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Manipulating Black-Box Networks for Centrality Promotion

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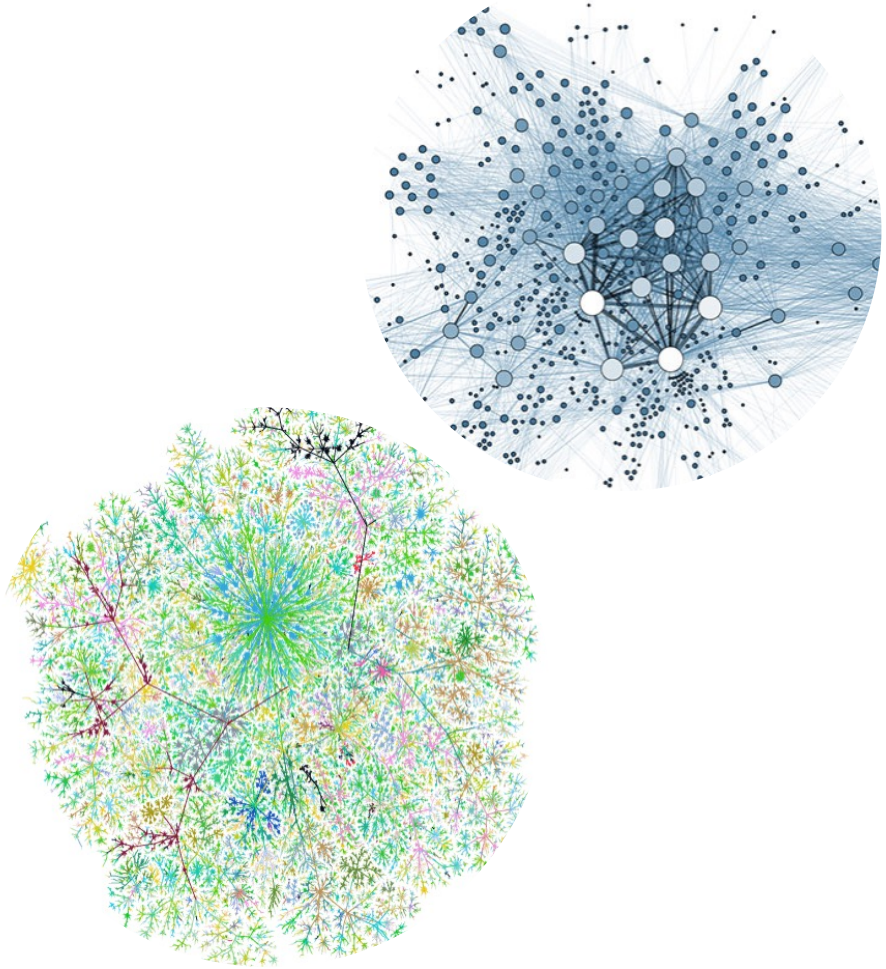
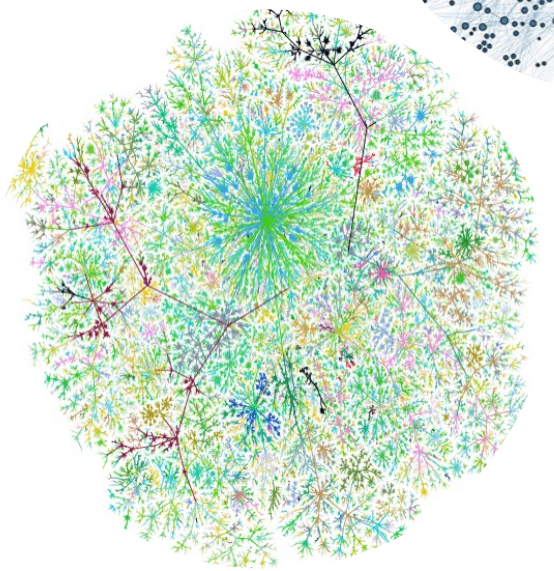
Graphs (Networks)

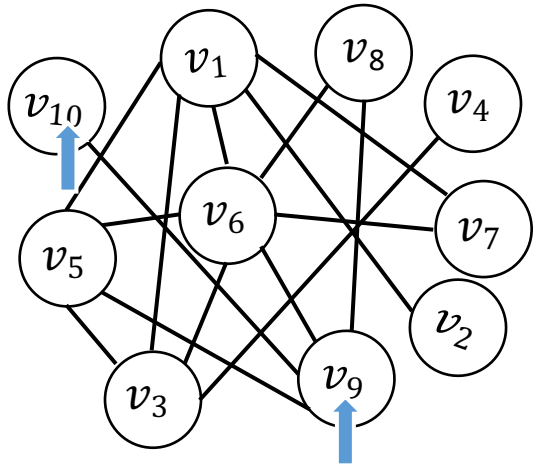


Q: Which node in the graph is the most important?

