^3)$

=

Calculate objective and check constraints in $O(n)$

×

Enumerate all possible insertion pairs in $O(n^2)$

Basic Algorithm

Goal

Time consuming

Basic Algorithm

How to reduce the time complexity?

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Partition-based Framework

Time complexity: $O(n^3)$

=

Calculate objective and check constraints in $O(n)$

×

Enumerate possible insertion pairs in $O(n^2)$

Basic Algorithm

Time complexity: $O(n^2)$

=

Calculate objective and check constraints in $O(1)$

×

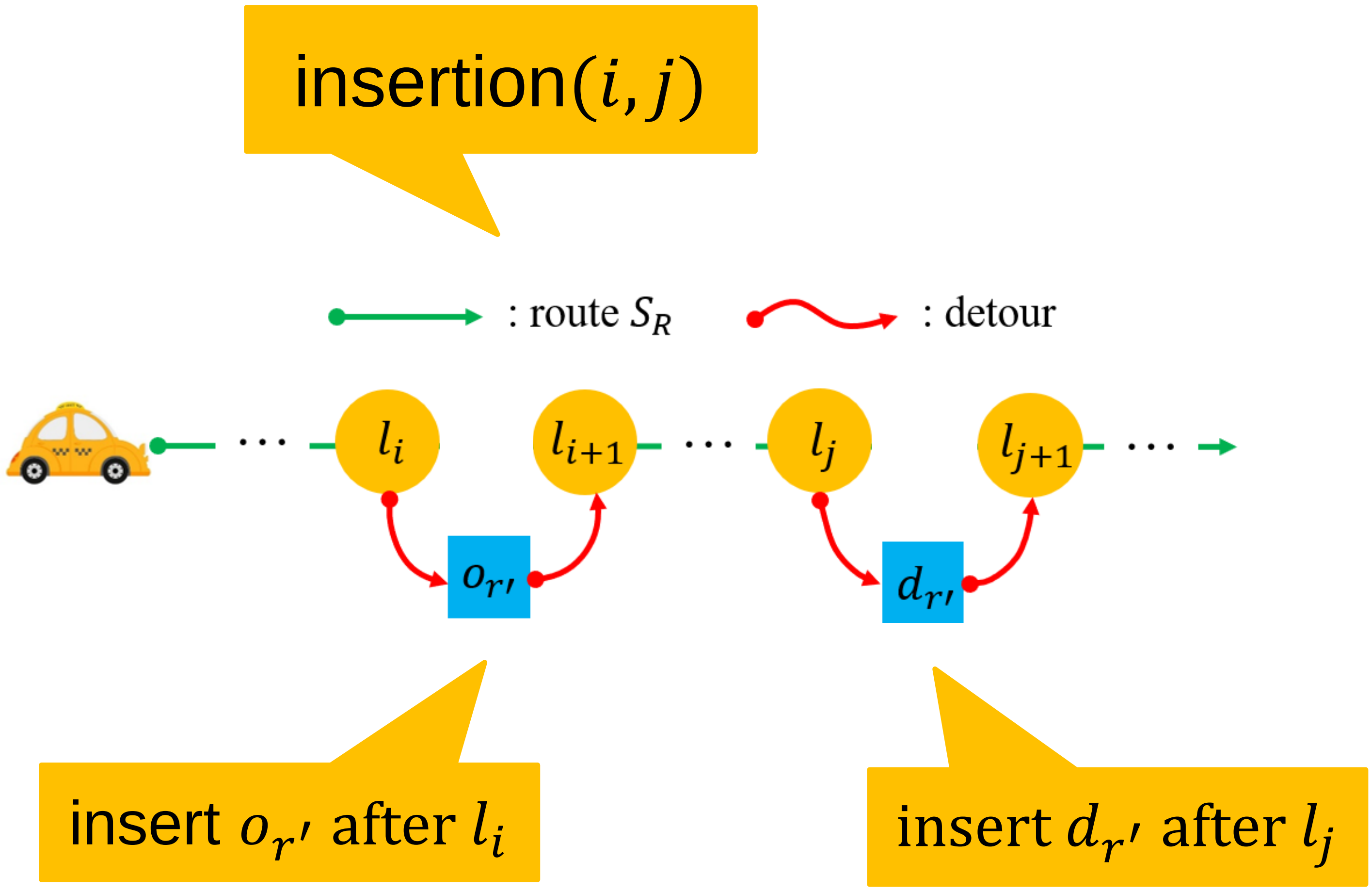
Enumerate all possible insertion pairs in $O(n^2)$

+

Pre-processing in $O(n^2)$

Partition-based Framework

Insertion(i, j)



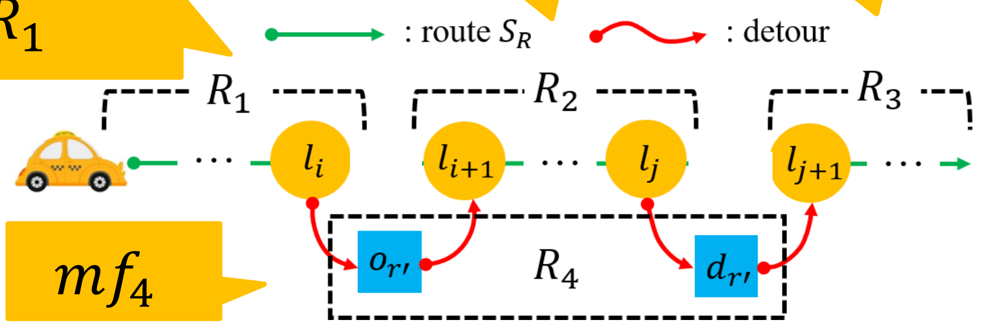
Partition-based Framework

- Basic idea:
  - Partition the set of requests R^+ into four parts
    - R_1: requests delivered before $i\text{-}th$ location
    - R_2: requests delivered between $i\text{-}th$ and $j\text{-}th$ location
    - R_3: requests delivered after $j\text{-}th$ location
    - R_4: new request r'
  - Objective calculation:
    - $\mathrm{OBJ}(S_{R^+}) = \max\{mf_1, mf_2, mf_3, mf_4\}$

mf_1: the maximum flow time of all requests in R_1

mf_2

mf_3



mf_4

Partition-based Framework

Time complexity: $O(n^2)$

=

Calculate objective and
check constraints in $O(1)$

×

Enumerate possible
insertion pairs in $O(n^2)$

+

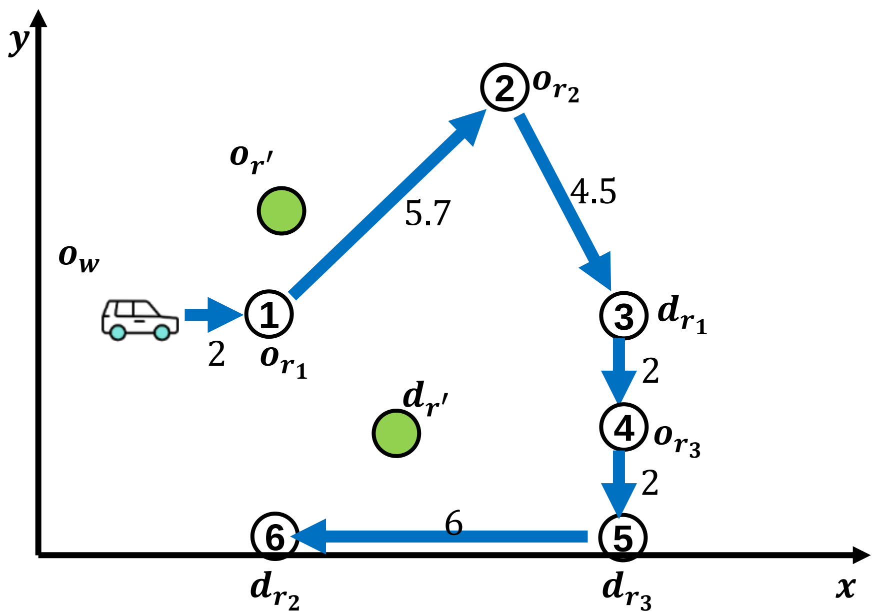
Pre-processing in $O(n^2)$

Pre-processing

- A matrix $mobj$
  - $mobj(i,j)$: the maximum flow time for requests between $i\text{-}th$ and $j\text{-}th$ location

$$mobj(i,j) = max\{mobj(i,j-1), flow\ time\ of\ request\ with\ destination\ l_j\}$$

$O(n^2)$



i \ j	0	1	2	3	4	5	6
0	0	0	0	12.2	12.2	16.2	22.2
1	-	0	0	12.2	12.2	16.2	22.2
2	-	-	0	12.2	12.2	16.2	22.2
3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

$mobj$

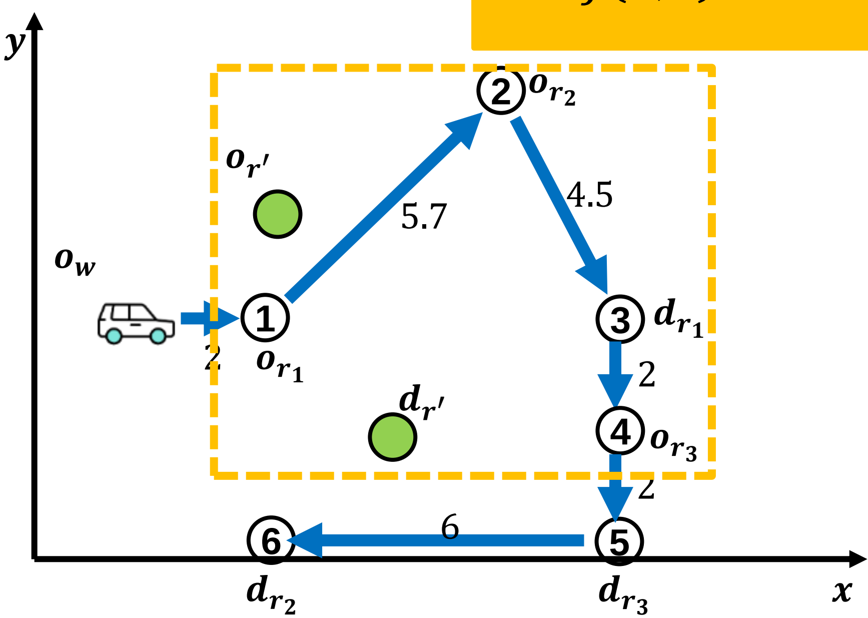
Pre-processing

- A matrix $mobj$
  - $mobj(i,j)$: the maximum flow time for requests between $i\text{-}th$ and $j\text{-}th$ location

$O(n^2)$

$$mobj(i,j) = max\{mobj(i,j-1), flow\ time\ of\ request\ with\ destination\ l_j\}$$

$$mobj(1,4) = max\{mobj(1,3), 0\} = max\{12.2, 0\} = 12.2$$



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3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

$mobj$

Partition-based Framework

Time complexity: $O(n^2)$

=

Calculate objective and check constraints in $O(1)$

×

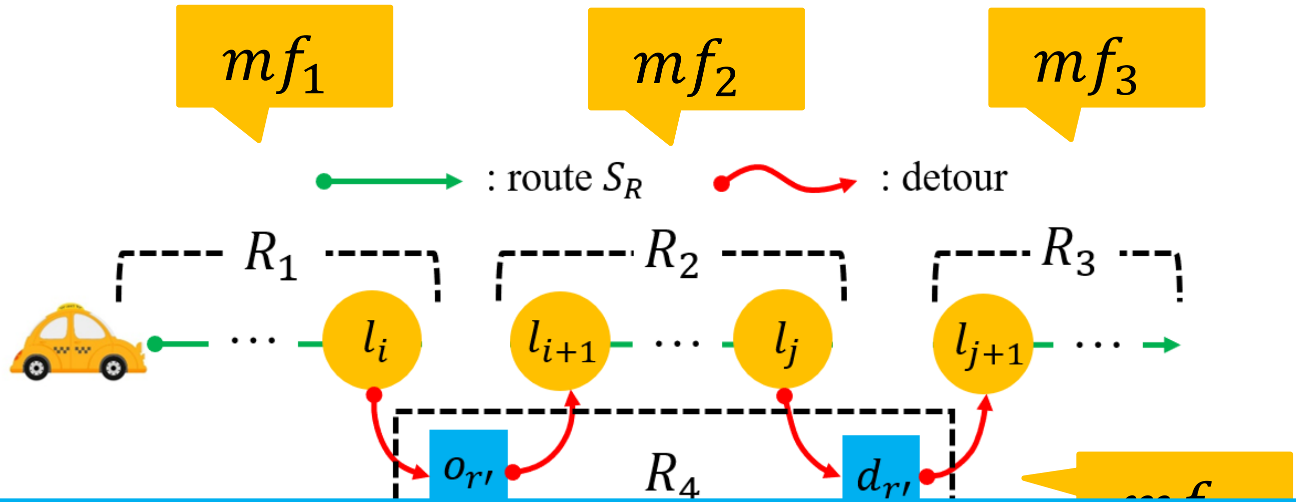
Enumerate possible insertion pairs in $O(n^2)$

