Recommending the Least Congested Indoor-Outdoor Paths without Ignoring Time

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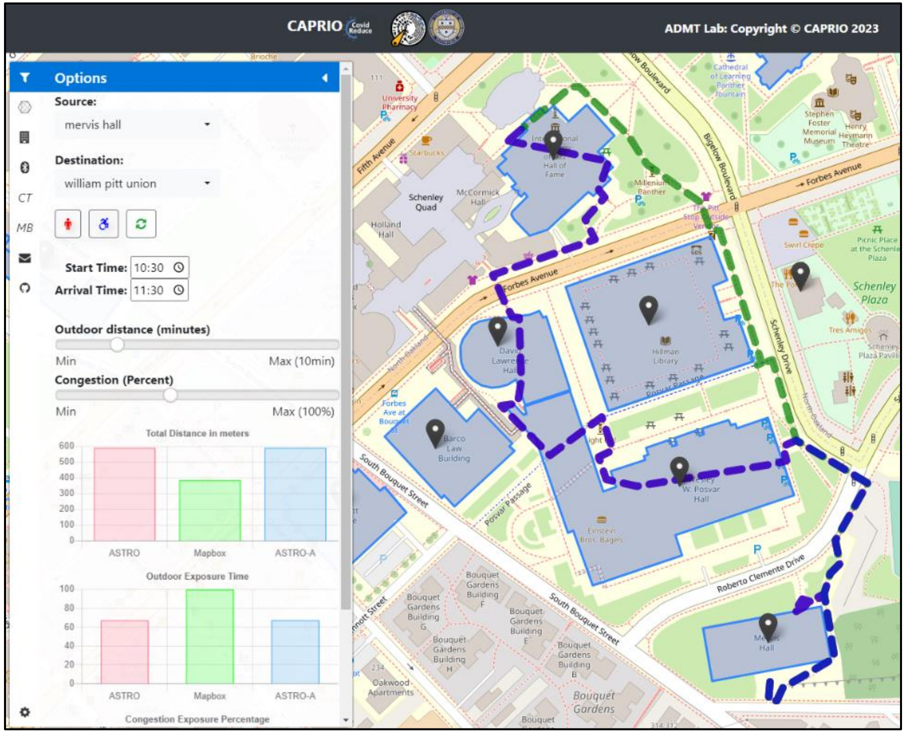
Motivation

- CAPRIO [VLDB'19, MDM'20 & 23] is a navigation app leveraging ASTRO [TSAS'22], a constraint-based indoor-outdoor path finding algorithm

- Path Finding Constraints
  - Outdoor Exposure (E)
  - Total Time Limit (T)
  - Congestion (C)
  - Accessibility (A)



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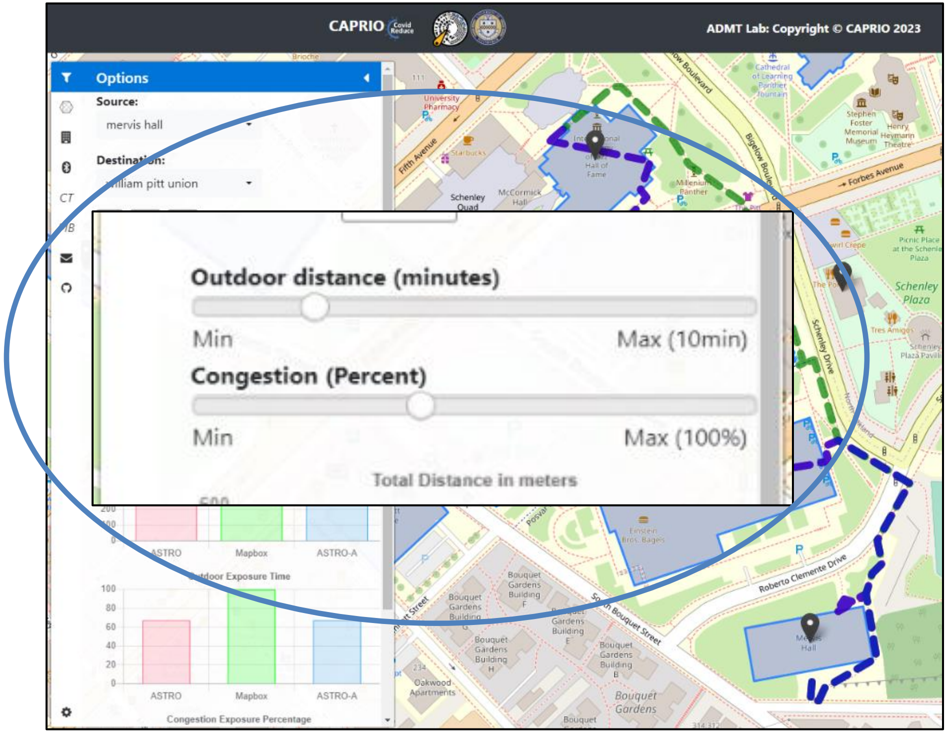
Objective

- Users whose primary concern is congestion must manually find their preferred path by tuning the congestion constraint

- Develop a path finding algorithm based on congestion to better serve these users



