

# Using Time Aware Graph Neural Networks to Predict Temporal Centralities in Dynamic Graphs

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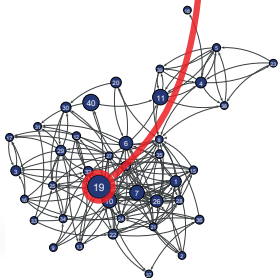
**NeurIPS 2024**



# Motivation

from → to

10 → 15  
43 → 38  
22 → 57  
19 → 35  
2 → 25  
48 → 31  
30 → 21  
8 → 7  
55 → 17  
20 → 27  
3 → 40  
51 → 5  
4 → 24  
56 → 5  
3 → 57  
31 → 11  
1 → 6  
40 → 3  
31 → 48  
25 → 5  
21 → 43  
41 → 30  
11 → 31  
5 → 56  
35 → 2  
15 → 10



## Closeness Centrality

$$c_C(v) = \frac{1}{\sum_{u \in V} d(u, v)}$$

with the distance  $d(u, v)$  as the length of the shortest path between nodes  $u$  and  $v$ .

## Betweenness Centrality

$$c_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{s,t}(v)}{\sigma_{s,t}}$$

with  $\sigma_{s,t}$  the number of the shortest paths between nodes  $s$  and  $t$  and  $\sigma_{s,t}(v)$  the number of such paths that pass through node  $v$ .

# Motivation

from → to when

10 → 15 14:12:21

43 → 38 14:12:47

22 → 57 14:12:49

19 → 35 14:13:05

2 → 25 14:13:12

48 → 31 14:13:29

30 → 21 14:13:33

8 → 7 14:14:01

55 → 17 14:14:17

20 → 27 14:14:57

3 → 40 14:15:03

51 → 5 14:15:07

4 → 24 14:16:34

56 → 5 14:16:35

3 → 57 14:18:24

31 → 11 14:18:28

1 → 6 14:18:32

40 → 3 14:18:58

31 → 48 14:20:00

25 → 5 14:22:23

21 → 43 14:24:55

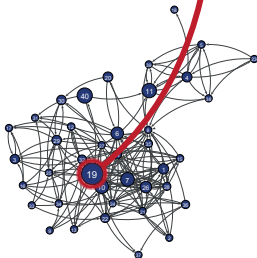
41 → 30 14:27:02

11 → 31 14:29:46

5 → 56 14:30:01

35 → 2 14:31:04

15 → 10 14:31:29



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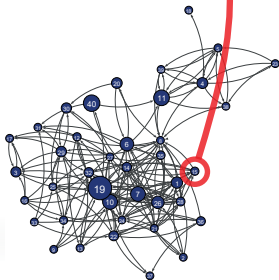
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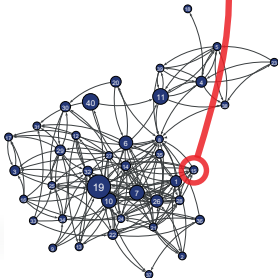
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## Temporal Closeness Centrality

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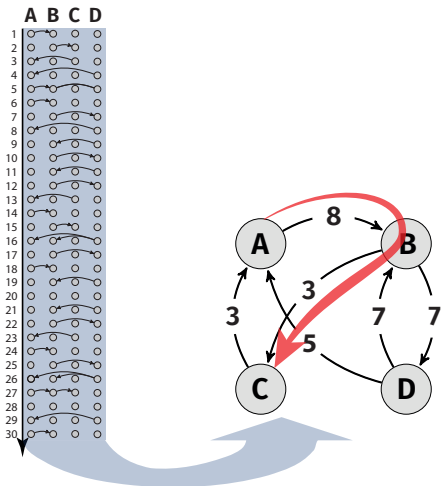
with the distance  $d(u, v)$  as the length of the shortest **time-respecting** path between nodes  $u$  and  $v$ .