+

Pre-processing in $O(n^2)$

Objective Calculation

- The formulas of mf_1, mf_2, mf_3, mf_4:
  - $mf_1 = mobj(0, i)$ detour of inserting the origin after l_i
  - $mf_2 = \boxed{det(i, o_{r'})} + \boxed{mobj(i+1, j)}$ matrix in pre-processing
  - $mf_3 = det(i, o_{r'}) + det(j, d_{r'}) + mobj(j, n)$
  - $mf_4 = arr(j) + det(i, o_{r'}) + dis\left(l_j, d_{r'}\right) + (\alpha - 1)t_{r'}$

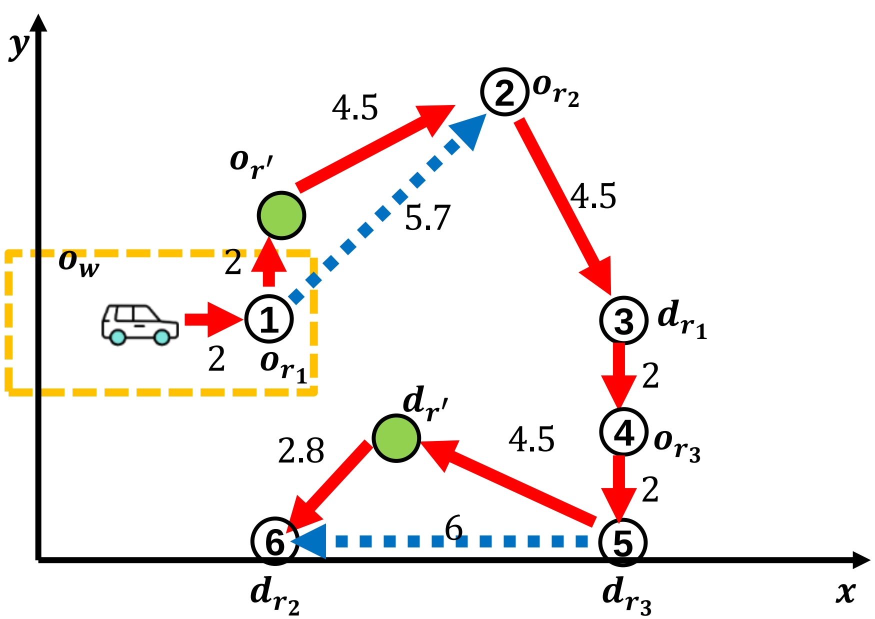


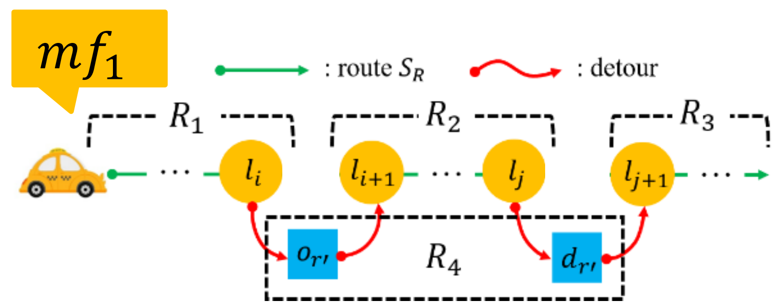
We can calculate the objective in $O(1)$ time with formulas

Objective Calculation

- Insertion (1,5)
  - $mf_1 = mobj(0,1) = 0$

$R_1 = \emptyset$





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3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

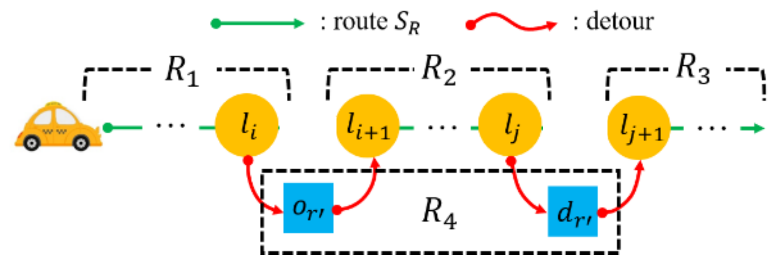
$mobj$

Objective Calculation

- Insertion (1,5)
  - $mf_2 = det(1, o_{r'}) + mobj(2,5) = 0.8 + 16.2 = 17$

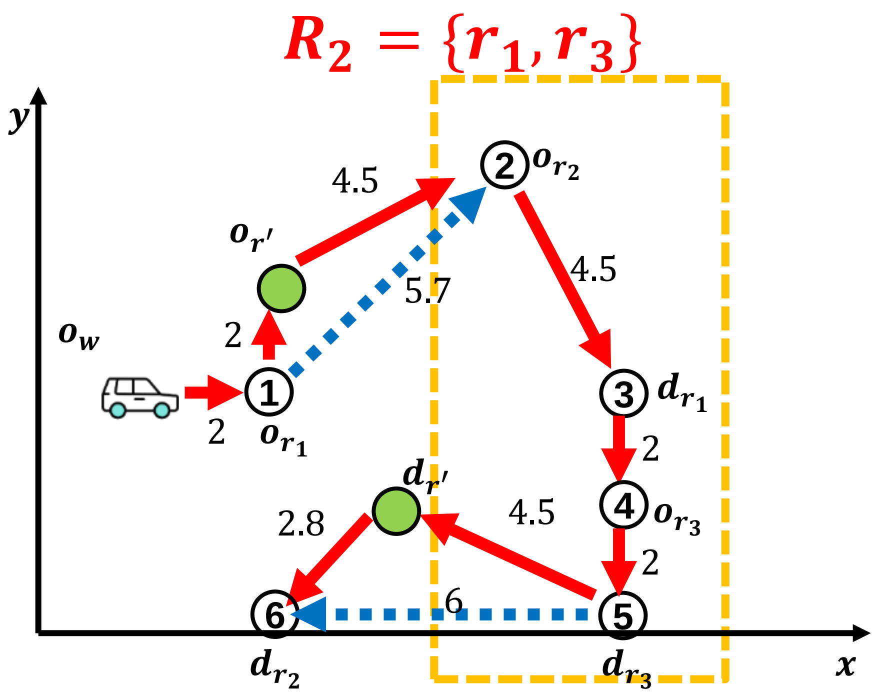
$det(k,p)$: the detour of inserting p after k-th location

mf_2



i \ j	0	1	2	3	4	5	6
0	0	0	0	12.2	12.2	16.2	22.2
1	-	0	0	12.2	12.2	16.2	22.2
2	-	-	0	12.2	12.2	16.2	22.2
3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

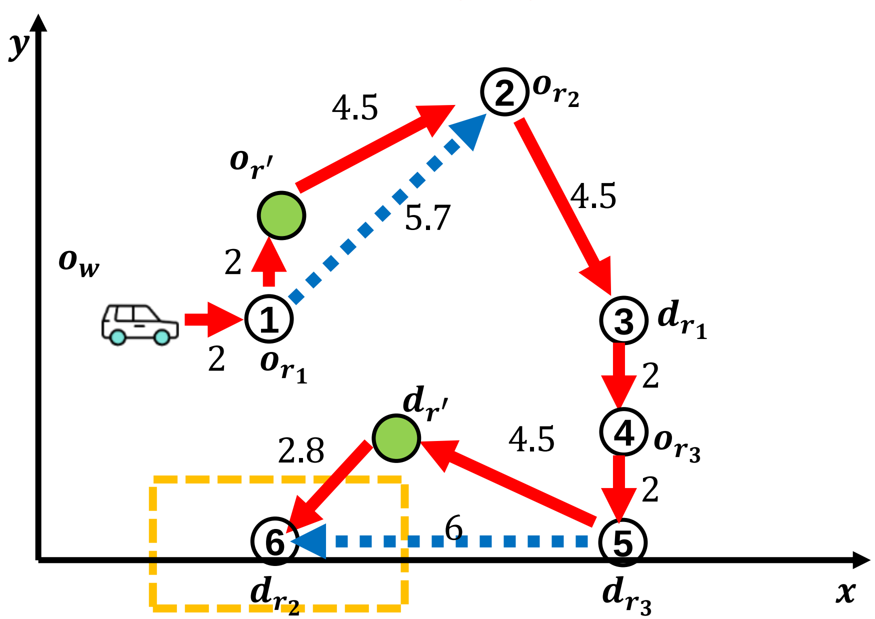
$mobj$



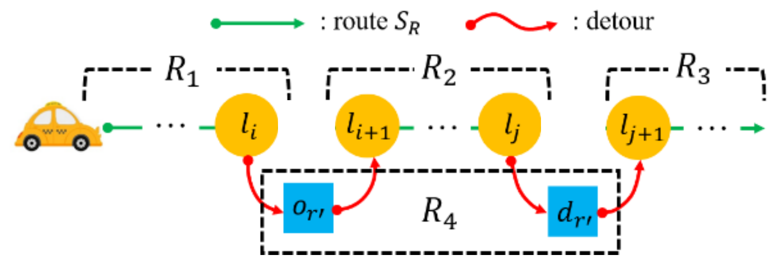
Objective Calculation

- Insertion (1,5)
  - $mf_3 = det(1, o_{r'}) + det(5, d_{r'}) + mobj(6,6) = 0.8 + 1.3 + 22.2 = 24.3$

$R_3 = \{r_2\}$



mf_3



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3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

mobj

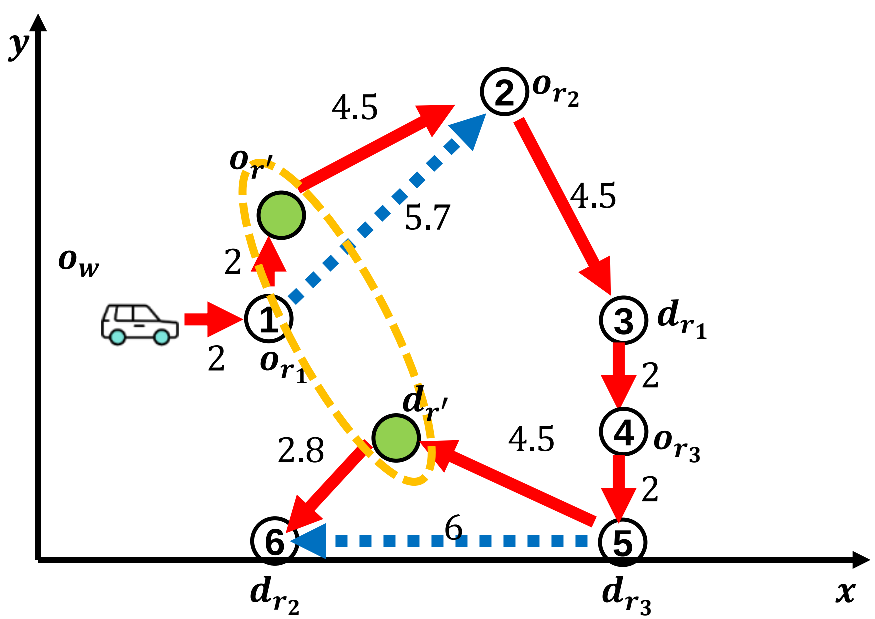
Objective Calculation

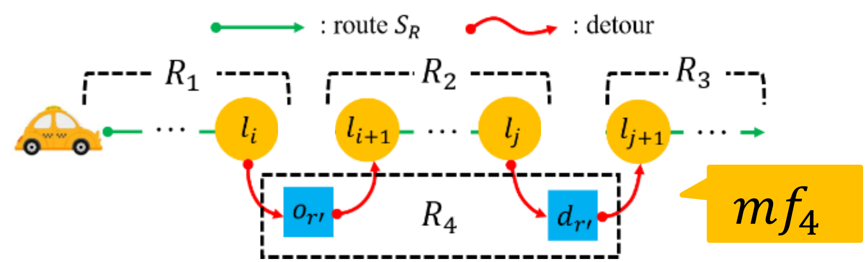
- Insertion $(1,5)$
  - mf_4 is the flow time of r': $21.5 - 0 = 21.5$

arrival time of $d_{r'}$

release time of r'

