Contracting and Compressing Shortest path Databases ICAPS 2021

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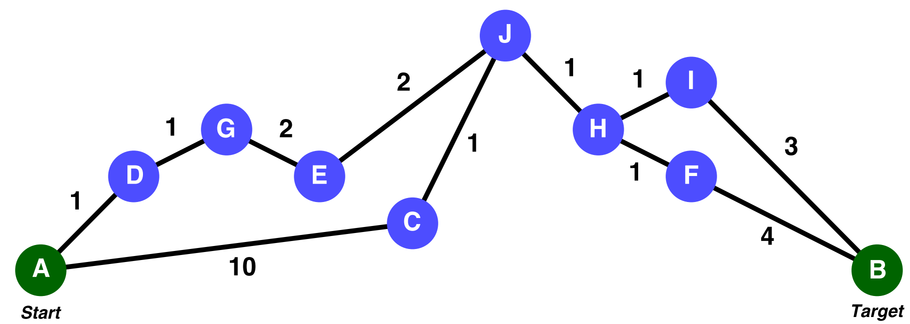
Monash University

Shortest Path Problem in Road Network

- Road Network:
  - A directed or undirected graph
    - A set of vertices: V.
    - A set of edges: $E \subseteq V \times V$.
    - Each edge $e \in E$ has a non-negative weight $w(e)$, which can represent travel time, distance and so on.
- Shortest Path Problem:
  - Given a start s and target t.
  - Find an optimal path which minimize the sum of weight on each edge.



An example of undirected road network graph. The start and target are shown in green, and the weight of each edge are shown in the figure correspondingly.

Compressed Path Databases (CPD) [1]

- Compressed Path Databases:

Background
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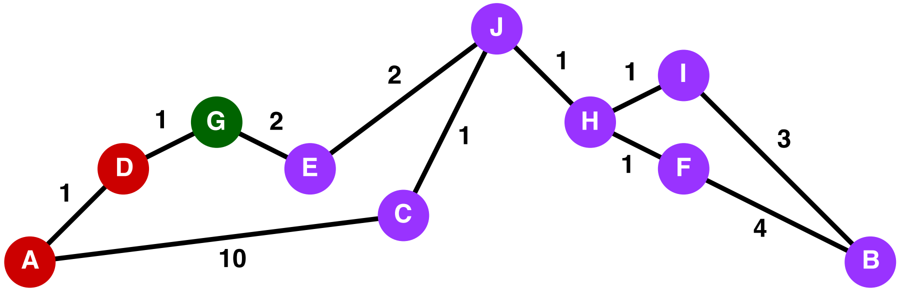
- Compressed Path Databases:
  - Construction:
    - First move table:

Ordering	G	D	A	C	J	E	H	F	B	I
G	*	D	D	E	E	E	E	E	E	E
J	E	E	E	C	*	E	H	H	H	H
I	H	H	H	H	H	H	H	H	B	*



From the source node G, the optimal first move to any node colored red (resp. purple) is D (resp. E).

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- Compressed Path Databases:
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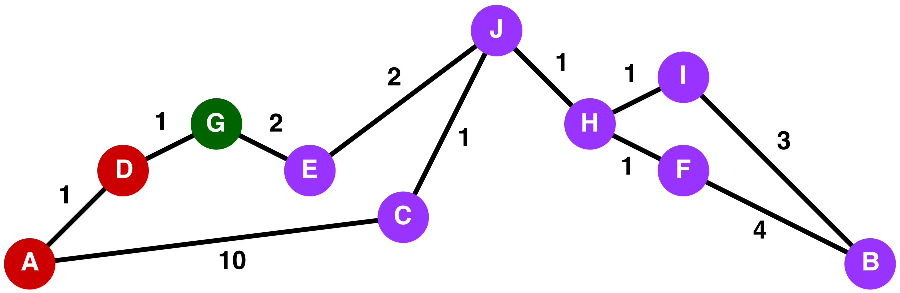
      - [A – J]: indicates the optimal first move.

Ordering	G	D	A	C	J	E	H	F	B	I
G	*	D	D	E	E	E	E	E	E	E
J	E	E	E	C	*	E	H	H	H	H
I	H	H	H	H	H	H	H	H	B	*



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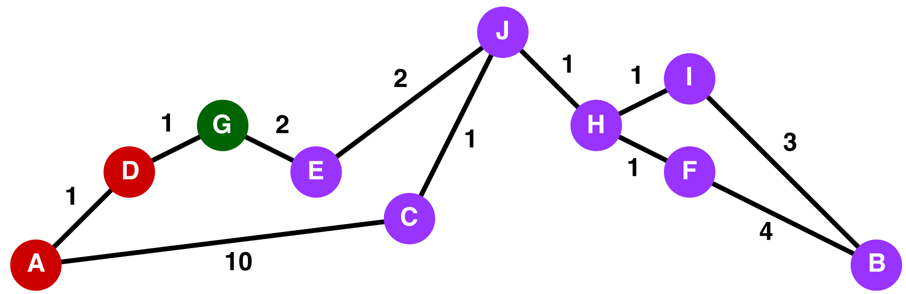
Ordering	G	D	A	C	J	E	H	F	B	I
G	$\boxed{*}$	D	D	E	E	E	E	E	E	E
J	E	E	E	C	*	E	H	H	H	H
I	H	H	H	H	H	H	H	H	B	*



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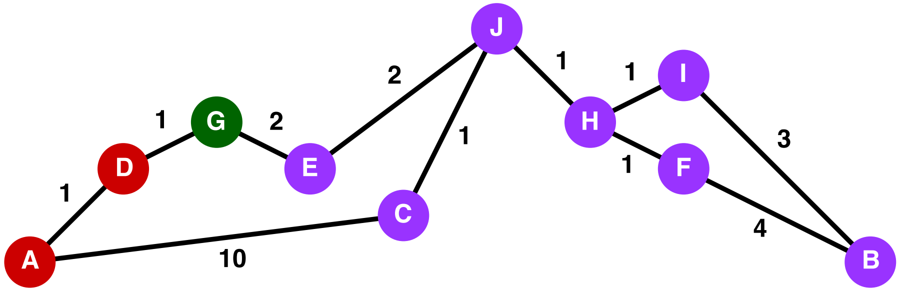
G	*	D	D	E	E	E	E	E	E	E
J	E	E	E	C	*	E	H	H	H	H
I	H	H	H	H	H	H	H	H	B	*