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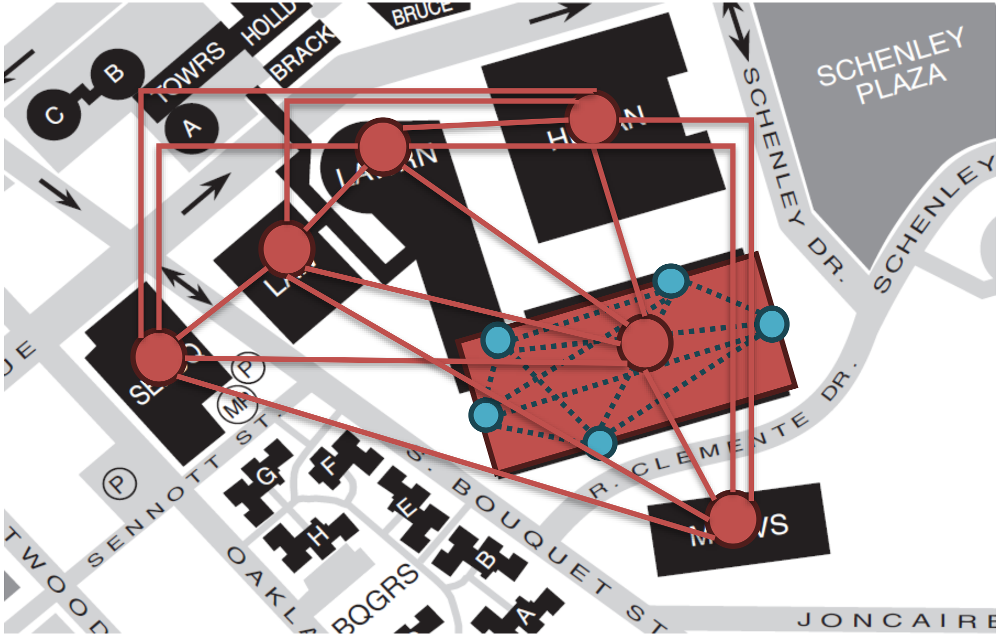
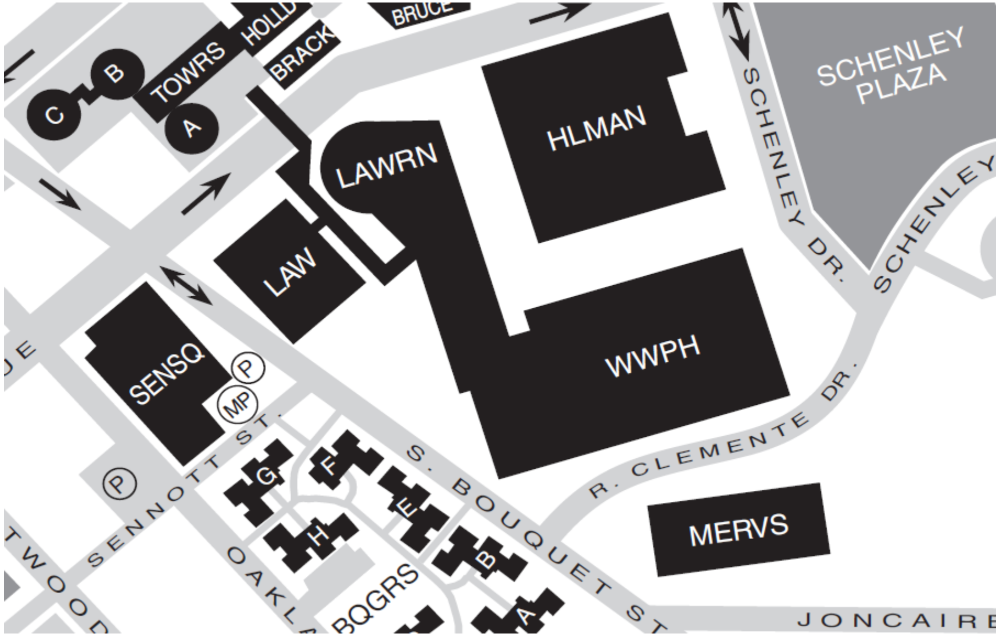
Outline

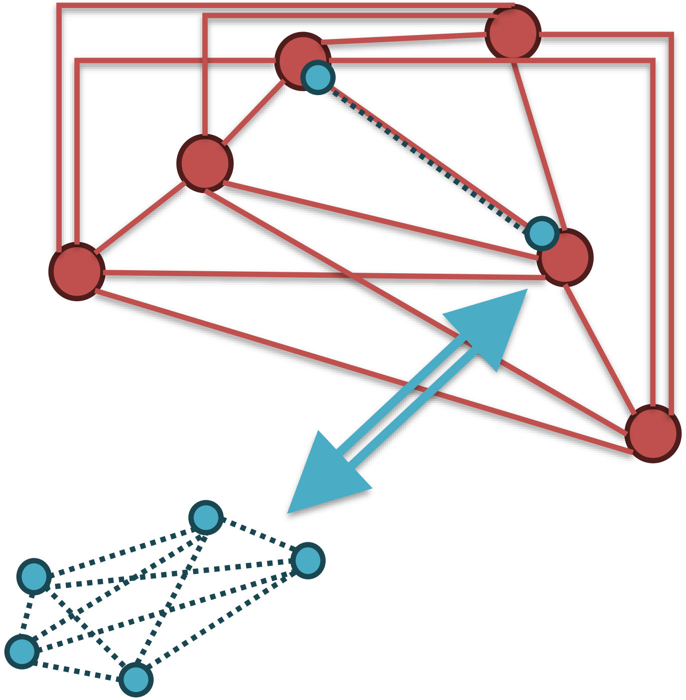
- Motivation
- Indoor-Outdoor Graphs
- ASTRO-C: Least Congestion Path Finding
- Random Graph Generator
- Experimental Evaluation
- Conclusion

Indoor-Outdoor Graph



Indoor-Outdoor Graph





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Least Congestion Path Finding

- Given:
  - Indoor-Outdoor Graph – $G(V_o, E_o, G_{Indoor})$
  - source outdoor vertex – v_s
  - terminal outdoor vertex – v_t
  - set of user-given constraints – $\Pi = (E, T, C, A)$
- Find:
  - Least congested, constraint-satisfying, indoor-outdoor path