$R_4 = \{r'\}$





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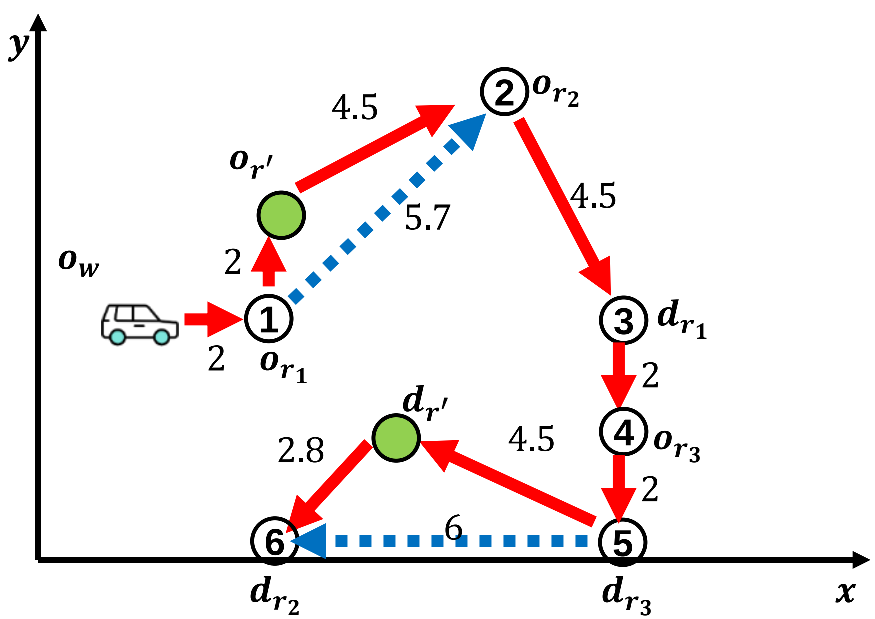
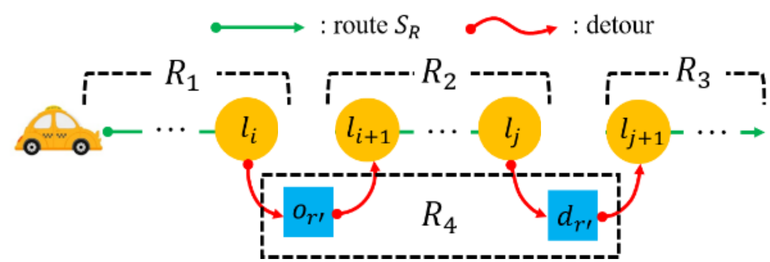
3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

$mobj$

Objective Calculation

- Insertion $(1,5)$
  - The answer is $\max(0, 17, 24.3, 21.5) = 24.3$





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3	-	-	-	12.2	12.2	16.2	22.2
4	-	-	-	-	0	16.2	22.2
5	-	-	-	-	-	16.2	22.2
6	-	-	-	-	-	-	22.2

$mobj$

Partition-based Framework

- Constraint checking:

Capacity constraint:

$$pck(i) \le c_w - c_{r'}$$
$$pck(j) \le c_w - c_{r'}$$

Deadline constraint:

$$det(i, o_{r'}) \le slk(i)$$
$$det(i, o_{r'}) + det(j, d_{r'}) \le slk(j)$$
$$arr(j) + det(i, o_{r'}) + dis\left(l_j, d_{r'}\right) \le e_{r'}$$

Constraint checking takes $O(1)$ time with formulas

Partition-based Framework

Time complexity: $O(n^2)$

=

Calculate objective and check constraints in $O(1)$

×

Enumerate possible insertion pairs in $O(n^2)$

+

Pre-processing in $O(n^2)$

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Segment-based DP Algorithm

Time complexity: $O(n^2)$

$=$

Calculate objective and check constraints in $O(1)$

$\times$

Enumerate possible insertion pairs in $O(n^2)$

$+$

Pre-processing in $O(n^2)$

Partition-based Framework

Time complexity: $O(n)$

$=$

Find optimal location to insert destination in $O(1)$

$\times$

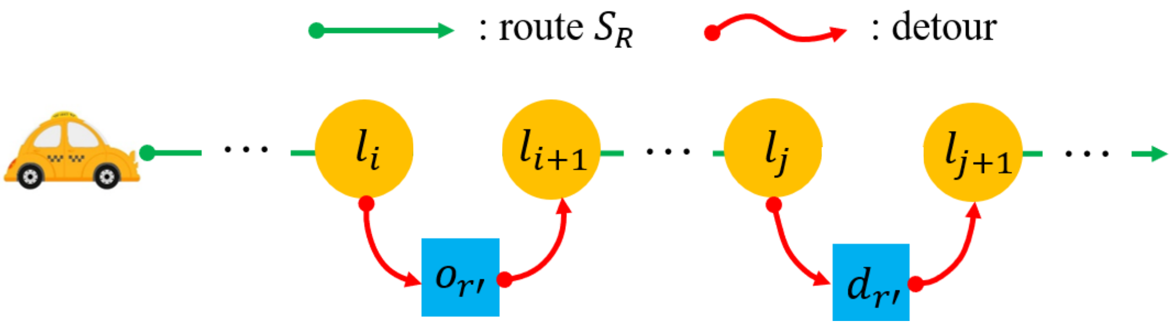
Enumerate locations to insert origin in $O(n)$

$+$

Pre-processing in $O(n)$

Segment-based DP Algorithm

Segment-based DP Algorithm

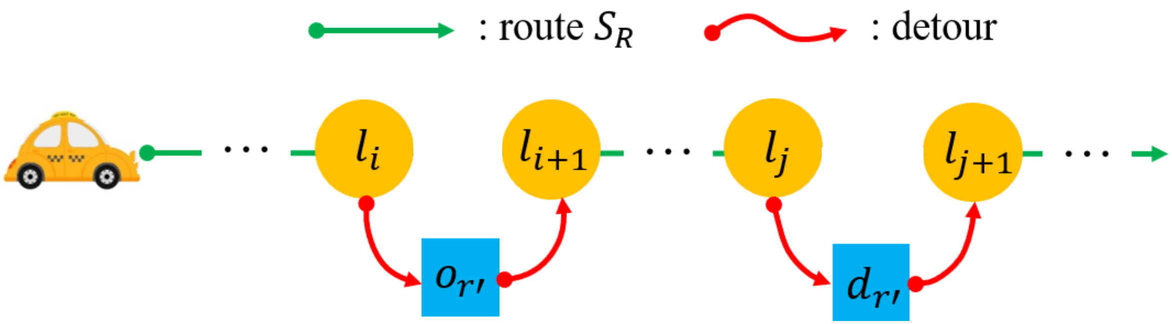


Enumerate i and j

$O(n^2)$

Partition-based Framework

Segment-based DP Algorithm



Enumerate i and j

Enumerate i,
find optimal j^*

$O(n^2)$

Reducing

$O(n)$

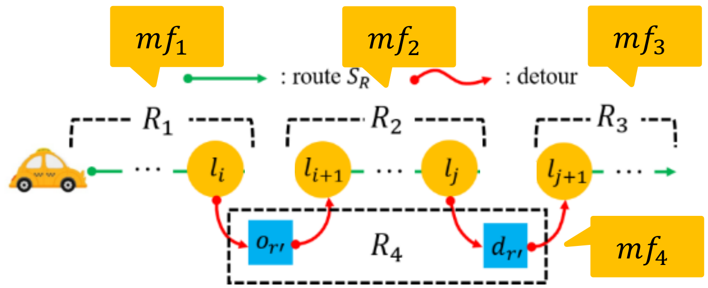
Partition-based Framework

Segment-based DP Algorithm

Segment-based DP Algorithm

- Objective Calculation

$$mf_1 = \boxed{mobj(0,i)}$$
$$mf_2 = \det(i, o_{r'}) + \boxed{mobj(i+1, j)}$$
$$mf_3 = \det(i, o_{r'}) + \boxed{\det(j, d_{r'}) + mobj(j, n)}$$
$$mf_4 = \det(i, o_{r'}) + \boxed{arr(j) + dis(l_j, d_{r'}) + (\alpha - 1)t_{r'}}$$



$$\text{OBJ}(S_{R^+}) = \max\{mf_1, mf_2, mf_3, mf_4\}$$

Partition-based Framework

partition i and j

$$A(i) = \det(i, o_{r'})$$
$$B(j) = \max\begin{cases} \det(j, d_{r'}) + mobj(j, n), \\ arr(j) + dis(l_j, d_{r'}) + (\alpha - 1)t_{r'} \}\end{cases}$$

relevant to i

relevant to j

$$\text{OBJ}(S_{R^+}) = A(i) + B(j)$$

Segment-based DP Algorithm

- Can $\min_{i,j} \text{OBJ}(S_{R^+}) = \min_i A(i) + \min_j B(j)$?

✕ It may violate constraints

Segment-based DP Algorithm

- How to get feasible $\min_{i,j} A(i) + B(j)$?

Segment-based DP Algorithm

- How to get feasible $\min_{i,j} A(i) + B(j)$?
- Method 1:
  - Enumerate i, calculate $A(i)$
    - Enumerate j, calculate $B(j)$ and check feasibility
    - Maintain the minimum and feasible $A(i) + B(j)$ $O(n^2)$

Segment-based DP Algorithm

- How to get feasible $\min_{i,j} A(i) + B(j)$?
- Method 1:
  - Enumerate i, calculate $A(i)$
    - Enumerate j, calculate $B(j)$ and check feasibility
    - Maintain the minimum and feasible $A(i) + B(j)$ $O(n^2)$
- Method 2:
  - Enumerate i, calculate $A(i)$
    - Find feasible and minimum $B(j^*)$ quickly $O(?)$

Segment-based DP Algorithm

- How to get feasible $\min_{i,j} A(i) + B(j)$?
- Method 1:
  - Enumerate i, calculate $A(i)$
    - Enumerate j, calculate $B(j)$ and check feasibility
    - Maintain the minimum and feasible $A(i) + B(j)$ $O(n^2)$
- Method 2:
  - Enumerate i, calculate $A(i)$
    - Find feasible minimum $B(j^*)$ directly $O(?)$

$$B(j^*) = \min_{\substack{i<j<brk(i) \\ det(i,o_{r'}) \le thr(j)}} B(j)$$

Segment tree
$O(\log n)$

$O(n \log n)$

Fenwick tree (dynamic)
$O(1)$

$O(n)$

Example

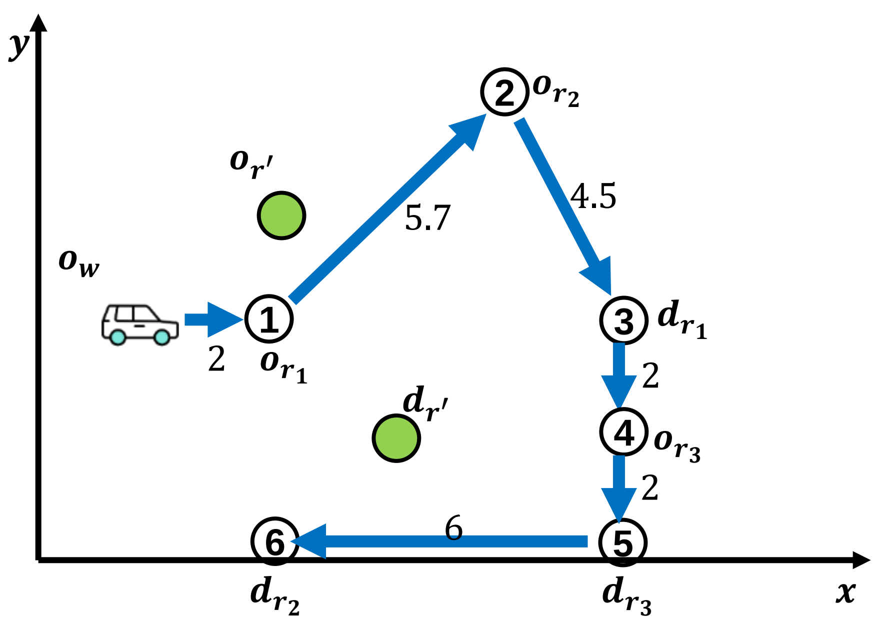
- Initialization
  - Initialize $thr(\cdot)$, $B(\cdot)$