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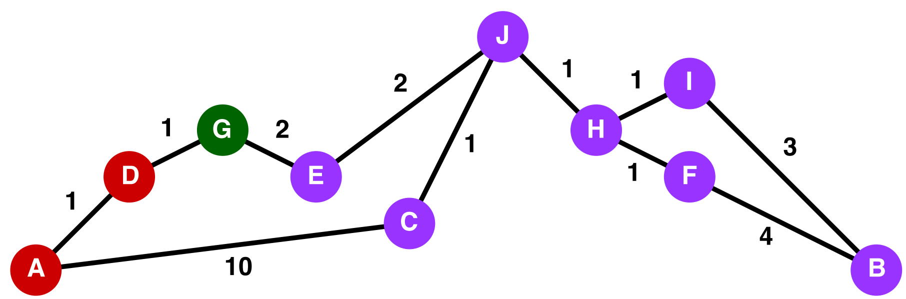
G	*	D	D	E	E	E	E	E	E	E
J	E	E	E	C	*	E	H	H	H	H
I	H	H	H	H	H	H	H	H	B	*



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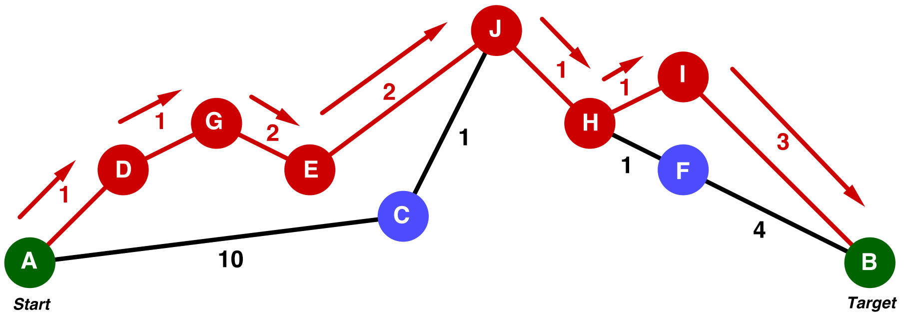
  - Query:
    - From a given s, CPD recursively extract the optimal first move until reaches t.



Exacting the shortest path from CPD, the shortest path from start to target is shown in red.

Contraction Hierarchy (CH) [3]

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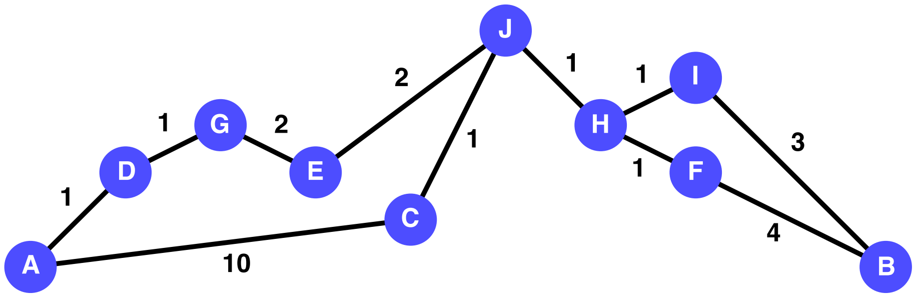

The lex order L is the alphabetical order shown in the figure.

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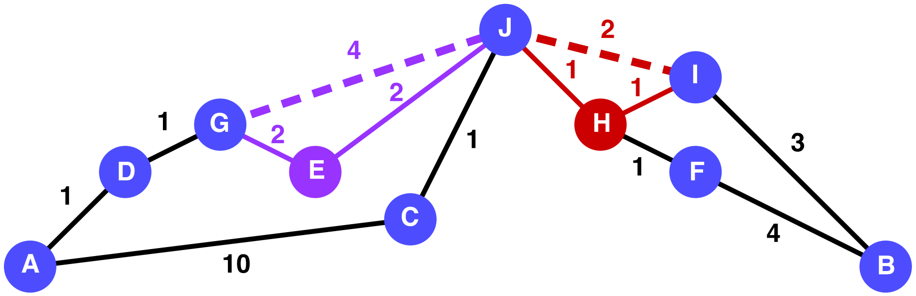
  - Construction:
    - Apply a total lex order L.
    - Contraction:
      - W.r.t. L, choose the least node v from the graph.



The result of contracting E (resp. H) in purple (resp. red). Dashed edges indicate shortcut edges.

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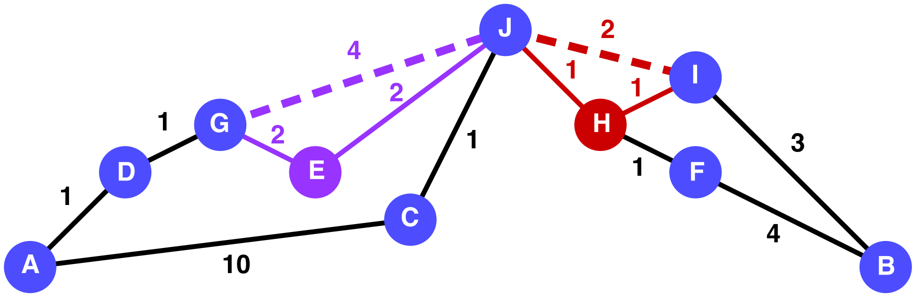
    - Contraction:
      - W.r.t. L, choose the least node v from the graph.
      - Add a shortcut edge (u, w) between each pair of in-neighbour u and out-neighbour w of v:
        - » v $<_L$ u & v $<_L$ w.
        - » v ∈ sp(u,w).