A: Centrality Measures

Graphs (Networks)





Q: Which node in the graph is the most important?

A: Centrality Measures

Degree $d(v_9) = 4$ $d(v_{10}) = 1$

Betweenness, Closeness, Eccentricity

Problem Statement

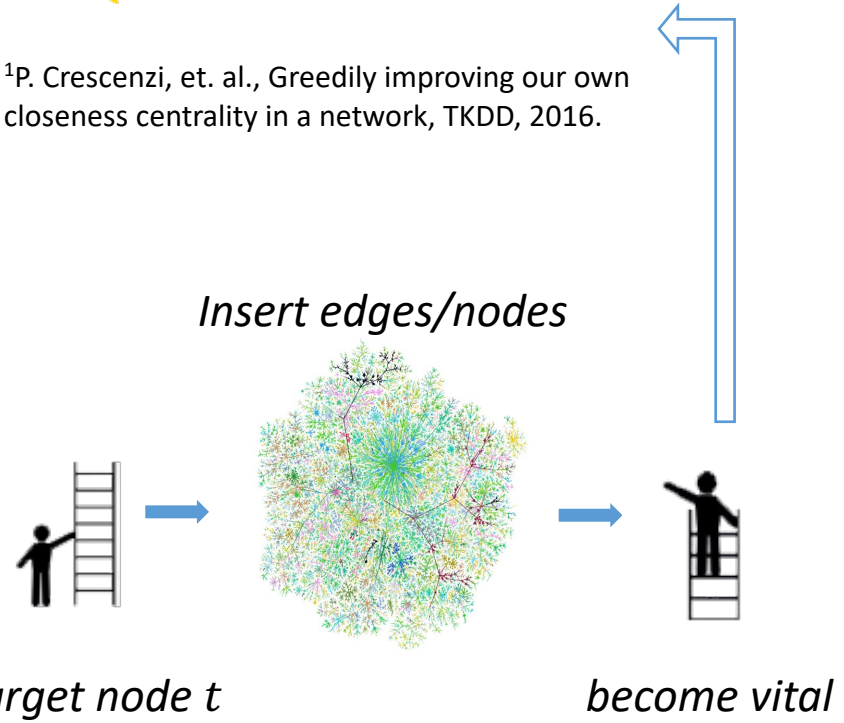
Vital Nodes

Nodes with high centrality values

Superior position (get high citations)[1]

[1]P. Crescenzi, et. al., Greedily improving our own closeness centrality in a network, TKDD, 2016.

Network Manipulation



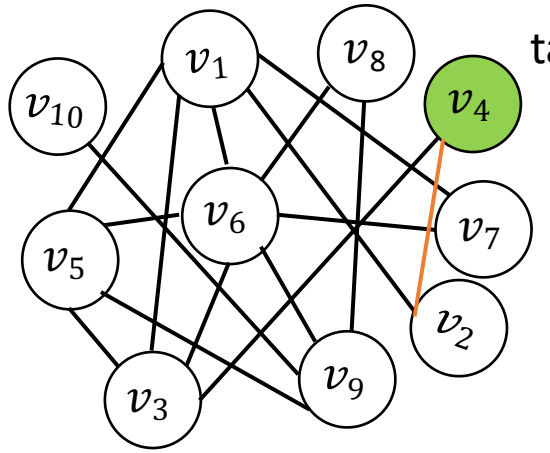
Existing Solutions

Idea: greedily choose some nodes to connect

Limitations

Unknown graph structure **(Black-Box Network)**

Ranking is promoted **(Ranking Promotion)**



Graph G, centrality value $c(t)$

closeness: $c(v_4) = 1/23$

G	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value	$\frac{1}{14}$	$\frac{1}{22}$	$\frac{1}{15}$	$\frac{1}{23}$	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{18}$	$\frac{1}{18}$	$\frac{1}{16}$	$\frac{1}{24}$
rank	2		4	9	2	1	6	6	5	10

$rank(v_4) = 9$: *there are 8 nodes with values higher than* v_4

Update Graph G', centrality value $c'(t)$

$c'(v_4) = 1/21$

G'	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value'	$\frac{1}{14}$	$\frac{1}{20}$	$\frac{1}{15}$	$\frac{1}{21}$	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{18}$	$\frac{1}{18}$	$\frac{1}{16}$	$\frac{1}{24}$
rank'	2		4	9	2	1	6	6	5	10