objective relevant to j

threshold of j

$index$				$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$



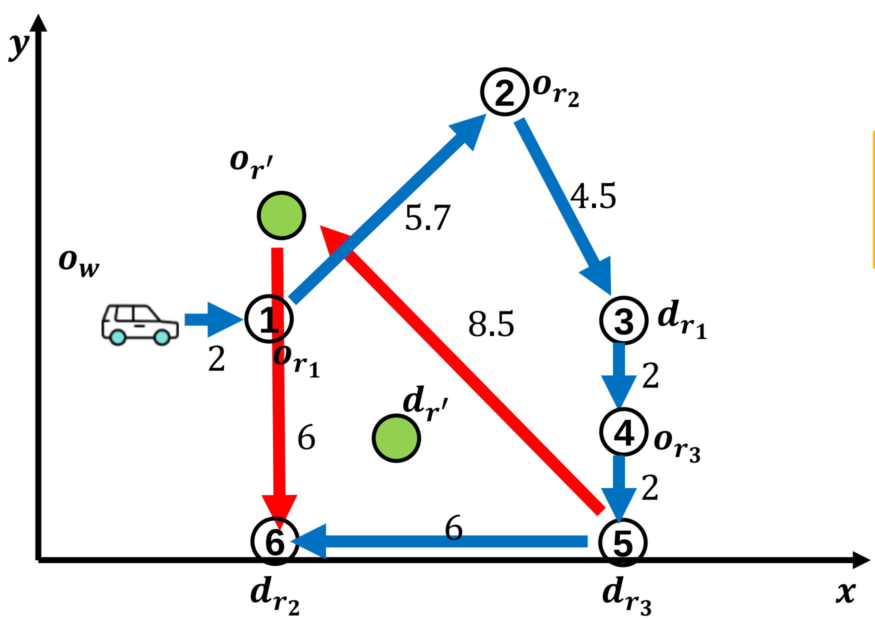
Example

- Enumerate $i = 5$ ($A(i) = 8.5$)
  - Update $B(6) = 25$ at point $thr(6) = -1$

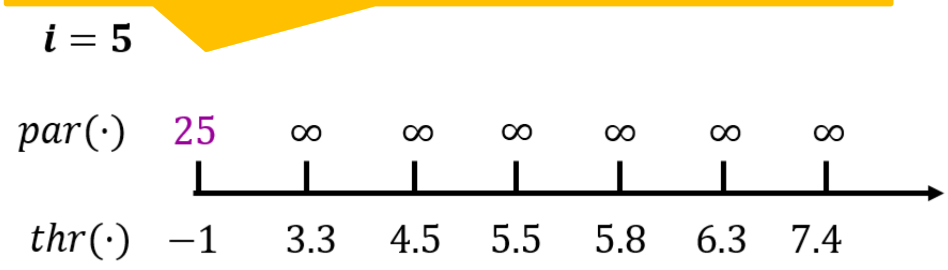
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



Update value of this point as 25



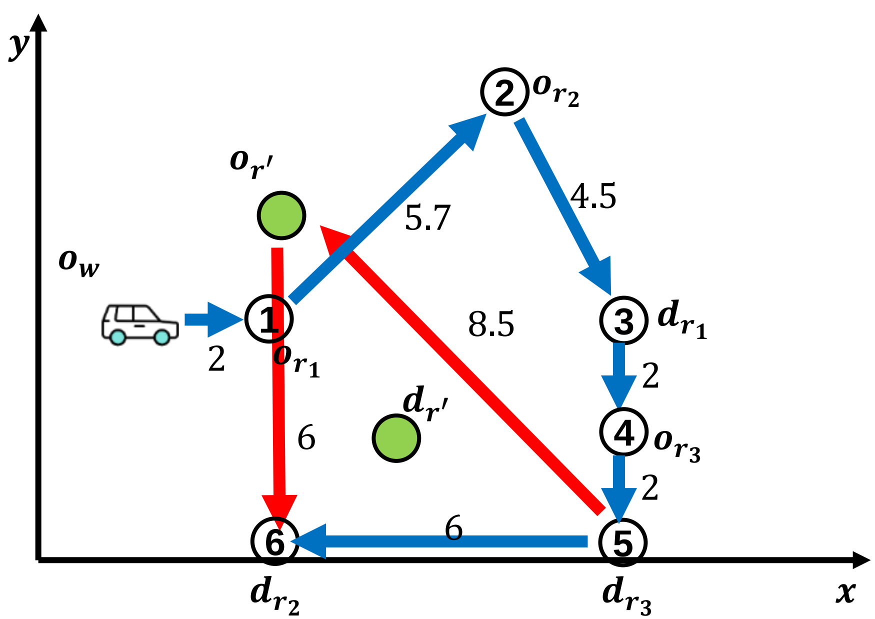
Example

- Enumerate $i = 5$ ($A(i) = 8.5$)
  - Query the segment $[det(5, o_{r'}), \infty)$

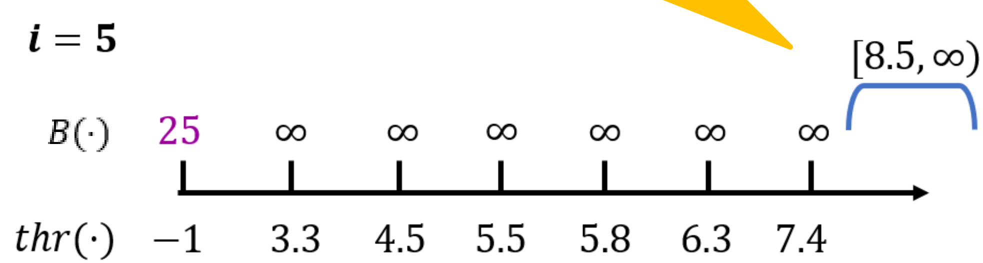
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



$det(5, o_{r'})$=8.5
The answer is ∞



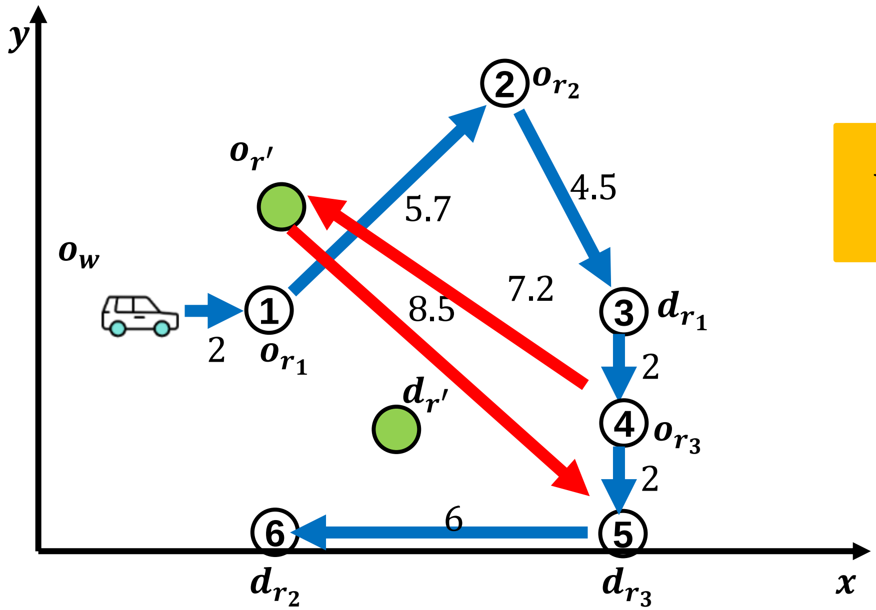
Example

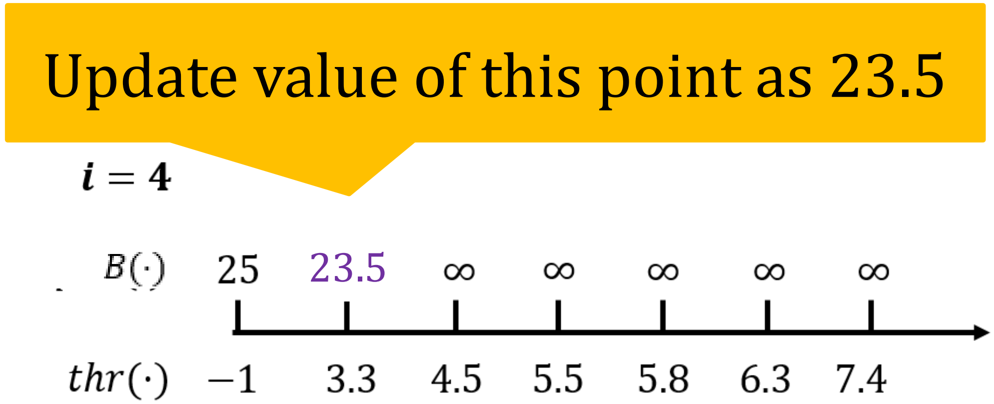
- Enumerate $i = 4$ ($A(i) = 13.7$)
  - Update $B(5) = 23.5$ at point $thr(5) = 3.3$

$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞





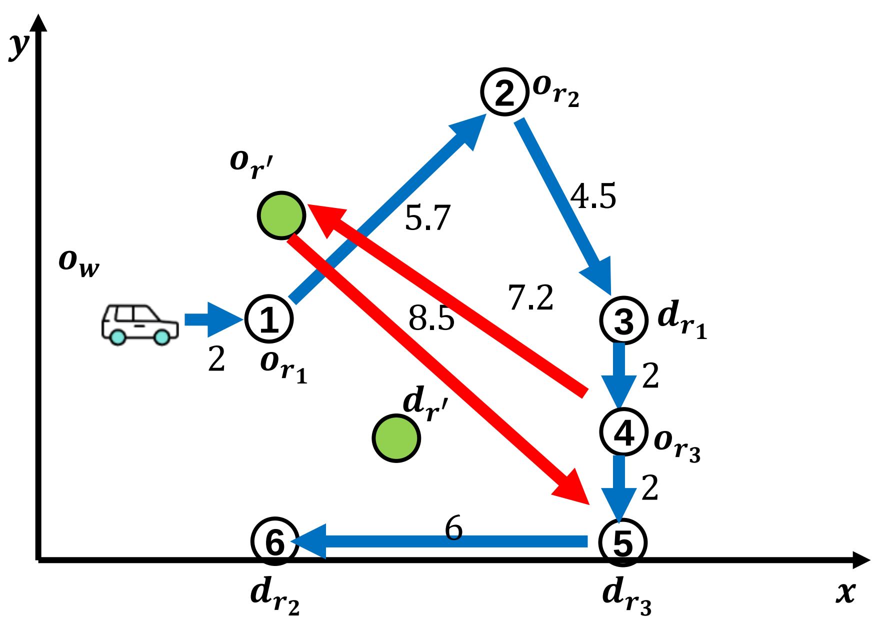
Example

- Enumerate $i = 4$ $(A(i) = 13.7)$
  - Query the segment $[det(4, o_{r'}), \infty)$

$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

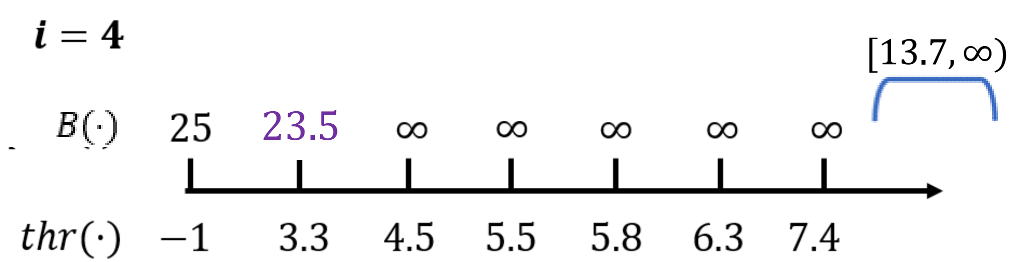
$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



$det(4, o_{r'}) = 13.7$

The answer is ∞



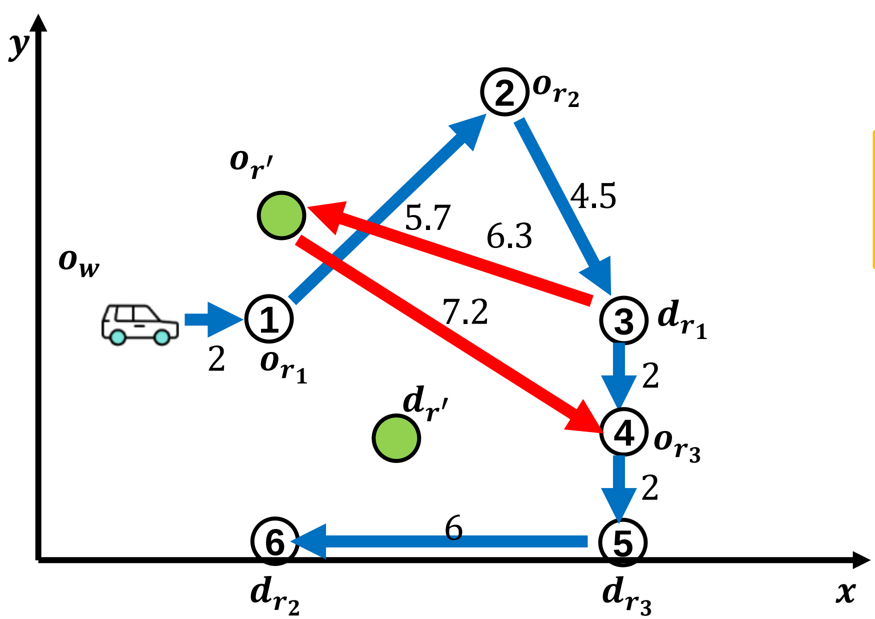
Example

- Enumerate $i = 3$ ($A(i) = 11.5$)
  - Update $B(4) = 28.7$ at point $thr(4) = 5.8$