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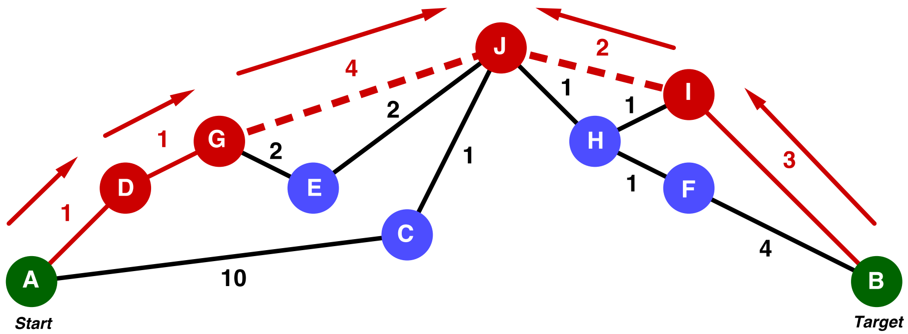

Bi-directional Dijkstra search from start and target, the shortest ch-path is shown in red.

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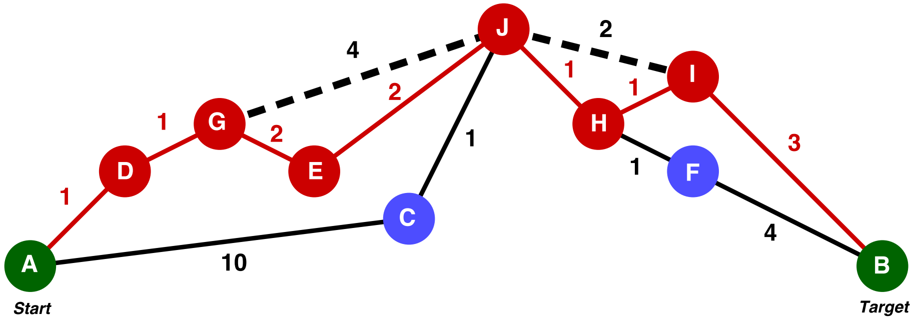
    - Bi-directional Dijkstra search.
    - Unpack the path.



Unpacking the CH path, the final shortest path is shown in red.

Our Approach:
CH-based Compressed Path Databases (CH-CPD)

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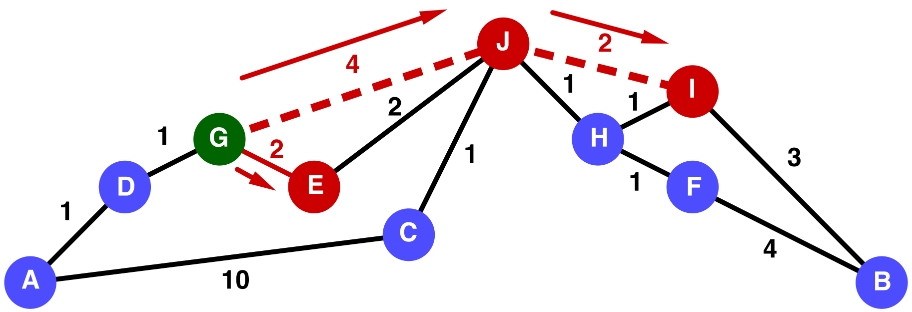
  - Construction:
    - Modified Dijkstra:
      - Up-then-down policy.



Deconstructing the ch-path gives following three cases: (i) up ch-path: <G, J>; (ii) up-down ch-path: <G, J, I>; (iii) down ch-path: <G, E>.

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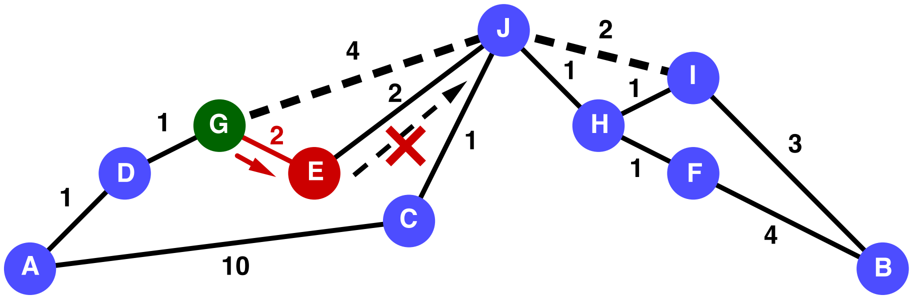

The up-then-down policy: the up successor J of E is pruned, because the predecessor G is lexically larger than E. (i.e., G $>_L$ E).

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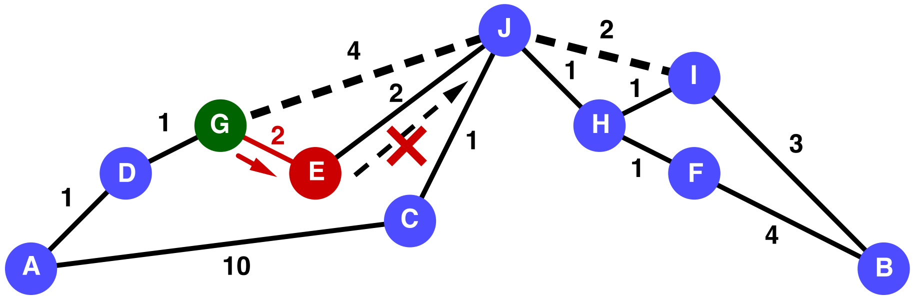
    - Distance table enhancement:



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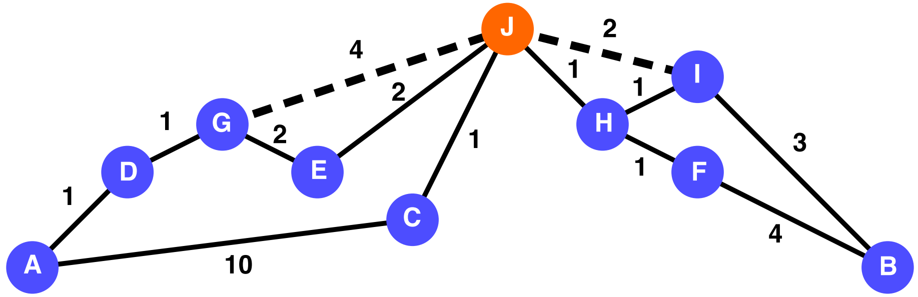
- CH-CPD:
  - Construction:
    - Modified Dijkstra:
      - Up-then-down policy.
    - Distance table enhancement:
      - Caching:
        - » Cache the distance table for top n% of CH-nodes.