## Temporal Betweenness Centrality

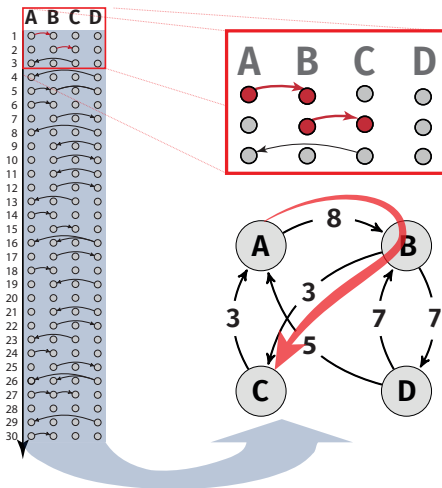
$$c_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{s,t}(v)}{\sigma_{s,t}}$$

with  $\sigma_{s,t}$  the number of the shortest **time-respecting** paths between nodes  $s$  and  $t$  and  $\sigma_{s,t}(v)$  the number of such paths that pass through node  $v$ .

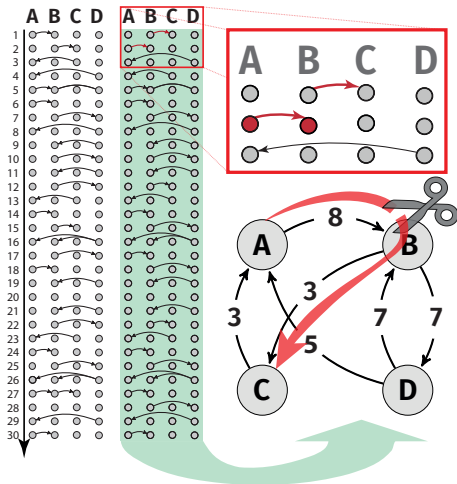
# Time respecting paths



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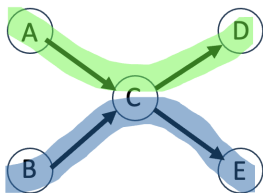
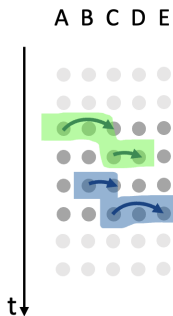


# Time respecting paths

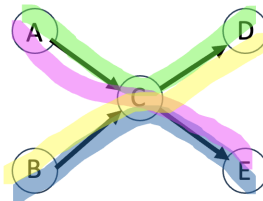




# Temporal Centralities



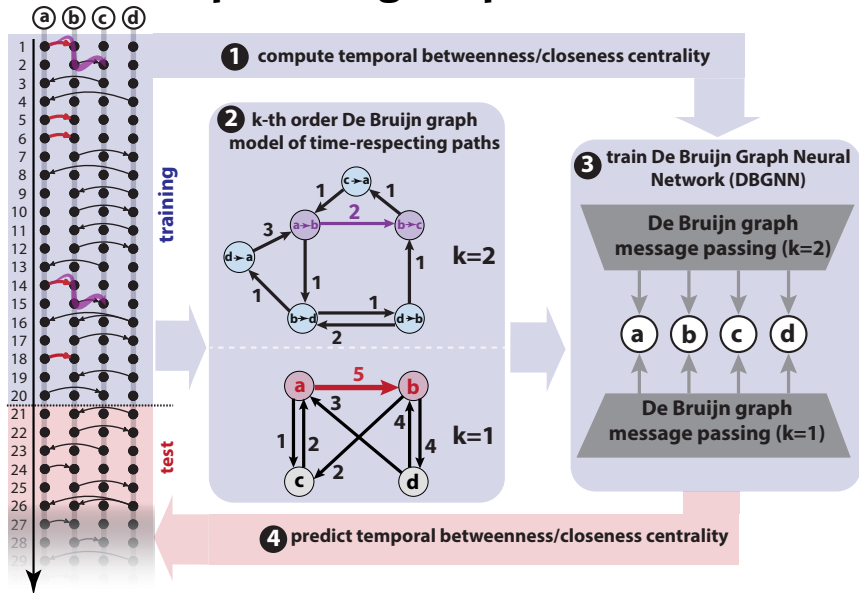
Time  
Aggregation :