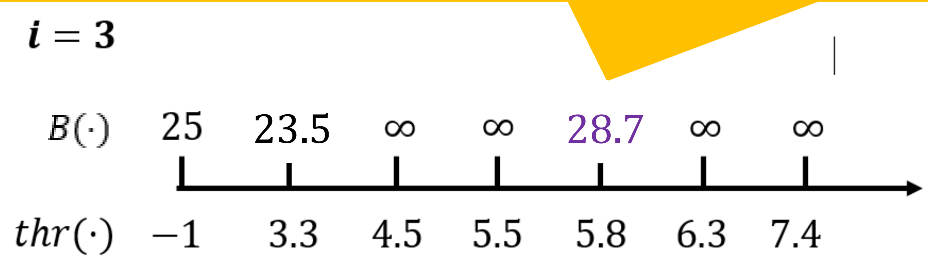
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



Update value of this point as 28.7



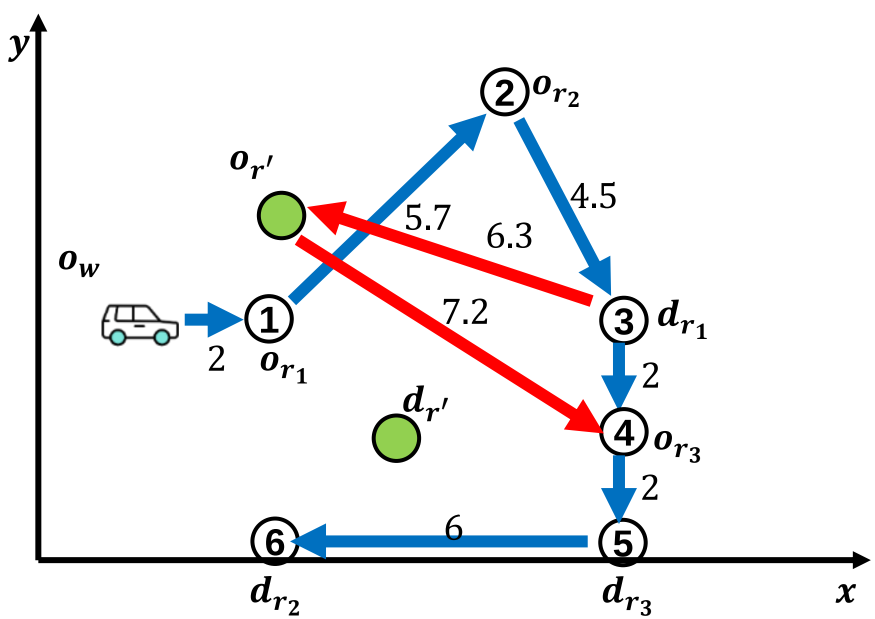
Example

- Enumerate $i = 3$ ($A(i) = 11.5$)
  - Query the segment $[det(3, o_{r'}), \infty)$

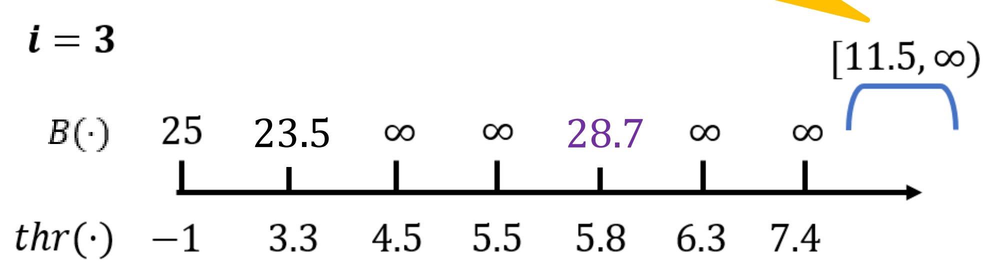
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



$det(3, o_{r'}) = 11.5$
The answer is ∞



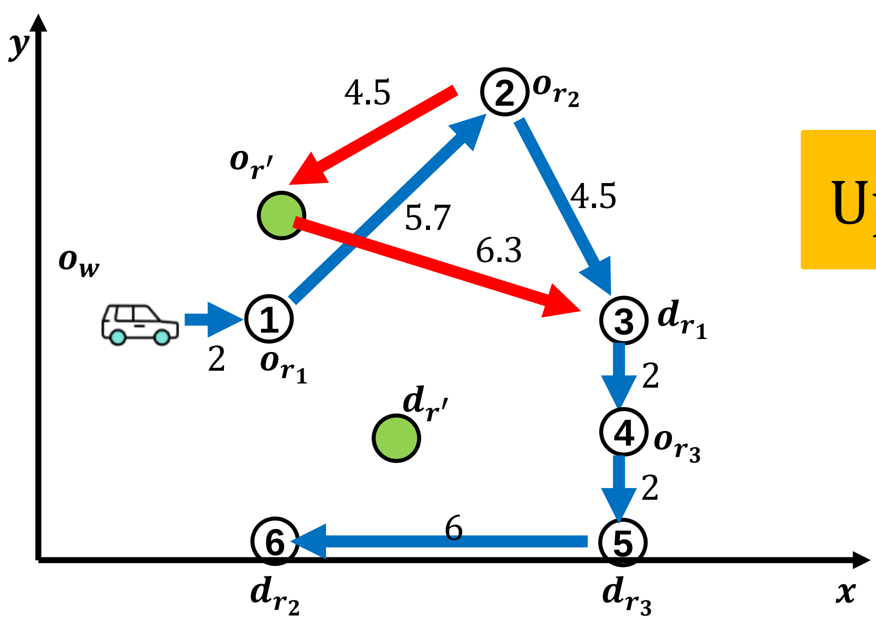
Example

- Enumerate $i = 2$ ($A(i) = 6.3$)
  - Update $B(3) = 28.7$ at point $thr(3) = 6.3$

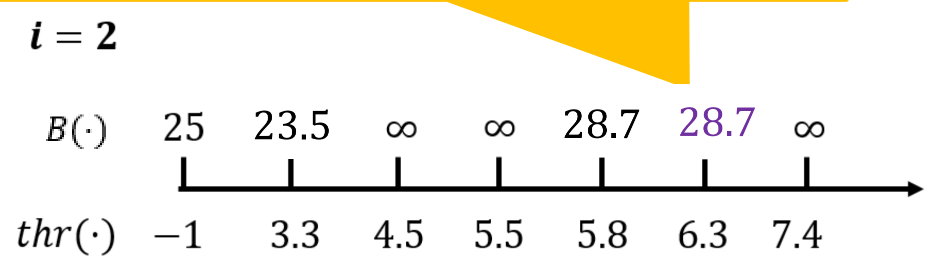
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



Update value of this point as 28.7



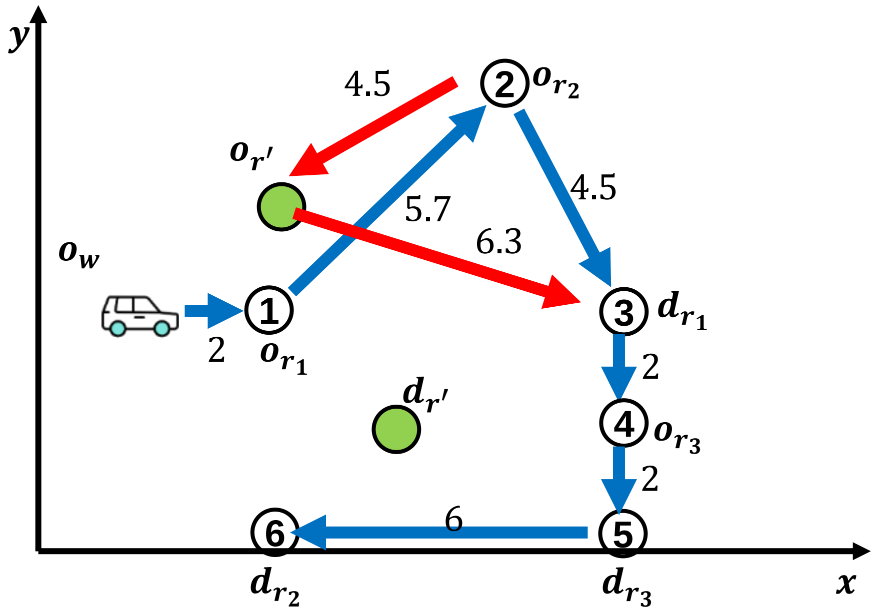
Example

- Enumerate $i = 2$ ($A(i) = 6.3$)
  - Query the segment $[det(2, o_{r'}), \infty)$

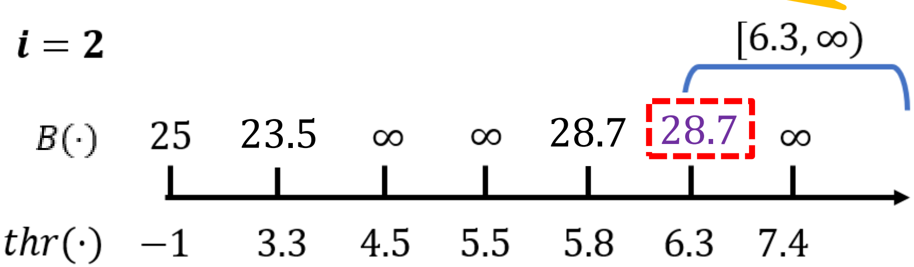
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: ∞



$det(2, o_{r'}) = 6.3$
The answer is 28.7



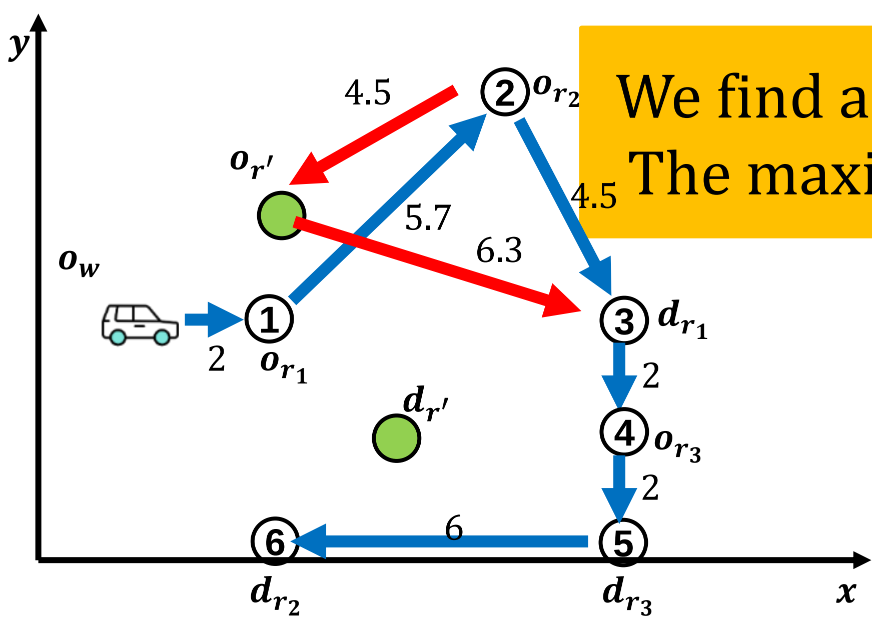
Example

- Enumerate $i = 2$ ($A(i) = 6.3$)
  - Query the segment $[det(2, o_{r'}), \infty)$

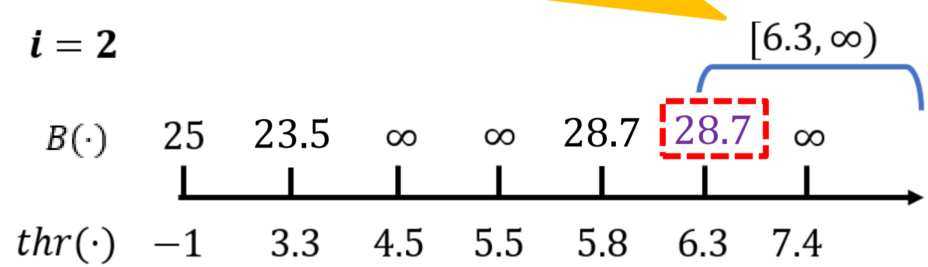
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: 35