Ordering	G	D	A	C	J	E	H	F	B	I
FirstMove(J,_)	G	G	G	C	*	E	H	H	I	I
$d(J, \_)$	4	5	6	1	0	2	1	2	5	2



Distance table enhancement: We cache the all-pairs distance when compute the first moves for node J.

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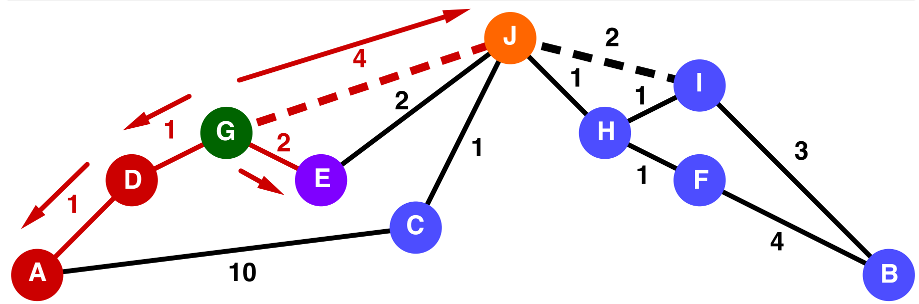
FirstMove(G,_)	*	D	D	-	J	E	-	-	-	-
$g(\mathtt{G}, \_)$	0	1	2	∞	4	2	∞	∞	∞	∞



Constructing CPD on top of CH. The source node G is highlighted as green. The first move on the optimal path from source node to any node are D, E and J shown as red, purple and orange, respectively

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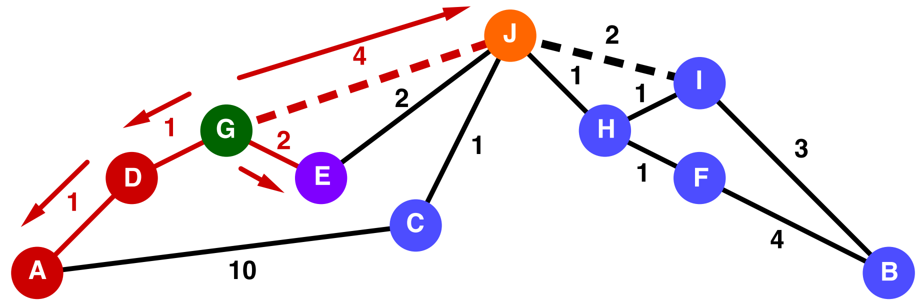
      - Pruning:
        - » Relax tentative distance.

Ordering	G	D	A	C	J	E	H	F	B	I
$d(J, \_)$	4	5	6	1	0	2	1	2	5	2
FirstMove(G,_)	*	D	D	-	J	E	-	-	-	-
$g(G, \_)$	0	1	2	5	4	2	5	6	9	6



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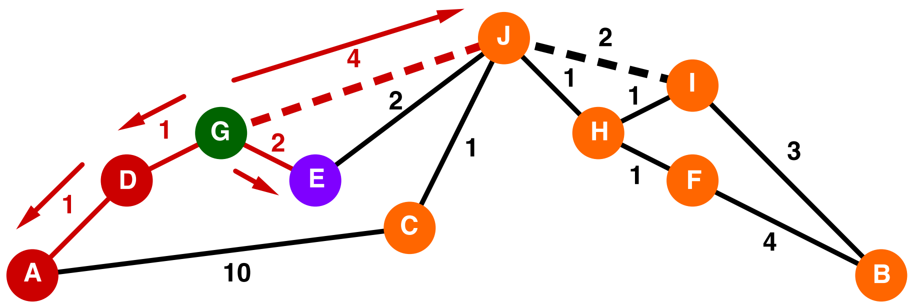

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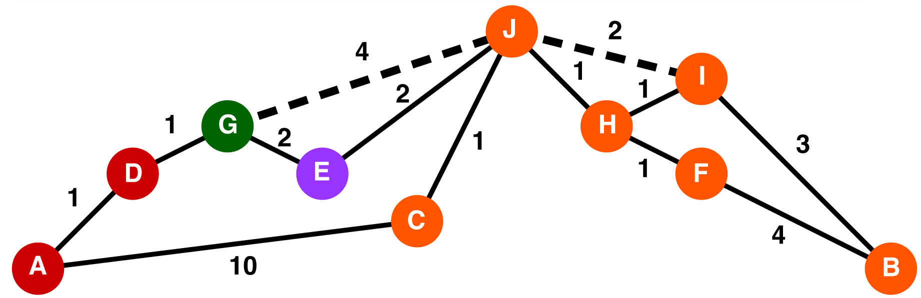
G	*	D	D	J	J	E	J	J	J	J
J	G	G	G	C	*	E	H	H	I	I
I	J	J	J	J	J	J	H	H	B	*



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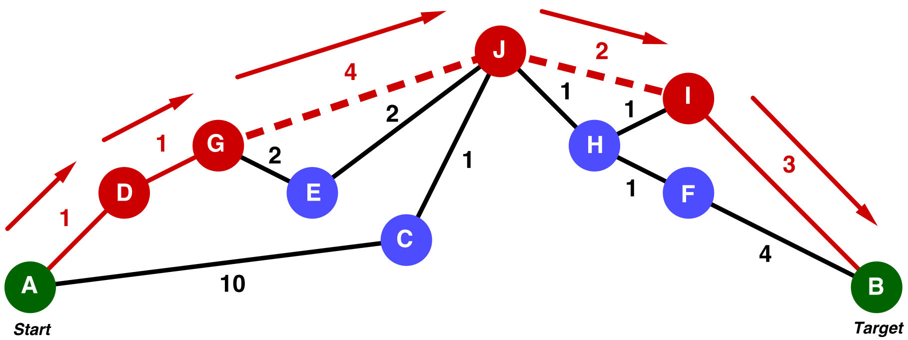
  - Query:
    - Extract and unpack the CH-path from CH-CPD.