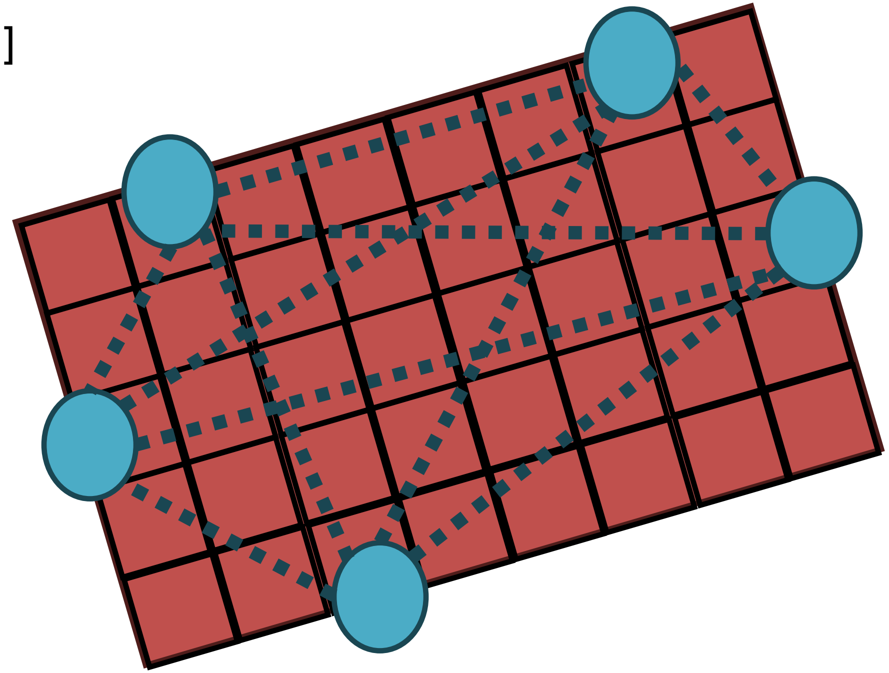
How do we define congestion?

- Based on model used by EPICGEN [VLDB'21]
- Congestion is predicted in 5-minute windows w.r.t. a 3m x 3m cell

$$congestion = \frac{\#\ of\ people\ predicted}{max\ \#\ of\ people\ w.r.t.\ 1m\ social\ distancing}$$

- Congestion for an indoor edge is the average of predicated congestion

$$\forall cell\ \in indoor\_edge$$
$$AVG\ (cell[congestion])$$

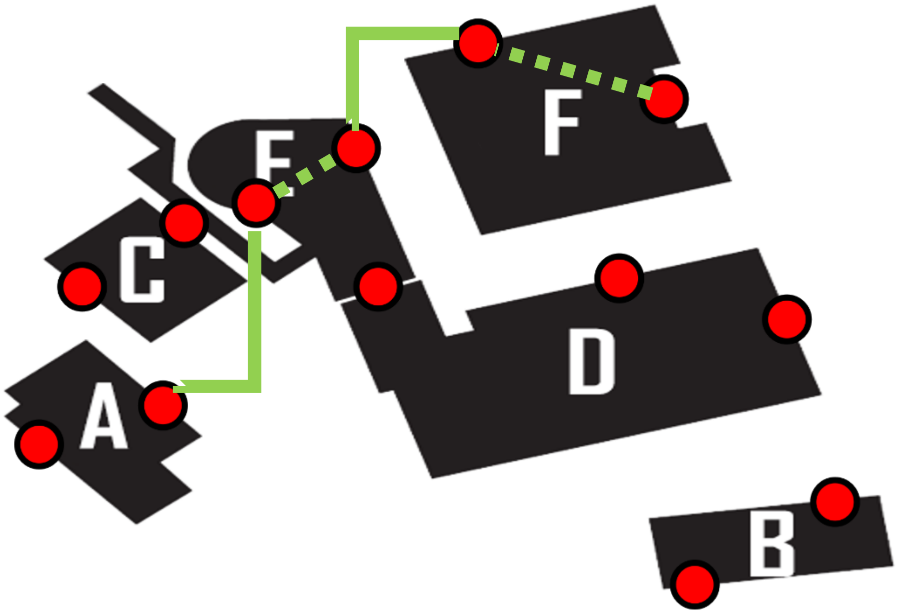


Cost Function

- <u>Key Assumption #1</u>

  As long as a metric is monotonically increasing, it can be used as the basis for a path finding cost function