We find a feasible solution: insertion(2,3)
The maximum flow time is 6.3+28.7=35



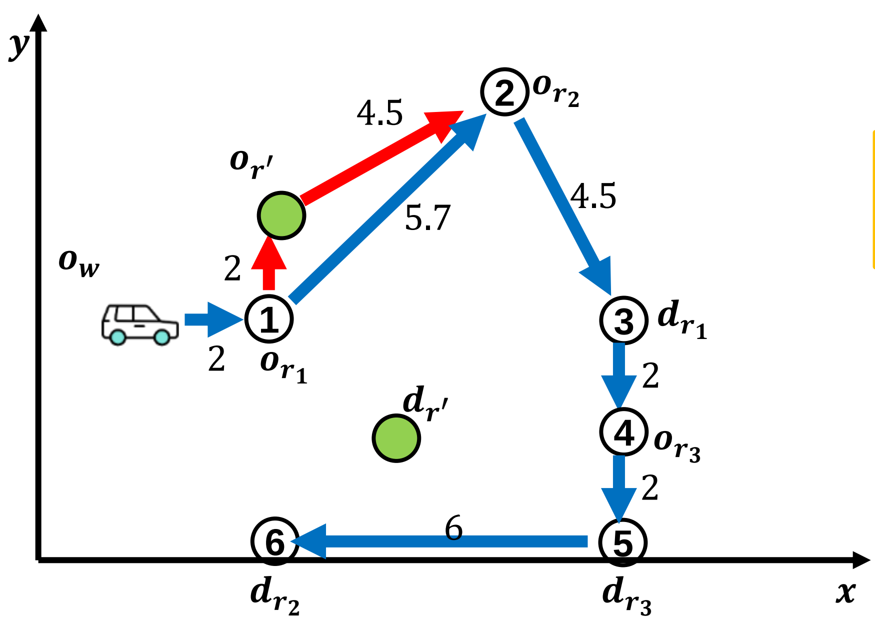
Example

- Enumerate $i = 1$ ($A(i) = 0.8$)
  - Update $B(2) = 28.5$ at point $thr(2) = 4.5$

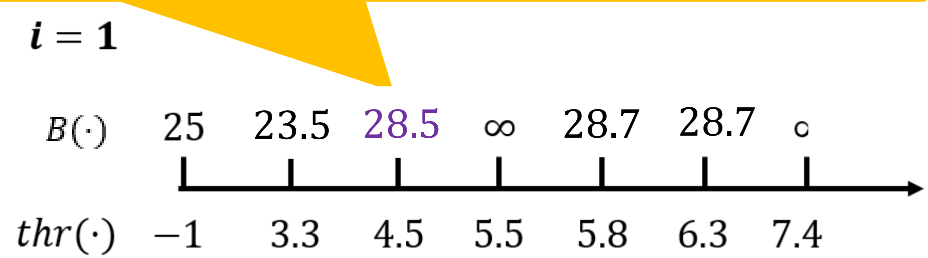
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\leq thr(j)}} B(j)$$

Optimal solution: 35



Update value of this point as 28.5



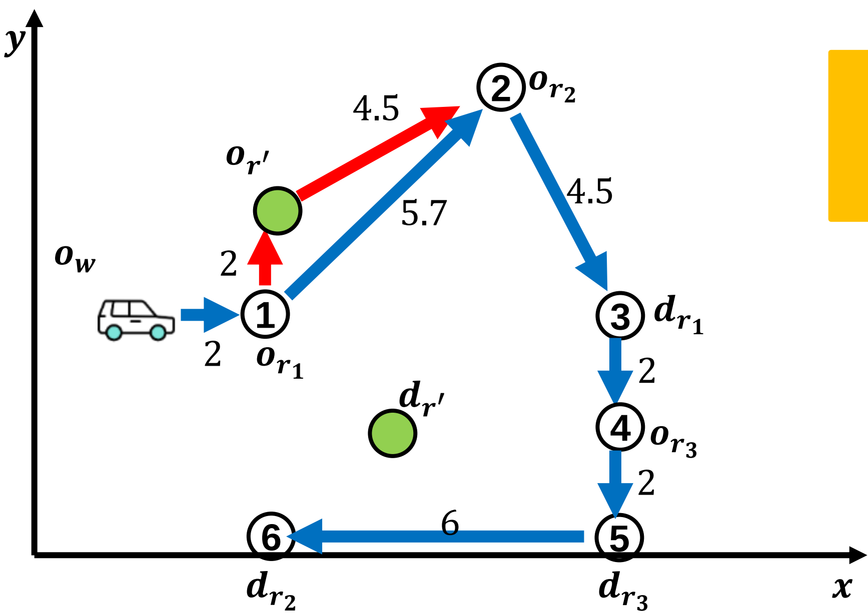
Example

- Enumerate $i = 1$ $(A(i) = 0.8)$
  - Query the segment $[det(1, o_{r'}), \infty)$

$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

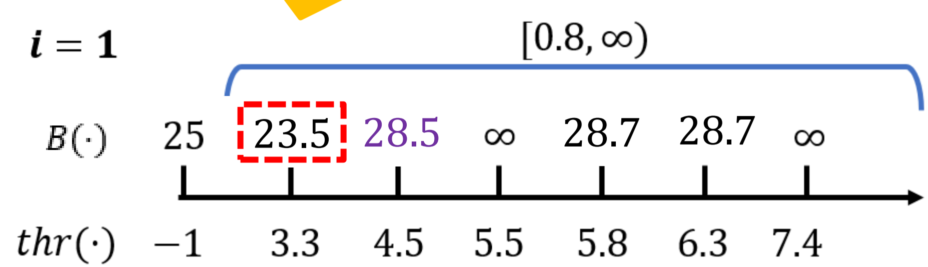
$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: 35



$det(1, o_{r'}) = 0.8$

The answer is 25.5



Example

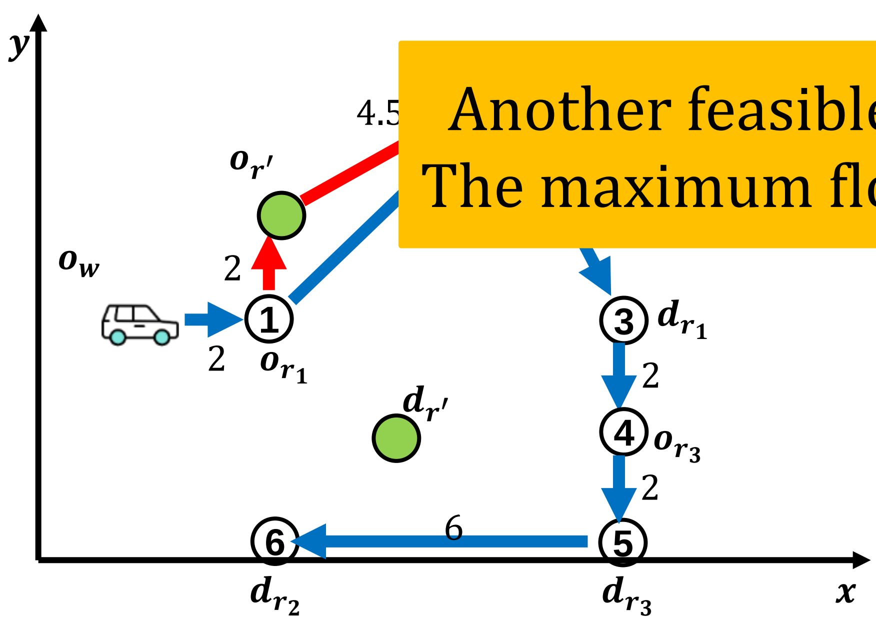
- Enumerate $i = 1$ $(A(i) = 0.8)$
  - Query the segment $[det(1, o_{r'}), \infty)$

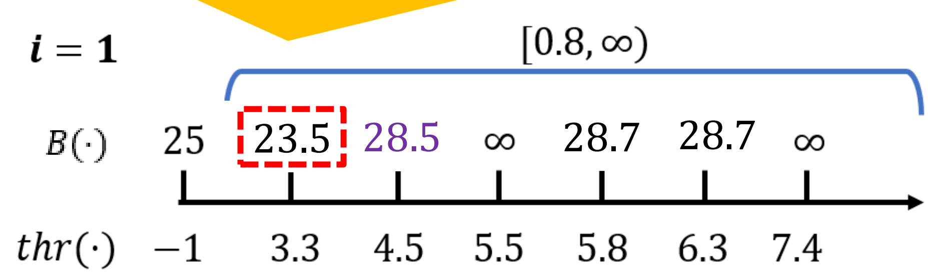
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i, o_{r'}) \le thr(j)}} B(j)$$

Optimal solution: 24.3

Another feasible solution: insertion(1,5)
The maximum flow time is 0.8+23.5=24.3





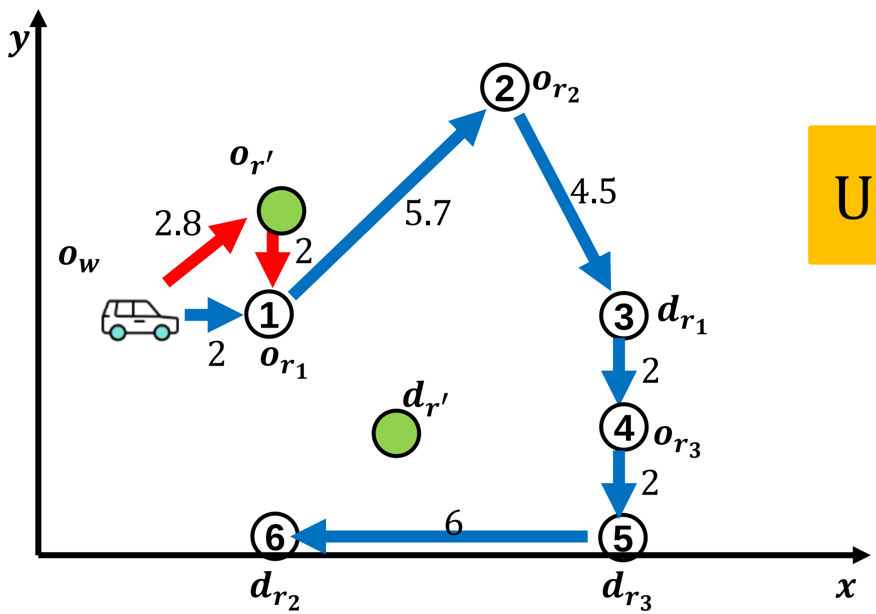
Example

- Enumerate $i = 0$ ($A(i) = 2.8$)
  - Update $B(1) = 25.6$ at point $thr(1) = 7.4$

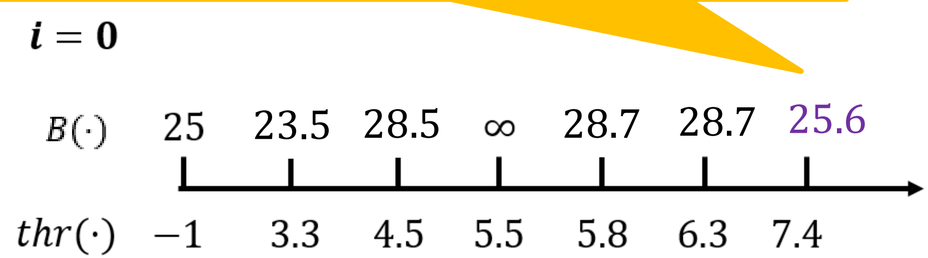
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: 24.3