Exacting the shortest ch-path from CH-CPD, the shortest ch-path from start to target is shown in red.

Our Approach:
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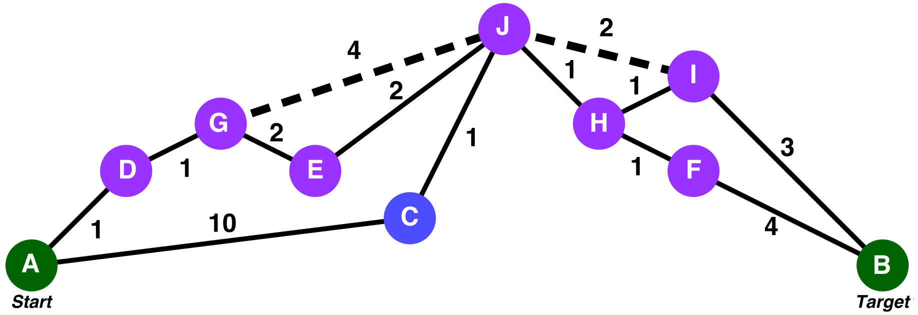
  - Construction:
    - Select top n% of CH nodes to construct a CH-CPD.



The partial CH-CPD nodes are D-J which shown in purple color.

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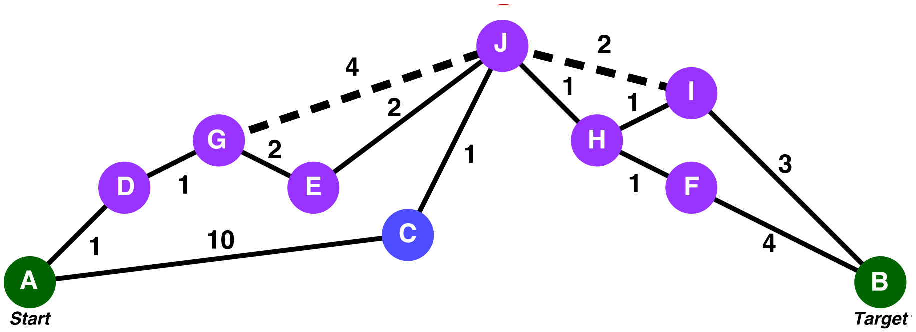
  - Bi-directional CPD search:



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    - Incremental exploration:
      - A* search:
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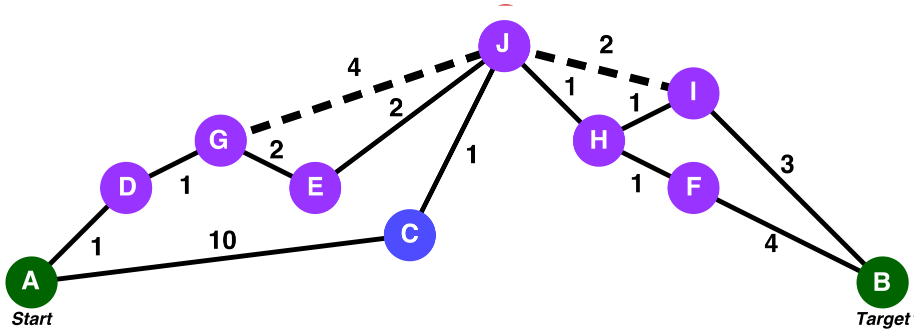

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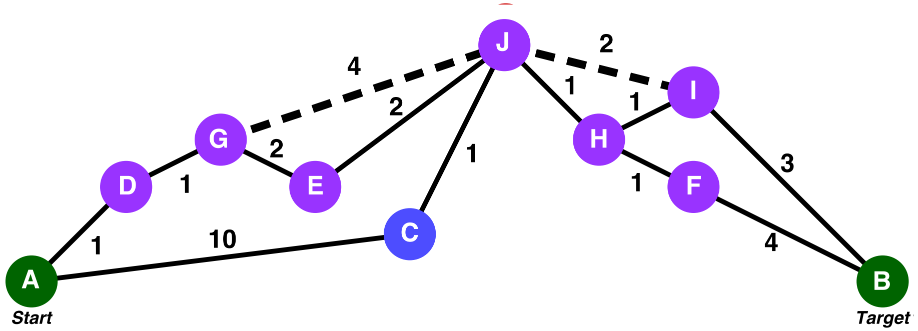

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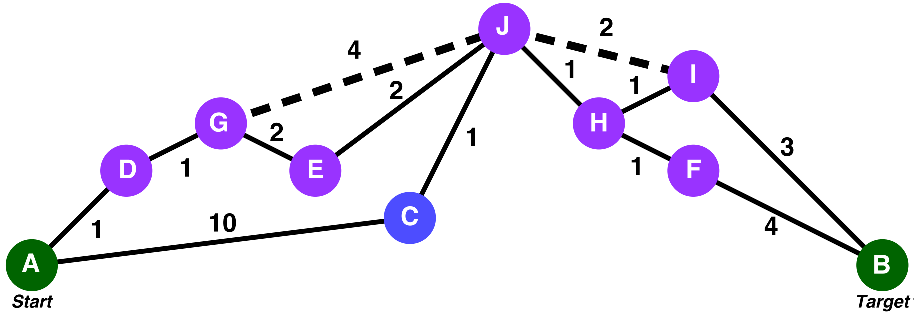

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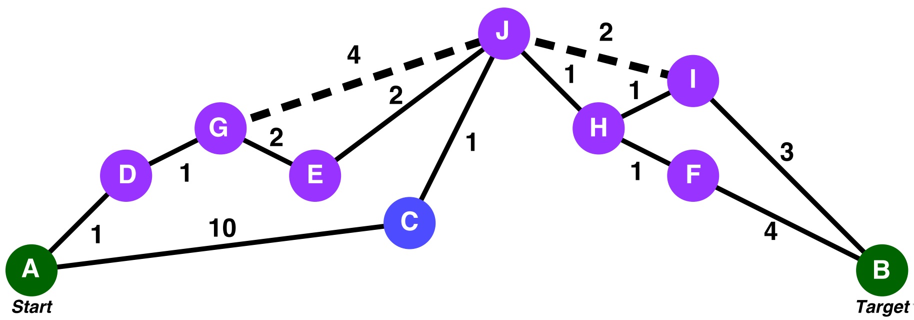
      - Shortest path (sp).