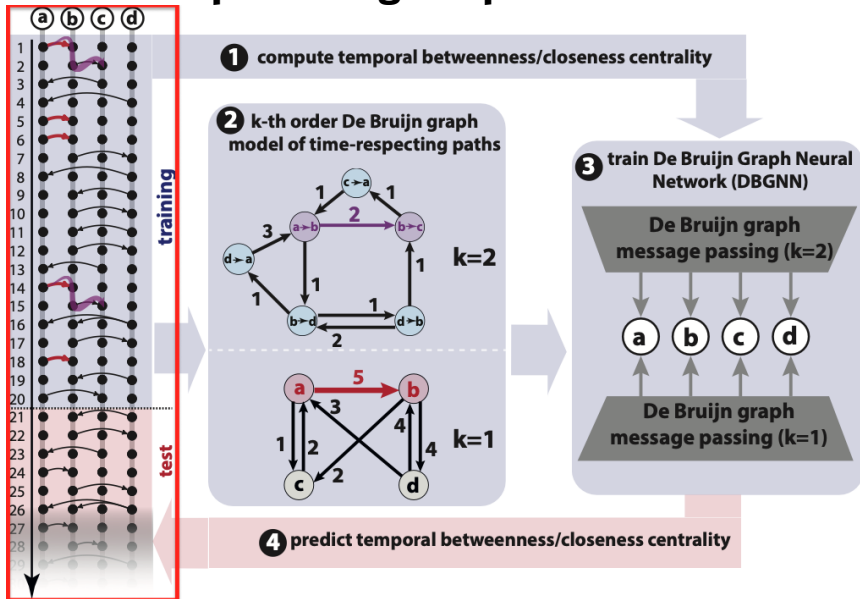
**PROBLEM:**

For large networks, the shortest paths between all node pairs are computationally expensive to calculate.

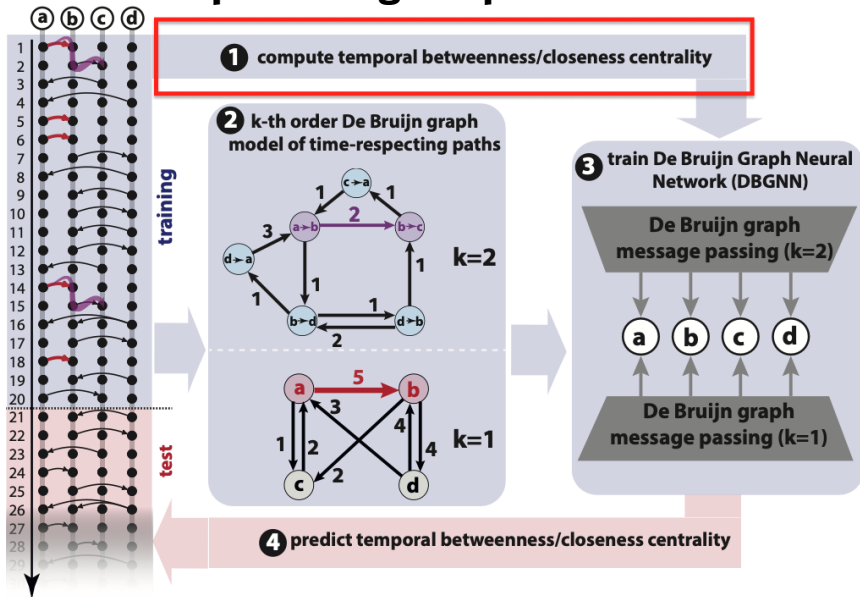
# DBGNN for predicting temporal centralities