Update value of this point as 25.6



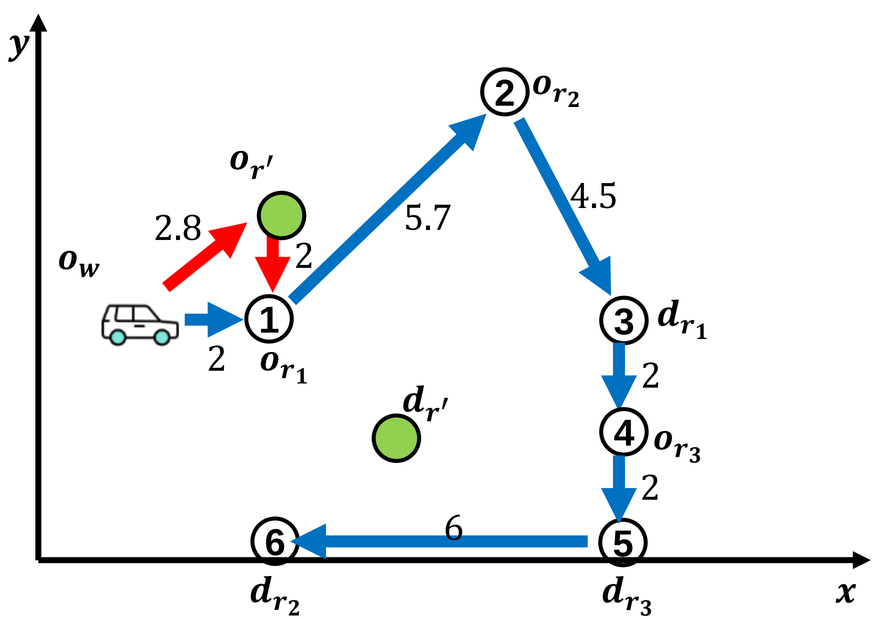
Example

- Enumerate $i = 0$ ($A(i) = 2.8$)
  - Query the segment $[det(0, o_{r'}), \infty)$

$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

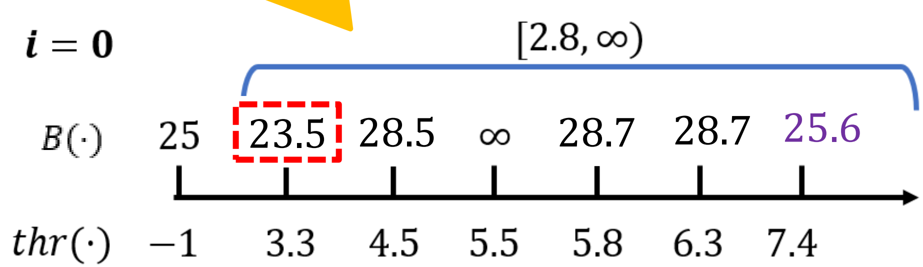
$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: 24.3



$det(0, o_{r'}) = 2.8$

The answer is 23.5



Example

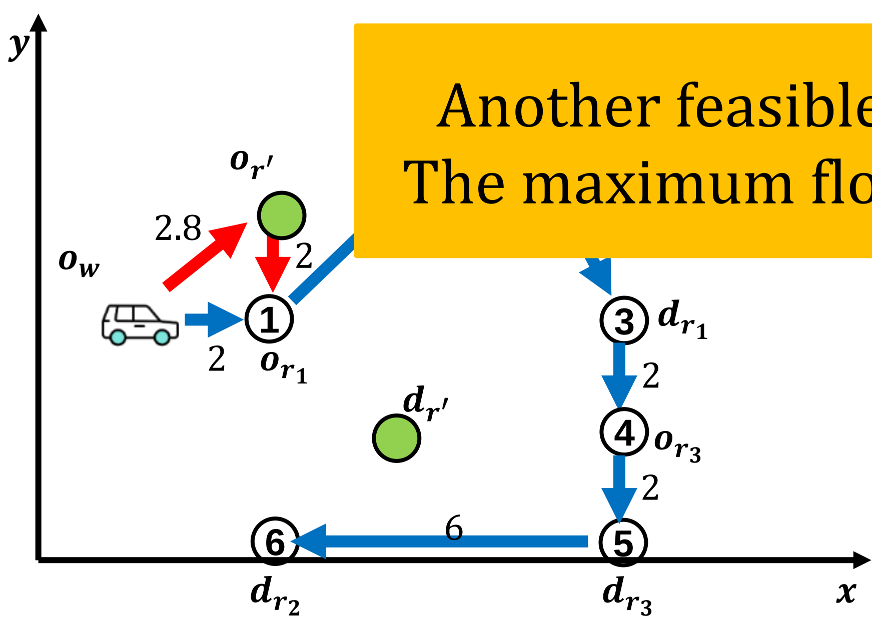
- Enumerate $i = 0$ $(A(i) = 2.8)$
  - Query the segment $[det(0, o_{r'}), \infty)$

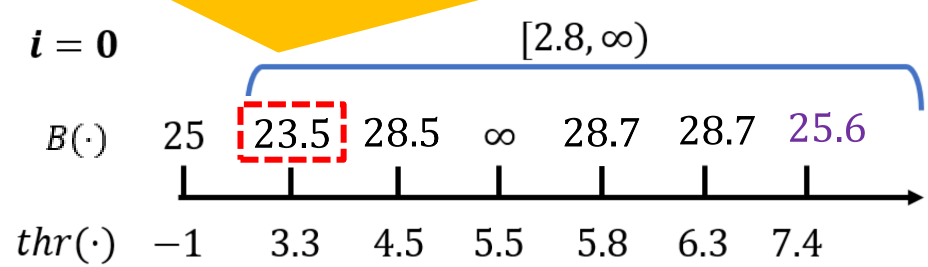
$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	−1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i)\\ det(i,o_{r'})\le thr(j)}} B(j)$$

Optimal solution: 24.3

Another feasible solution: insertion(0,5)
The maximum flow time is 2.8+23.5=26.3



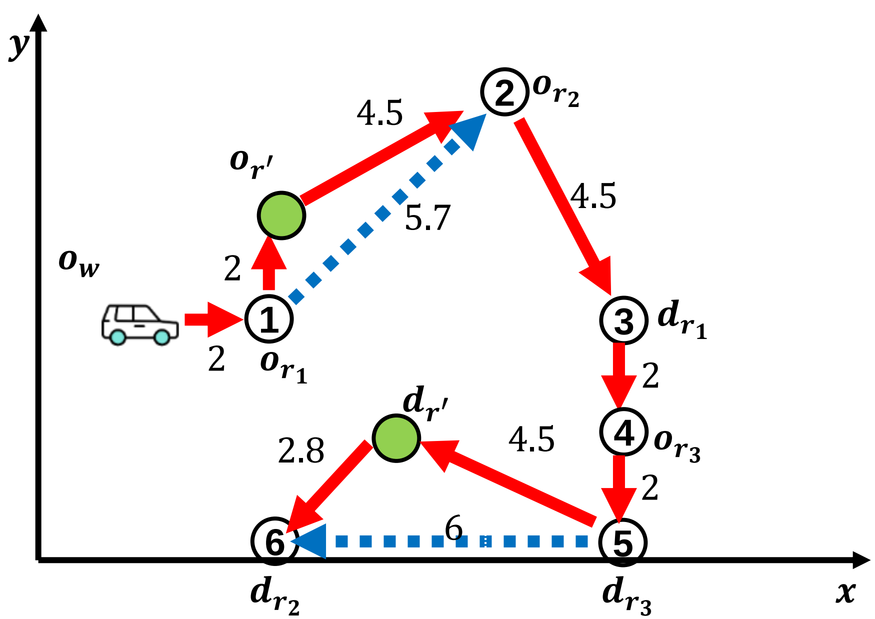


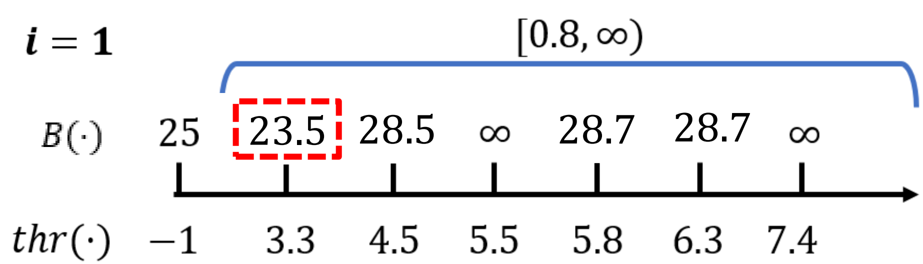
Example

- Finally, the optimal solution:
  - Insertion(1,5) with maximum flow time 24.3

$index$	$0(o_w)$	$1(o_{r_1})$	$2(o_{r_2})$	$3(d_{r_1})$	$4(o_{r_3})$	$5(d_{r_3})$	$6(d_{r_2})$
$thr(\cdot)$	5.5	7.4	4.5	6.3	5.8	3.3	-1
$B(\cdot)$	27.5	25.6	28.5	28.7	28.7	23.5	25

$$\min_{\substack{i<j<brk(i) \\ det(i,o_{r'})\le thr(j)}} B(j)$$





Outline

- Background
- Problem Statement
- Partition-based Framework
- Segment-based DP Algorithm
- Experimental Evaluations
- Conclusion

Experiments: Setup

- Two real datasets:
  - Taxi: collected in New York City, public dataset.
    - 517,100 requests
    - Worker’s capacity is small (Default: 4)
  - Logistics: collected in Shanghai by Cainiao, an urban logistics platform in China.
    - 345,849 requests
    - Worker’s capacity is large (Default: 120)

Experiments: Setup

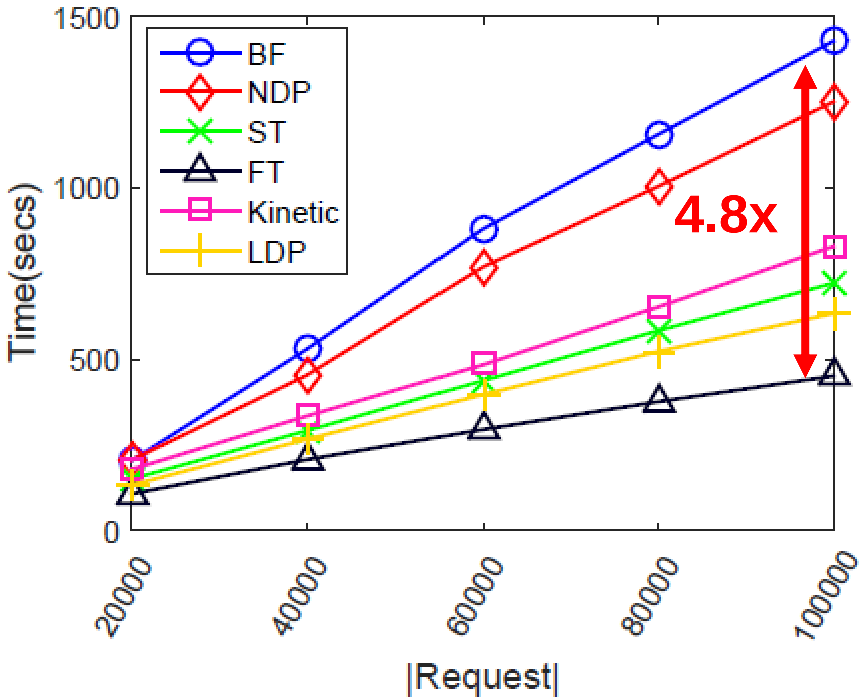
- Compared Algorithms:

Method		Complexity	Goal	
			Minimize total travel time	Minimize maximum flow time
Previous method	BF [ICDE'13] [EJOR'11]	$O(n^3)$	√	√
	Kinetic [VLDB'14]	$O(n^2)$	√	×
	LDP [VLDB'18]	$O(n)$	√	×
Our method	**NDP**	$\boldsymbol{O(n^2)}$	√	√
	ST	$\boldsymbol{O(n \log n)}$	√	√
	FT	$\boldsymbol{O(n)}$	√	√

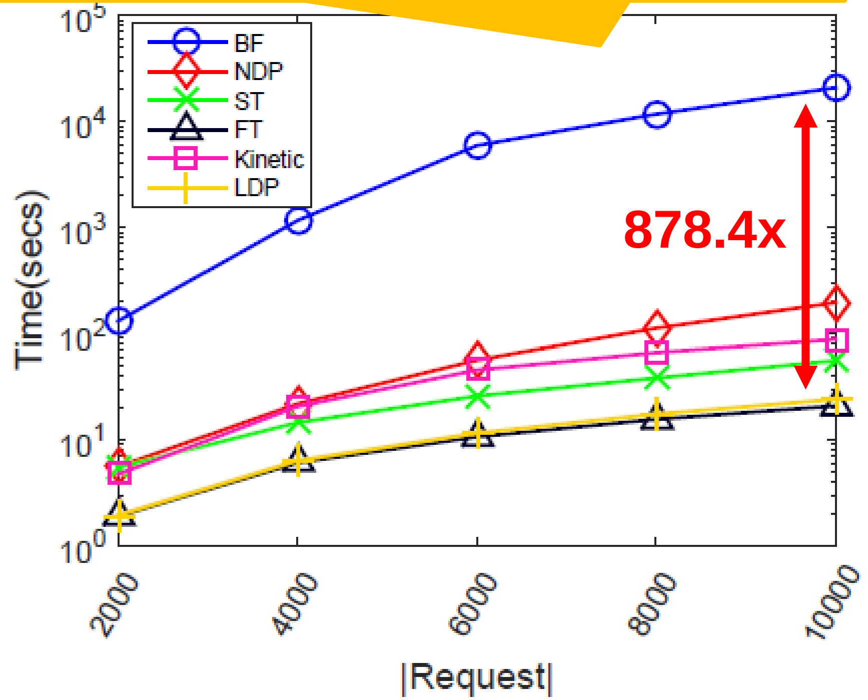
Experiments: Result

- Minimizing total travel time
  - FT is faster than LDP on Taxi and as fast as LDP on Logis