$$g(path) = \sum_{e \in path.E_i} e.congestion_{avg}$$

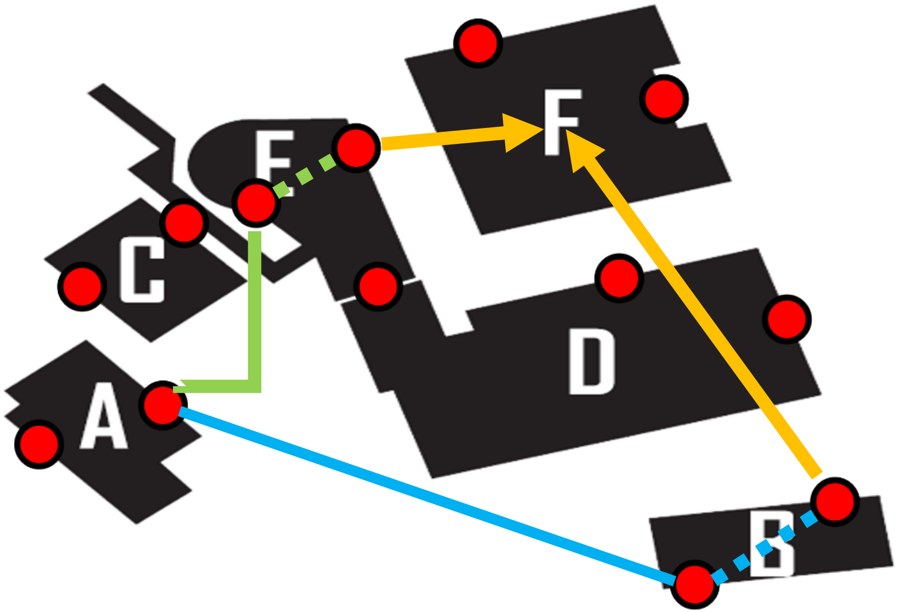


Heuristic Function

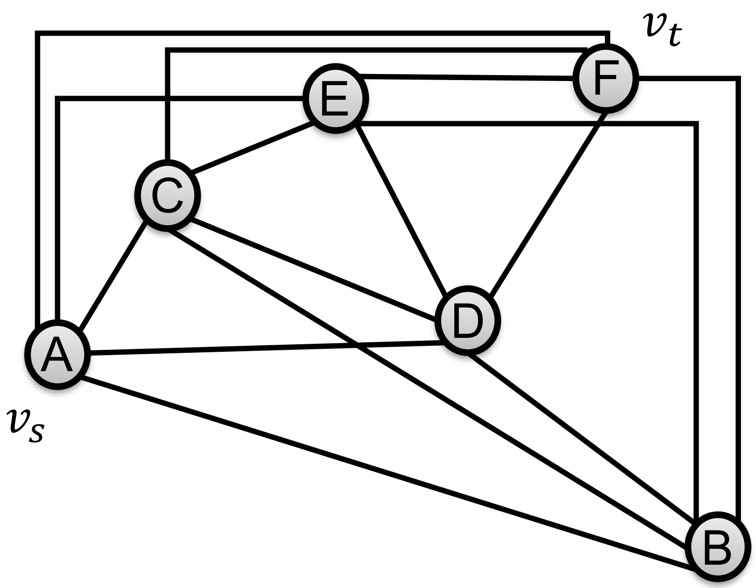
- <u>Key Assumption #2</u>

  The heuristic function h() can be decoupled from the cost function g() and thus need not use the same metrics

$$h(path) = path[time_{total}] + time\_heuristic(path)$$



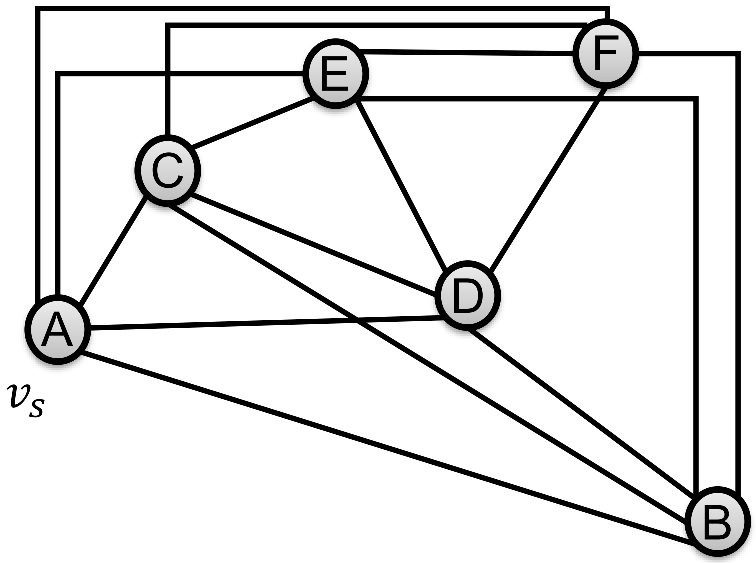
ASTRO-C Overview



Vertex	Prev	Cost	Time (w/ h)	Visited
A (v_s)	--	--	--	False
B		0	0	False
C		0	0	False
D		0	0	False
E		0	0	False
F (v_t)		0	0	False

PQ
A

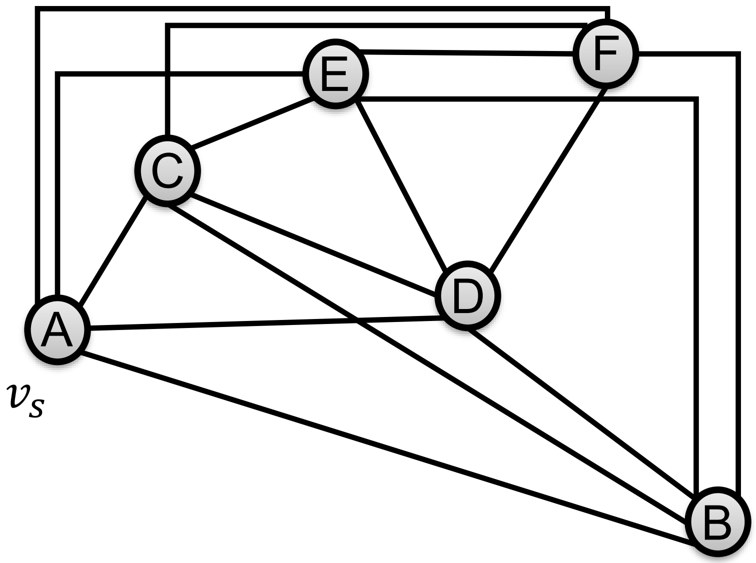
ASTRO-C Overview



Vertex	Prev	Cost	Time (w/ h)	Visited
A (v_s)	--	--	--	True
B		0	0	False
C	A	0.3	13	False
D	A	0.7	16	False
E		0	0	False
F (v_t)		0	0	False

PQ
C
D

ASTRO-C Overview



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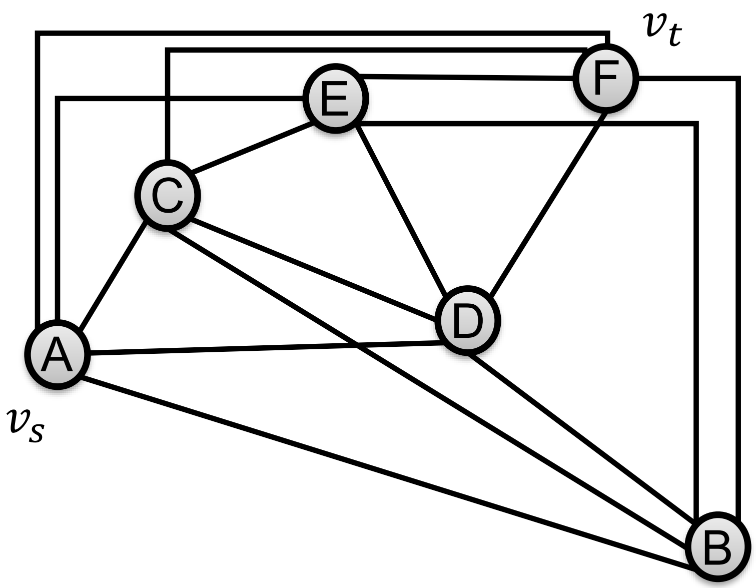
E	C	0.7	17	False
F (v_t)		0	0	False