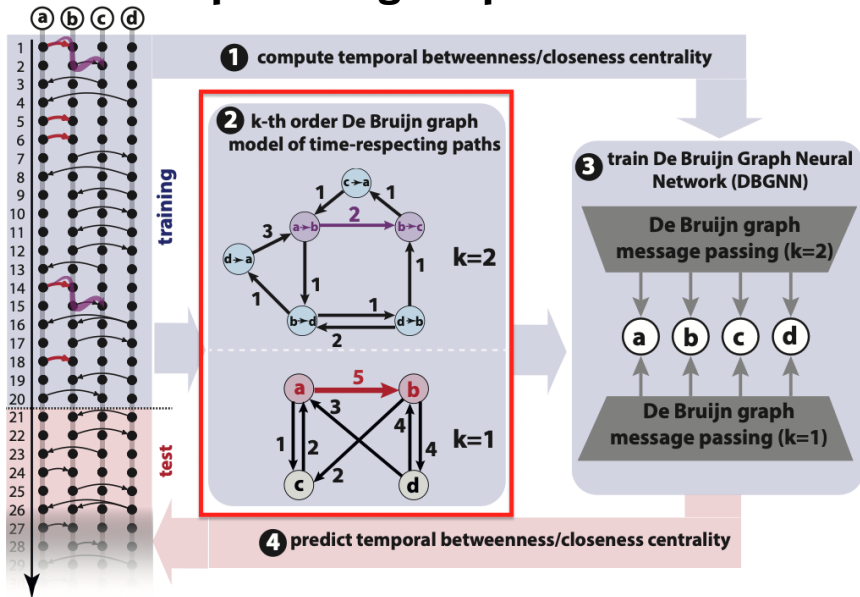
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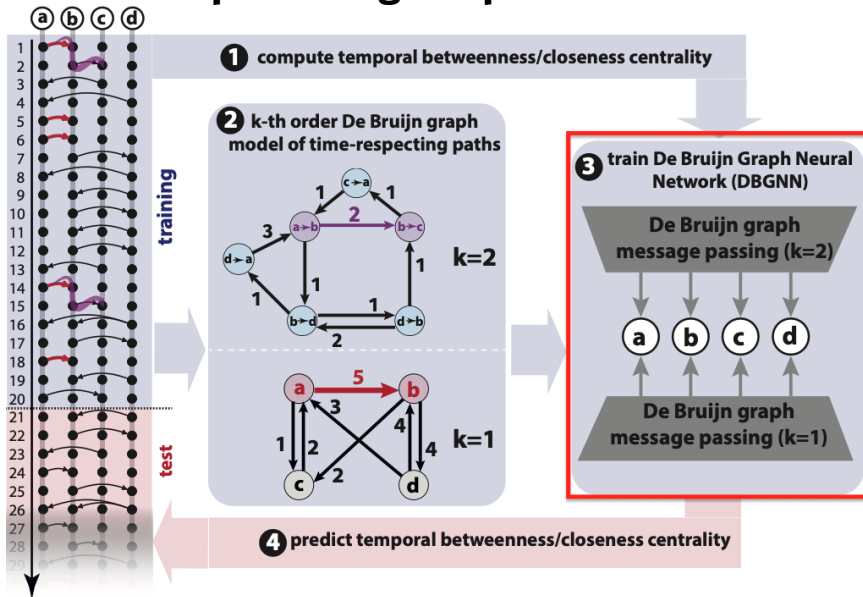
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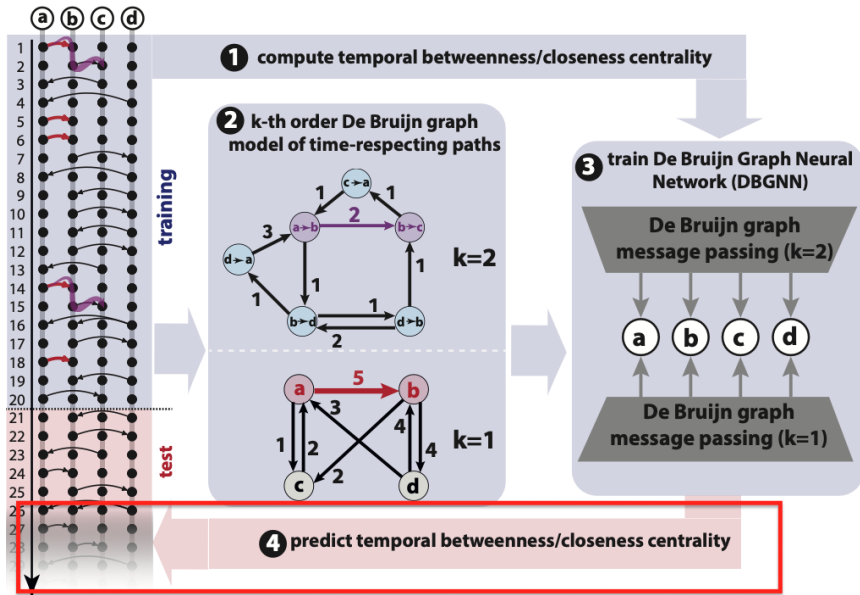
# DBGNN for predicting temporal centralities