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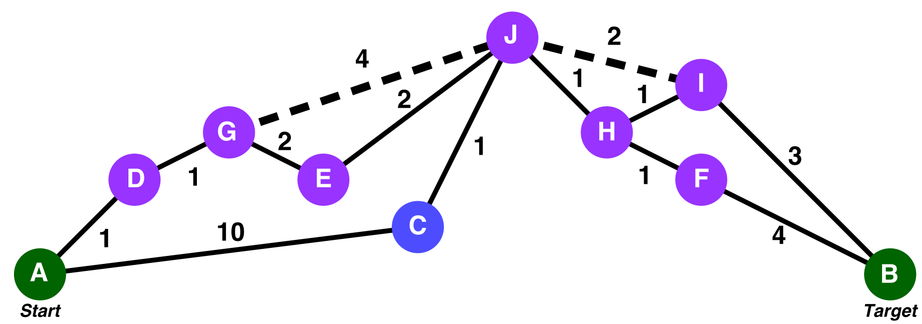
    - Pruning:



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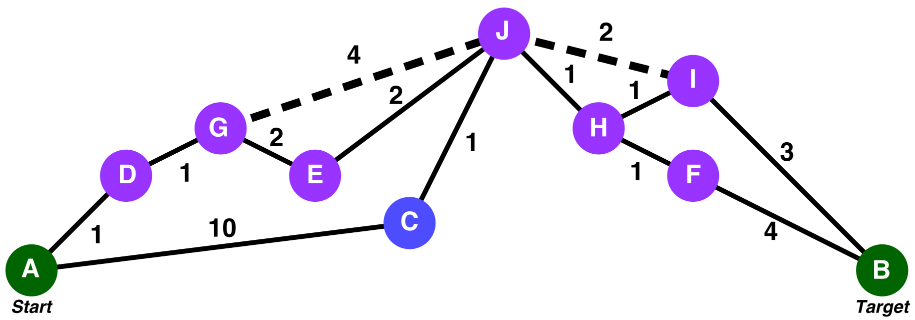
      - V_s & V_t .
      - Shortest path (sp).
    - Pruning:
      - Distance-based pruning:
        - » $g(s, v_s) + landmark(v_s, v_t) + g(v_t, t) \geq |sp|$.



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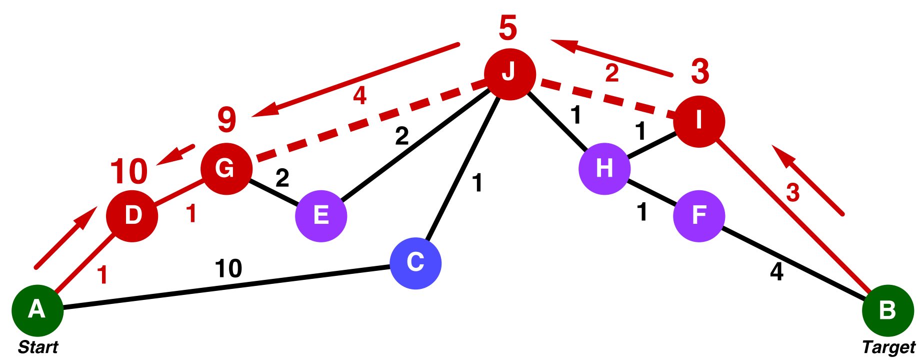
      - Cost caching.



Bi-directional CPD search caches distance on each node when extracts the path from I to D.

Our Approach: Partial CH-CPD

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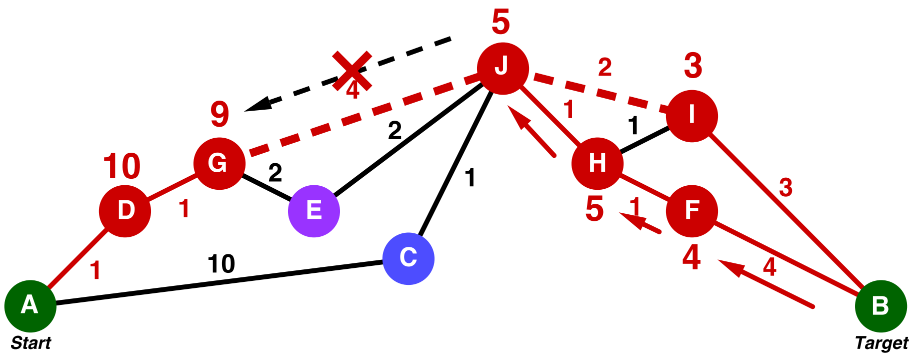

The path extraction from F to D terminates at J, because the cached distance g(B, J) < g(B, H) + d(H, J).