As for minimizing total travel time,
FT is 878.4 times faster than BF on Logistics



Dataset: Taxi

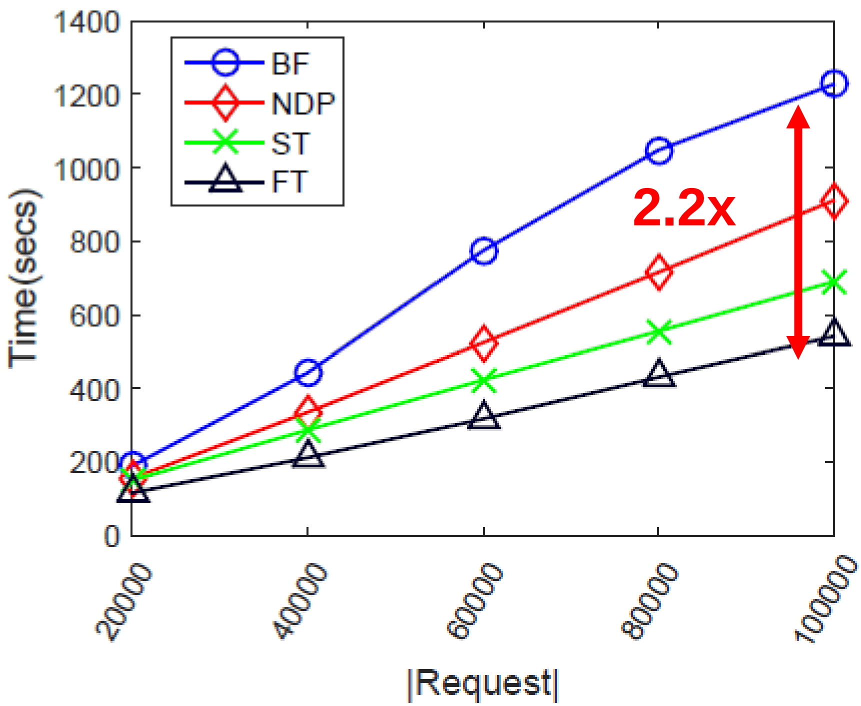


Dataset: logistics

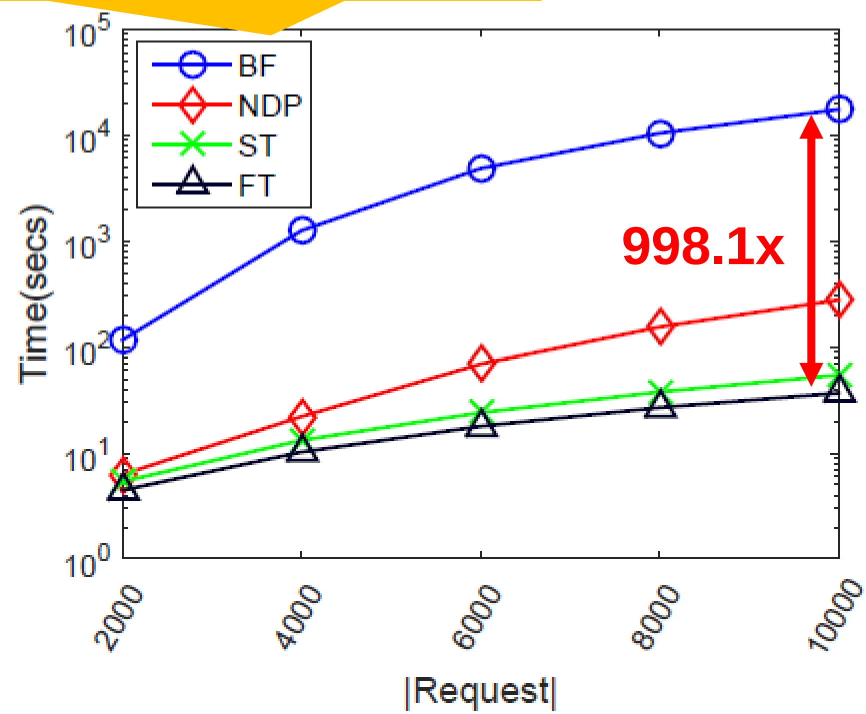
Experiments: Result

- Minimizing maximum flow time
  - FT outperforms the other algorithms

FT is 2.2 times faster than BF on Taxi and 998.1 times faster on Logistics



Dataset: Taxi

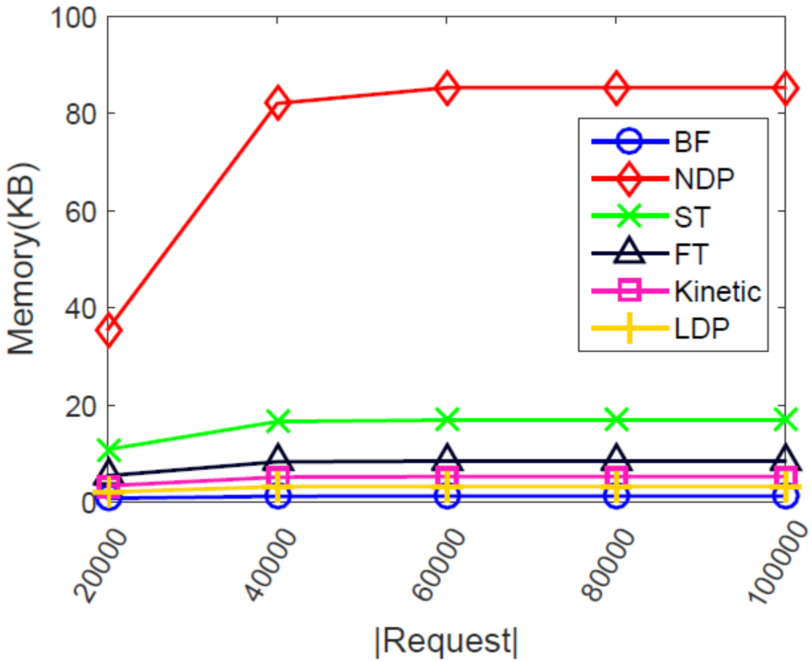


Dataset: logistics

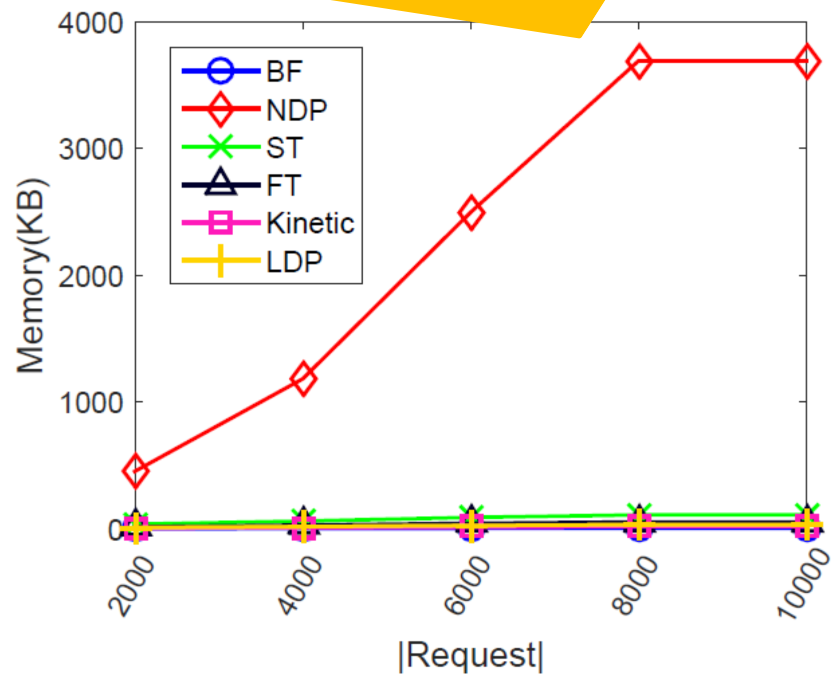
Experiments: Result

- Memory
  - The gap of memory cost among algorithms (except

The gap of memory cost between FT to other algorithms is less than 0.1MB



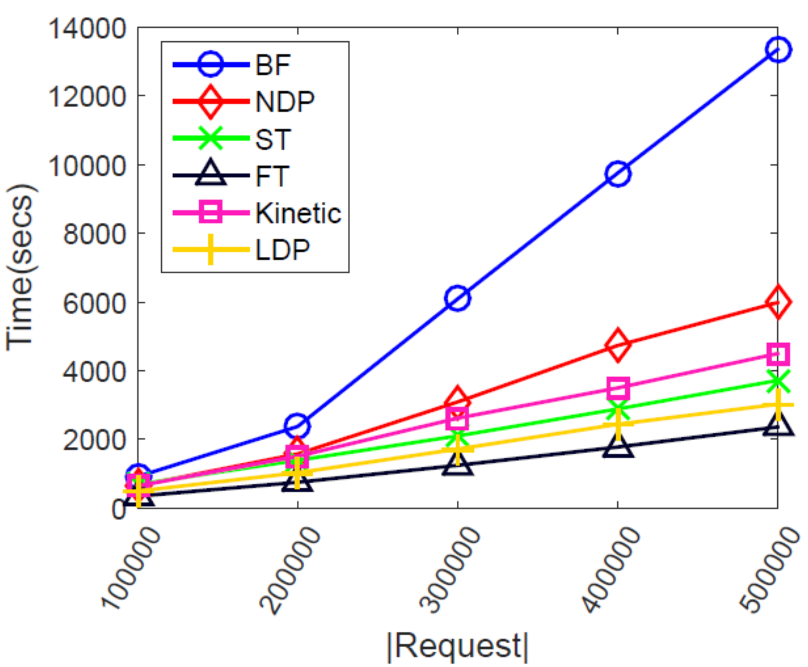
Dataset: Taxi



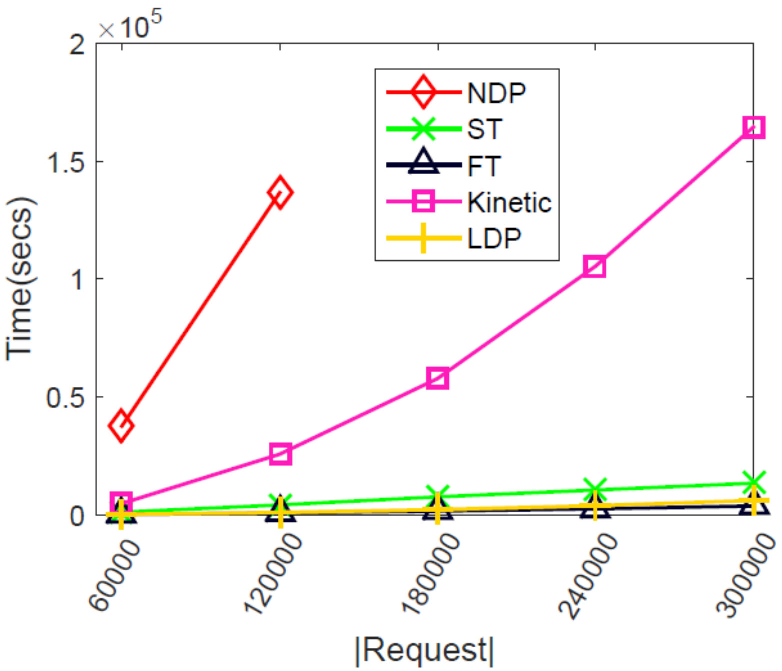
Dataset: logistics

Experiments: Result

- Scalability
  - Our algorithms are fit for hundred thousands of requests.



Dataset: Taxi



Dataset: logistics

Outline

- Background
- Problem Statement
- Partition-based Framework
- Segment-based DP Algorithm
- Experiments
- Conclusion

Conclusion

- We propose a partition-based framework to reduce the time complexity of the generic insertion operator from $O(n^3)$ to $O(n^2)$.
- By utilizing some efficient index structures, we further propose a linear insertion operator.
- Experiments on real datasets show that the insertion operator can be accelerated by up to 998.1 times on urban-scale datasets.

Q & A

Thank You