# DBGNN for predicting temporal centralities



# DBGNN for predicting temporal centralities





# Results - Closeness Centrality

Experiment	DBGNN		GCN		EVO		TGN	
	Spearmanr	hitsIn10	Spearmanr	hitsIn10	Spearmanr	hitsIn10	Spearmanr	hitsIn10
ants-1-1	<b>0.900</b> ± 0.017	7.300 ± 0.733	0.805 ± 0.011	<b>7.850</b> ± 0.366	0.622 ± 0.045	3.800 ± 0.523	0.283 ± 0.038	2.780 ± 0.54
ants-1-2	<b>0.944</b> ± 0.006	<b>6.650</b> ± 0.587	0.702 ± 0.003	6.000 ± 0.0	0.339 ± 0.312	3.150 ± 1.496	0.305 ± 0.03	3.000 ± 0.51
ants-2-1	<b>0.974</b> ± 0.004	<b>8.600</b> ± 0.503	0.861 ± 0.004	7.150 ± 0.366	0.117 ± 0.025	3.150 ± 0.988	0.325 ± 0.032	3.080 ± 0.46
ants-2-2	<b>0.964</b> ± 0.004	<b>8.050</b> ± 0.394	0.662 ± 0.025	7.300 ± 0.47	0.722 ± 0.057	5.550 ± 1.356	0.373 ± 0.072	3.680 ± 0.642
eu-email-dept4	<b>0.972</b> ± 0.003	<b>8.800</b> ± 0.41	0.285 ± 0.157	2.200 ± 2.042	0.486 ± 0.111	4.750 ± 1.293	0.664 ± 0.026	5.084 ± 0.566
eu-email-dept2	<b>0.968</b> ± 0.006	<b>8.550</b> ± 0.605	0.563 ± 0.007	3.000 ± 0.0	0.503 ± 0.094	1.550 ± 0.759	0.574 ± 0.096	3.519 ± 0.876
eu-email-dept3	<b>0.992</b> ± 0.001	<b>8.850</b> ± 0.366	0.653 ± 0.009	5.000 ± 0.0	0.504 ± 0.034	3.750 ± 1.743	0.465 ± 0.025	3.187 ± 0.277
sp-workplace	<b>0.893</b> ± 0.009	<b>7.900</b> ± 0.553	0.639 ± 0.002	6.000 ± 0.0	0.388 ± 0.07	3.000 ± 0.649	0.164 ± 0.061	2.692 ± 0.312
sp-hypertext	<b>0.977</b> ± 0.004	<b>7.750</b> ± 0.55	0.809 ± 0.001	7.000 ± 0.0	0.622 ± 0.061	3.800 ± 0.696	0.360 ± 0.037	3.022 ± 0.607
sp-hospital	<b>0.918</b> ± 0.006	<b>7.850</b> ± 0.489	0.744 ± 0.002	5.300 ± 0.47	0.695 ± 0.067	4.600 ± 0.681	0.509 ± 0.058	5.649 ± 0.335
haggle	<b>0.948</b> ± 0.005	<b>9.300</b> ± 0.47	0.393 ± 0.001	4.950 ± 0.759	0.630 ± 0.102	2.250 ± 0.716	0.559 ± 0.021	3.242 ± 0.331
manufacturing-email	<b>0.971</b> ± 0.002	<b>7.900</b> ± 0.641	0.556 ± 0.004	3.750 ± 0.444	0.716 ± 0.084	2.550 ± 1.146	0.496 ± 0.028	2.258 ± 0.573
sp-highschool-2013	<b>0.925</b> ± 0.002	<b>7.800</b> ± 0.41	0.540 ± 0.002	2.000 ± 0.0	0.276 ± 0.026	2.900 ± 0.308	0.166 ± 0.041	1.776 ± 0.165