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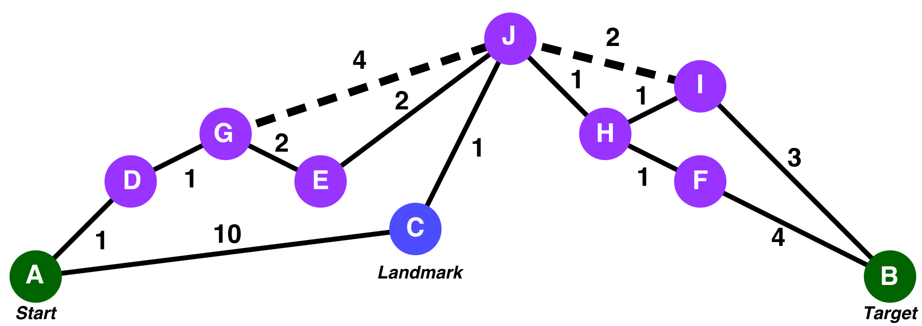

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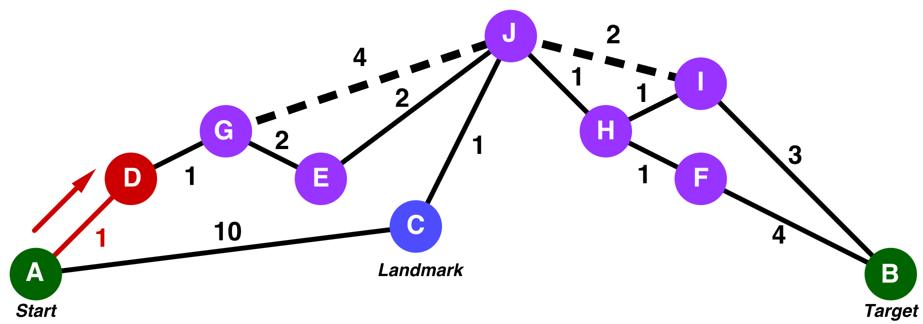

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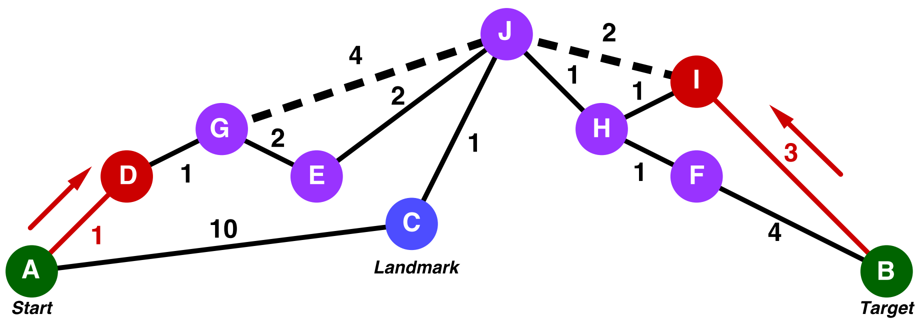

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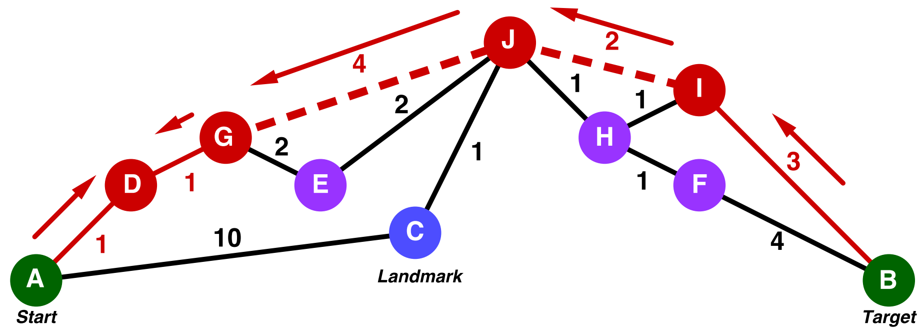

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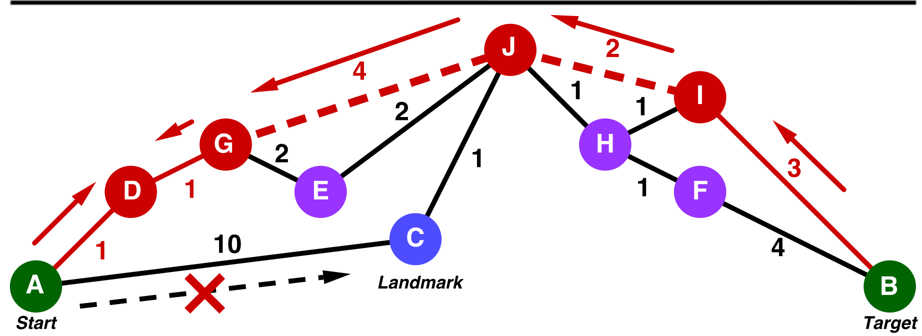
Ordering	G	D	A	C	J	E	H	F	B	I
$d(C, \_)$	5	6	7	0	1	3	2	3	6	3



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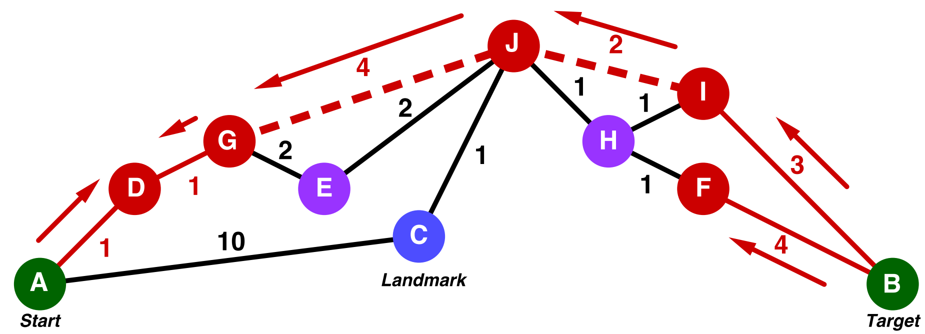

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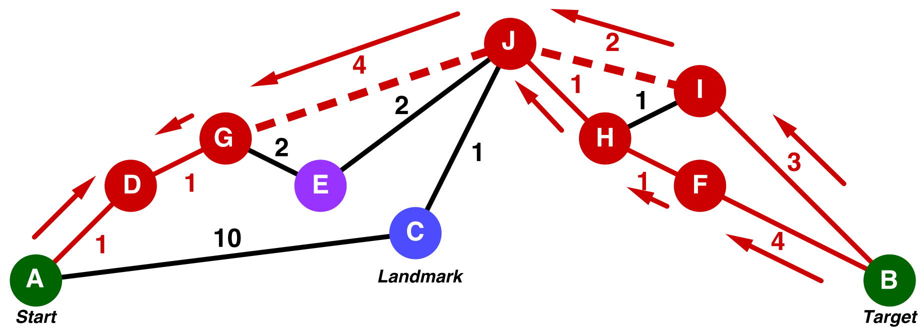