PQ
D
E

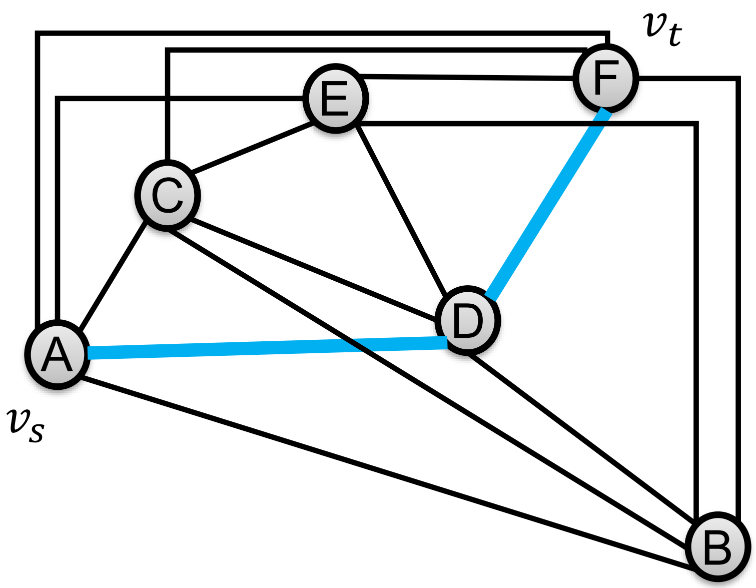
ASTRO-C Overview



Vertex	Prev	Cost	Time (w/ h)	Visited
A (v_s)	--	--	--	True
B	D	1.0	29	False
C	A	0.3	13	True
D	A	0.8	16	True
E	C	0.8	17	False
F (v_t)	E	0.8	18	False

PQ
F
E
B

ASTRO-C Overview



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E	C	0.8	17	False
F (v_t)	E	0.8	18	True

PQ
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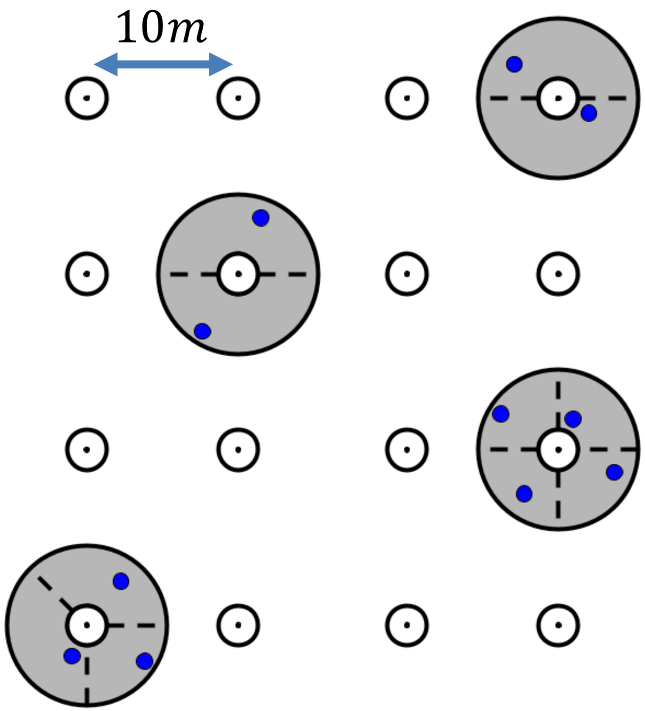
Random Graph Generator

- The graph is a square 2d grid



Parameters

$\boldsymbol{N}$ – # of buildings

$\boldsymbol{P}$ – % of area covered by buildings

$\boldsymbol{h}$ – % of high congestion buildings

$\boldsymbol{m}$ – % of medium congestion buildings

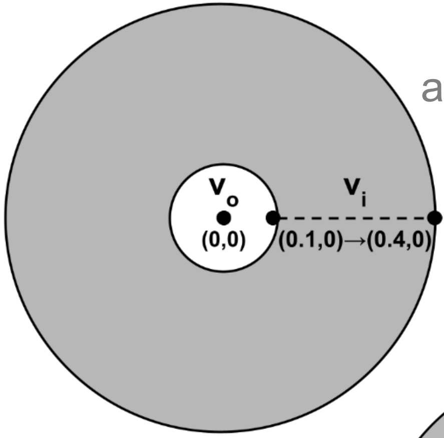
$\boldsymbol{l}$ – % of low congestion buildings

$\boldsymbol{constant}$ – equal congestion in all buildings

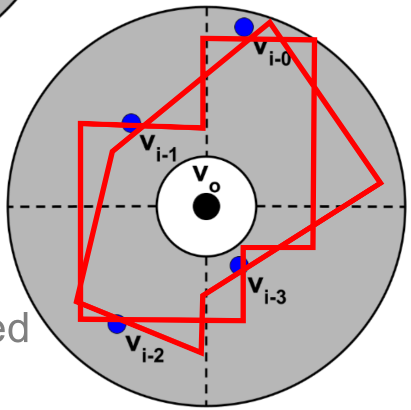
Building Generation

1. Random unoccupied coordinate on grid is chosen for the new outdoor vertex

2. Randomly generate between 2-4 indoor vertices within the coordinate's bounded area
   - Lower bound guarantees indoor traversal time
   - Upper bound guarantees no indoor vertices will overlap



Bounded area around coordinate



Example generated building

Outline

Experimental Methodology

Algorithms – ASTRO and ASTRO-C

Methodology – generate 10 graphs for each experiment, compare the average results

Graph Configuration – $N = 100, P = 0.75, h = 0.3, m = 0.4,$ $l = 0.3, constant = False$