# Results - Betweenness Centrality

Experiment	DBGNN		GCN		EVO		TGN	
	Spearmanr	hitsIn10	Spearmanr	hitsIn10	Spearmanr	hitsIn10	Spearmanr	hitsIn10
ants-1-1	<b>0.636</b> ± 0.063	<b>6.050</b> ± 1.234	0.282 ± 0.147	2.350 ± 1.424	0.404 ± 0.084	4.050 ± 0.51	0.263 ± 0.056	3.400 ± 0.424
ants-1-2	<b>0.655</b> ± 0.078	<b>4.750</b> ± 0.91	0.498 ± 0.157	4.600 ± 1.392	0.339 ± 0.312	3.150 ± 1.496	0.257 ± 0.084	3.725 ± 0.411
ants-2-1	0.284 ± 0.073	<b>3.550</b> ± 0.887	0.161 ± 0.126	2.200 ± 1.196	0.096 ± 0.089	2.150 ± 0.366	<b>0.309</b> ± 0.017	2.111 ± 0.192
ants-2-2	0.466 ± 0.239	4.000 ± 1.451	0.185 ± 0.287	2.100 ± 1.832	<b>0.599</b> ± 0.042	<b>4.400</b> ± 1.957	0.357 ± 0.088	3.050 ± 0.574
eu-email-dept4	0.322 ± 0.062	3.900 ± 1.252	-0.047 ± 0.244	1.950 ± 1.432	<b>0.486</b> ± 0.111	<b>4.750</b> ± 1.293	0.292 ± 0.019	4.164 ± 0.378
eu-email-dept2	0.383 ± 0.071	2.900 ± 1.41	0.240 ± 0.089	<b>4.000</b> ± 1.487	<b>0.503</b> ± 0.094	1.550 ± 0.759	0.225 ± 0.023	3.274 ± 0.348
eu-email-dept3	<b>0.532</b> ± 0.068	5.700 ± 0.979	0.408 ± 0.1	<b>6.400</b> ± 0.883	0.504 ± 0.034	3.750 ± 1.743	0.236 ± 0.096	3.151 ± 0.568
sp-workplace	<b>0.588</b> ± 0.065	<b>4.350</b> ± 1.04	0.441 ± 0.103	3.450 ± 0.887	0.294 ± 0.072	3.400 ± 0.94	0.077 ± 0.02	1.963 ± 0.064
sp-hypertext	<b>0.839</b> ± 0.017	6.300 ± 0.865	0.786 ± 0.021	<b>6.400</b> ± 0.503	0.622 ± 0.061	3.800 ± 0.696	0.260 ± 0.048	2.574 ± 0.545
sp-hospital	<b>0.832</b> ± 0.03	<b>8.000</b> ± 1.257	0.804 ± 0.041	6.950 ± 0.945	0.695 ± 0.067	4.600 ± 0.681	0.522 ± 0.076	6.463 ± 0.402
haggle	0.626 ± 0.023	5.650 ± 1.04	<b>0.680</b> ± 0.003	<b>5.850</b> ± 0.366	0.630 ± 0.102	2.250 ± 0.716	0.628 ± 0.013	3.302 ± 0.191
manufacturing-email	<b>0.744</b> ± 0.106	<b>3.750</b> ± 1.251	0.404 ± 0.14	1.700 ± 0.865	0.578 ± 0.111	1.850 ± 0.489	0.320 ± 0.113	1.824 ± 0.265
sp-highschool-2013	<b>0.661</b> ± 0.03	<b>3.500</b> ± 1.469	0.465 ± 0.055	0.850 ± 0.875	0.267 ± 0.056	1.350 ± 0.587	0.114 ± 0.007	1.224 ± 0.08

# Any questions?