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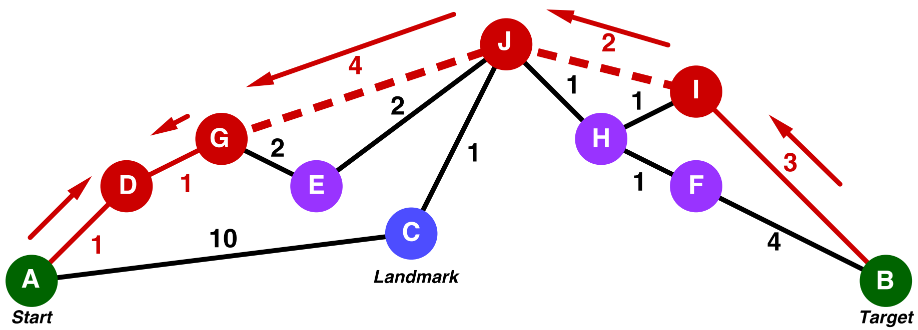

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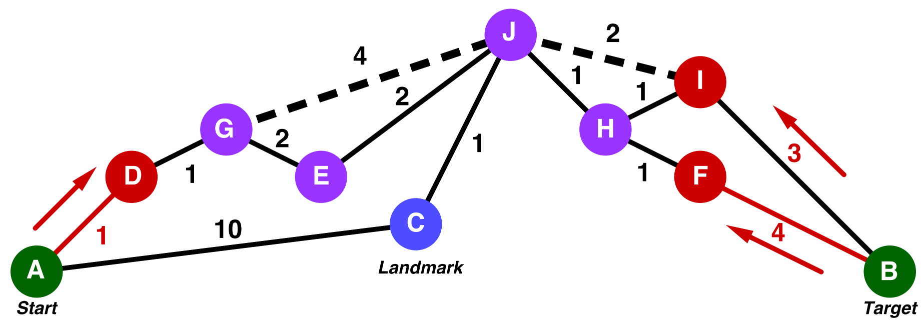

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Map Type	Build Time (Mins)							Memory (MB)						
	CH-CPD					Competitors		CH-CPD					Competitors	
	20%	40%	60%	80%	100%	CPD	CH	20%	40%	60%	80%	100%	CPD	CH
NY Distance	0.36	0.73	1.18	1.87	2.95	8.76	0.24	70	104	183	271	338	219	29
NY Travel Time	0.27	0.96	1.79	2.24	3.00	11.03	0.16	63	88	156	222	277	188	28

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MONASH University

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  - Query performance:

Map Type	Average Runtime (µs)									
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	20%	40%	60%	80%	100%	CPD	CH	CH+L	PHL	SHP
NY Distance	23.17	20.83	17.19	13.67	11.42	26.38	38.64	25.58	25.36	26.76
NY Travel Time	19.16	18.82	14.83	12.85	9.53	18.23	25.27	20.06	18.32	14.93

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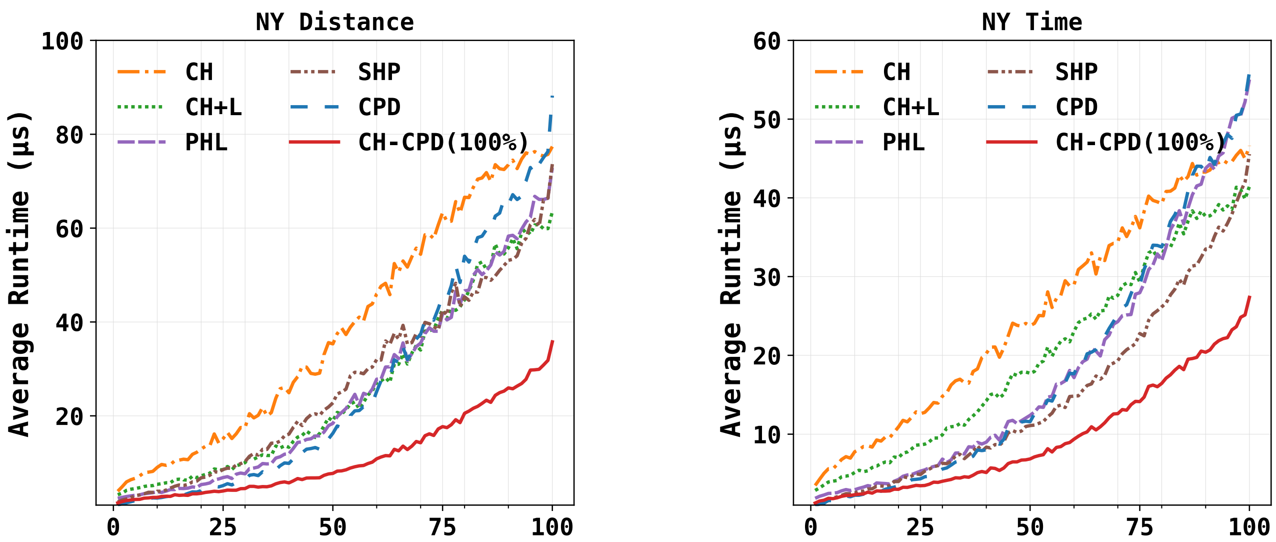

Runtime comparison. The x-axis shows the percentile ranks of path queries sorted based on actual distances between start and target.

Reference

[1] B. Strasser, D. Harabor, A. Botea, Fast first-move queries through run-length encoding, in: Proceedings of the Seventh Annual Symposium on Combinatorial Search, SOCS 2014, Prague, Czech Republic, 15-17 August 2014, AAAI Press, 2014.

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Thank you for listening