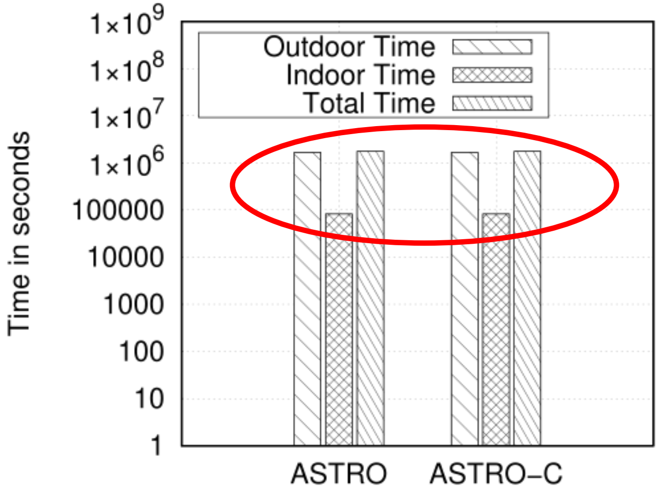
Path Constraints – $T = \frac{(2*graph\_bounds*distance)}{1.4}, E = 30m,$

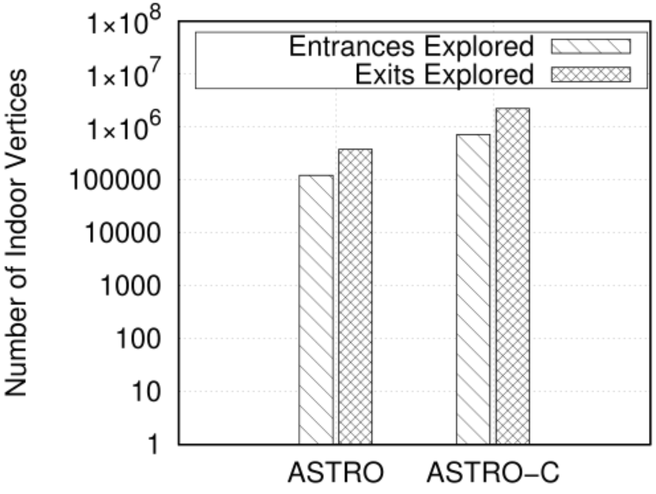
$$C = unbounded, A = False$$

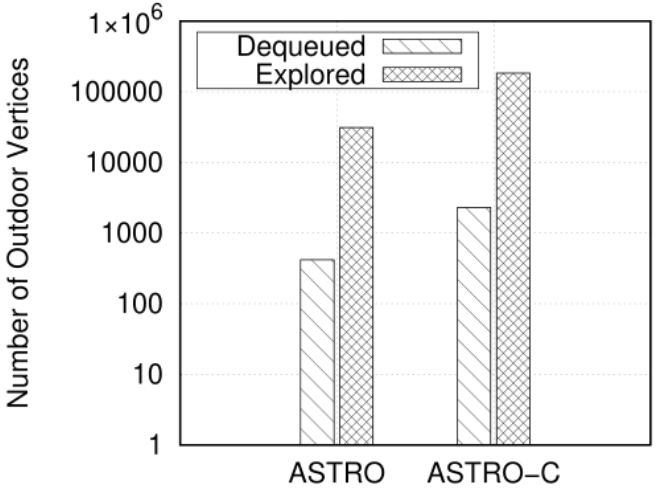
Metrics – Total Path Time &
Avg. Congestion (<1 meets social distancing guidelines)

Experiment 1 – Constant Congestion

- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(100,\ 0.75,\ 0.3,\ 0.4,\ 0.3,\ \boldsymbol{True})$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds*10m}{1.4m/s},\ 30m,\ unbound,\ False\right)$



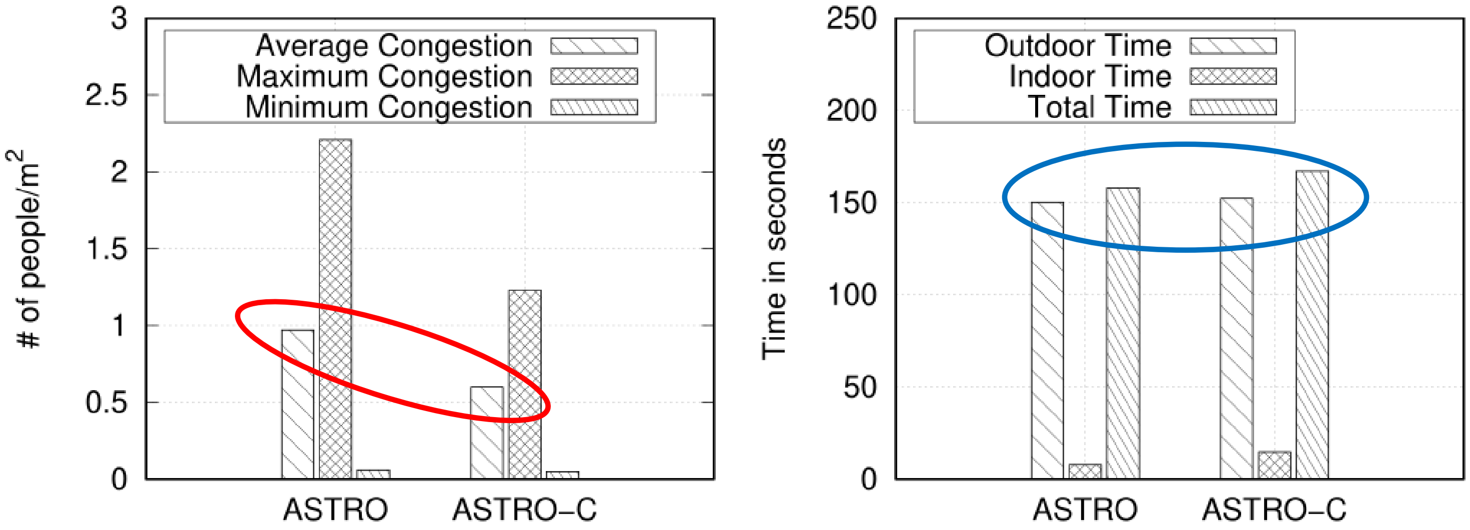




ASTRO & ASTRO-C find the **same paths in constant congestion** environments

Experiment 2 – Standard Configuration

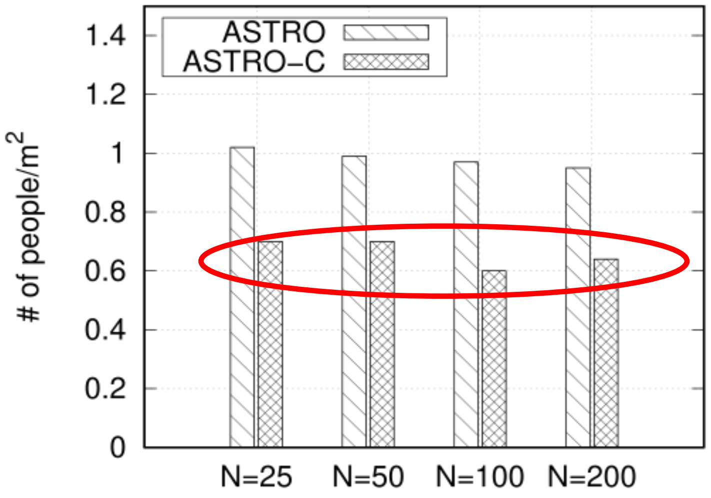
- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(100,\ 0.75,\ 0.3,\ 0.4,\ 0.3,\ \ False)$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds\ *10m}{1.4m/s},\ 30m,\ unbound,\ False\right)$

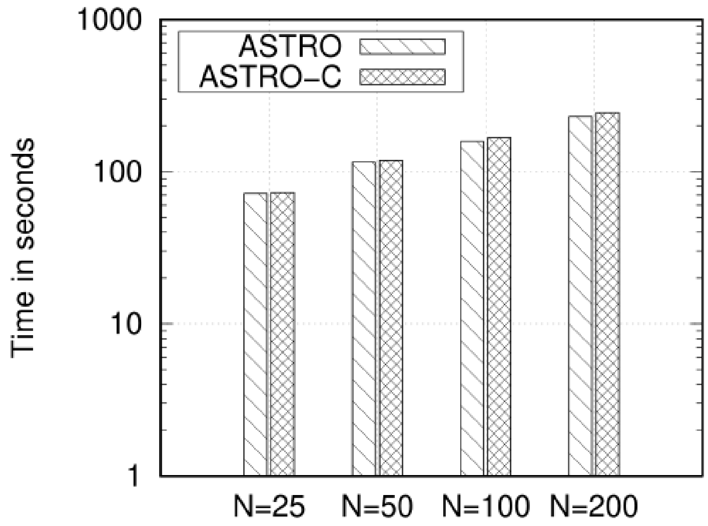


Paths found by ASTRO-C have **significantly less congestion** at the expense of **minimal additional time**

Experiment 3 – # of Buildings

- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(\{\mathbf{25},\ \mathbf{50},\ \mathbf{100},\ \mathbf{200}\},\ 0.75,\ 0.3,\ 0.4,\ 0.3,\ False)$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds\ *10m}{1.4m/s},\ 30m,\ unbound,\ False\right)$

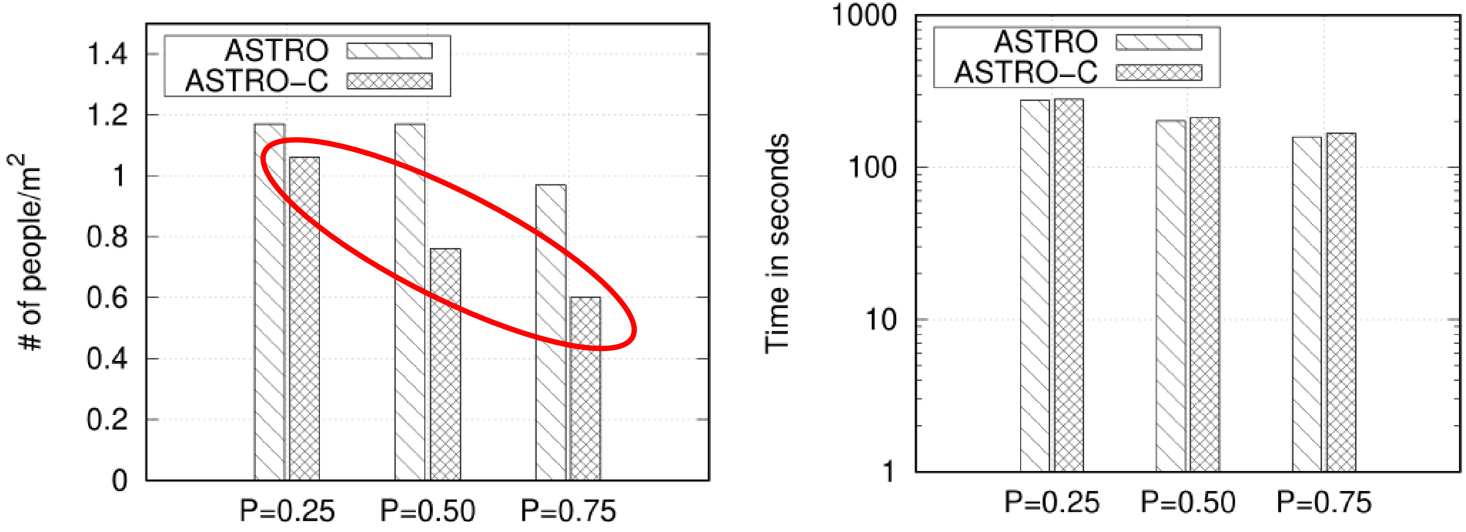




Even as the # of buildings increase, ASTRO-C shows a **consistent significant reduction in congestion**

Experiment 4 – Building Density

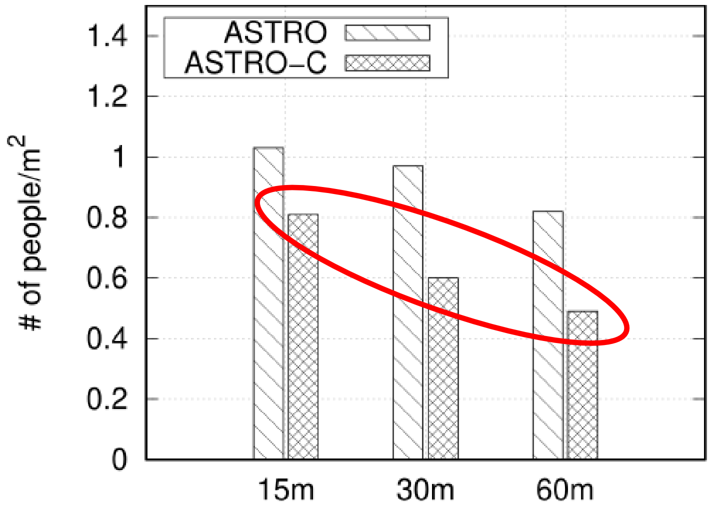
- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(100,\ \{\mathbf{0.25},\ \mathbf{0.50},\ \mathbf{0.75}\},\ 0.3,\ 0.4,\ 0.3,\ \ False)$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds*10m}{1.4m/s},\ 30m,\ unbound,\ False\right)$

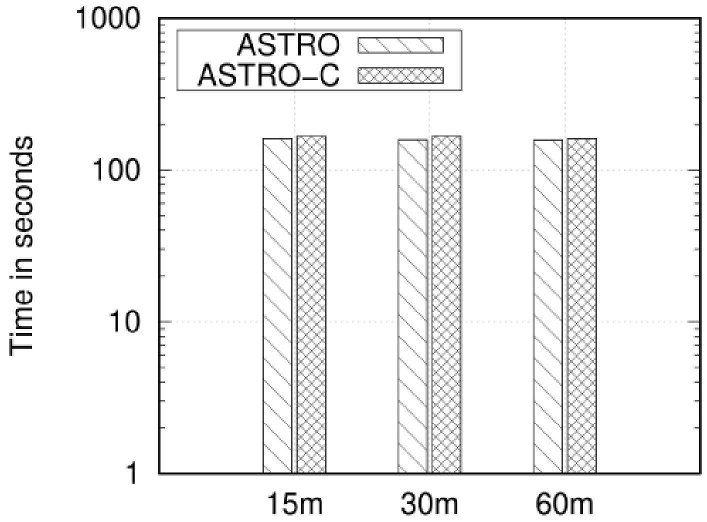


As density of buildings increases, the **reduction in congestion increases** as well

Experiment 5 – Outdoor Exposure

- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(100,\ 0.75,\ 0.3,\ 0.4,\ 0.3,\ False)$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds*10m}{1.4m/s},\ \{\mathbf{15m},\ \mathbf{30m},\ \mathbf{60m}\},\ unbound,\ False\right)$

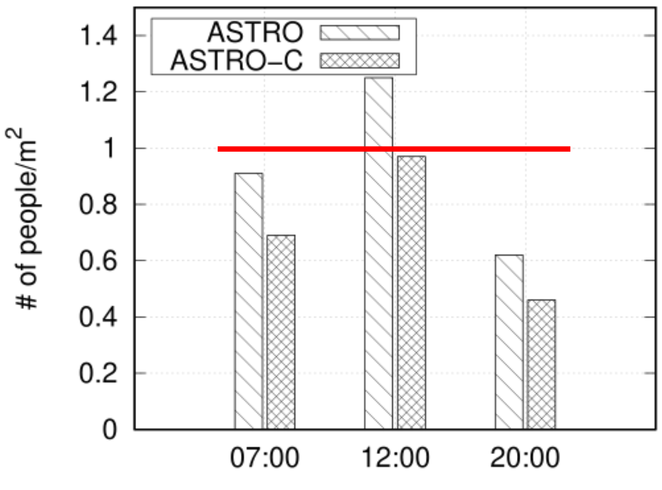


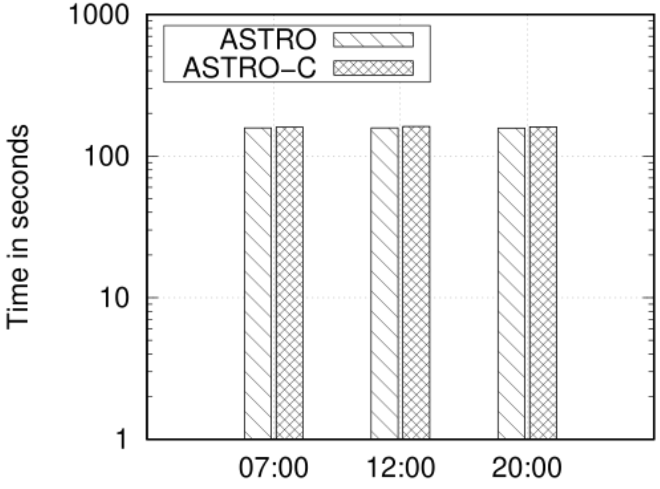


As the outdoor exposure constraint increases, the **reduction in congestion increases** as well

Experiment 6 – Time of Day

- Graph $(N,\ P,\ h,\ m,\ l,\ c)$: $(100,\ 0.75, \{[\mathbf{0.4},\ \mathbf{0.68},\ \mathbf{0.28}],\ [\mathbf{0.68},\ \mathbf{0.28},\ \mathbf{0.04}],\ [\mathbf{0.28},\ \mathbf{0.04},\ \mathbf{0.68}]\},\ False)$
- Path $(T,\ E,\ C,\ A)$: $\left(\frac{2*graph\_bounds*10m}{1.4m/s},\ 30m,\ unbound,\ False\right)$





ASTRO-C can recommend paths that **meet the social distancing throughout the day**

Conclusions

Major Contributions

- Generally, ASTRO-C is able to significantly reduce congestion without a significant additional time cost
- The Random Graph Generator can generate usable Indoor-Outdoor graphs which simulate many different environments

Future Work

- Extend the Random Graph Generator to generate dynamic congestion throughout the day
- Open-source the CAPRIO and Random Graph Generator codebases
- Explore departure alternatives to optimize time while reducing potential congestion

Thank You! Any Questions?

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