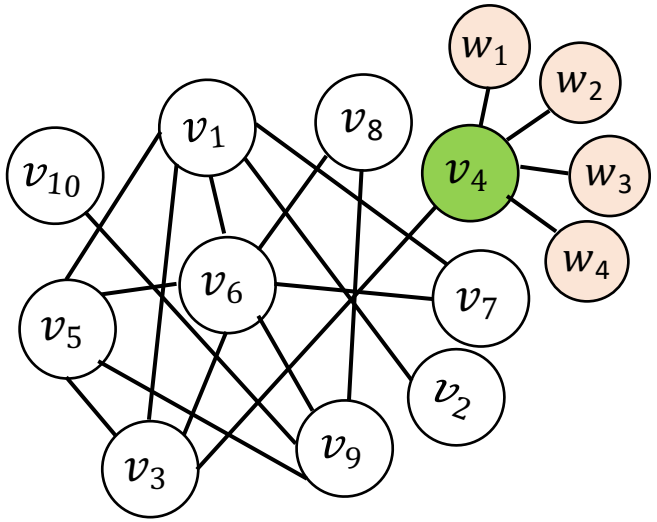
Goal #1

Goals

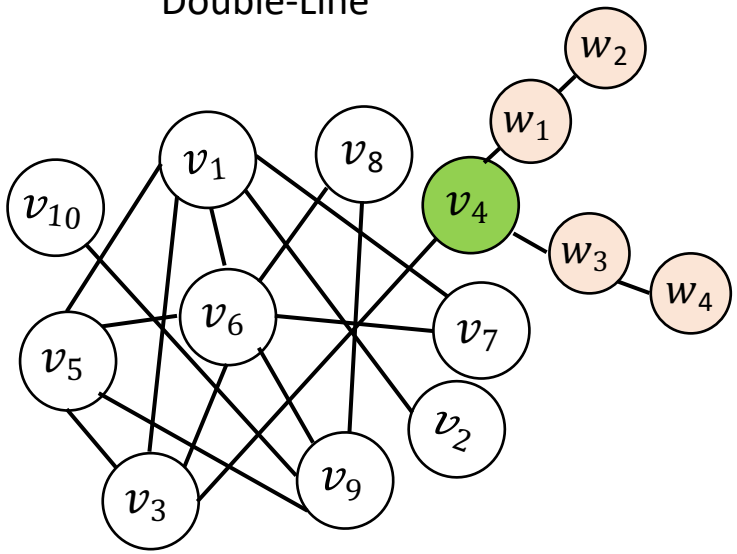
Black-Box Network Insert nodes/edges around target node

Ranking Promotion

Multi-Point



Double-Line

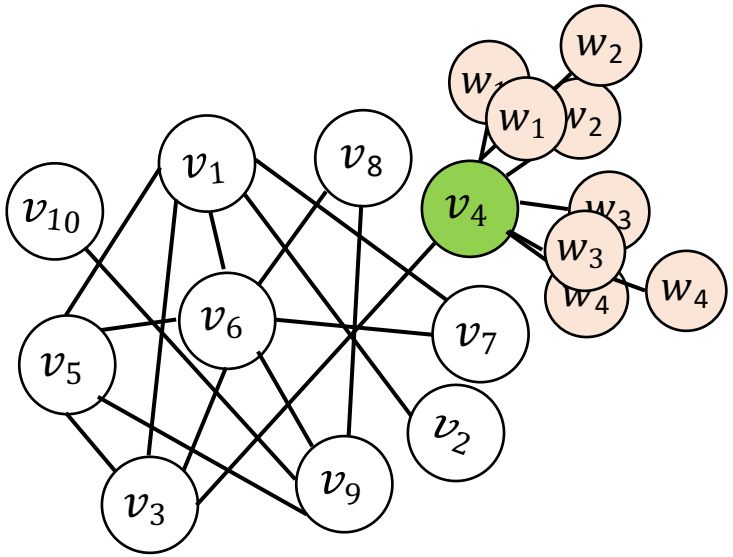


Goal #2

Goals

Black-Box Network — Insert nodes/edges around target node

Ranking Promotion — Non-trivial — How to choose a strategy for a centrality measure?



Do any of the strategies work for eccentricity promotion?

Multi-Point strategy: no

Double-Line strategy: yes

G	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{4}$
rank	3	7	3	7	1	1	3	3	3	7

G'	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value'	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{4}$
rank'	3	7	3	7	1	1	3	3	3	7

w_1	w_2	w_3	w_4
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
7	7	7	7

Our Solution

Goals

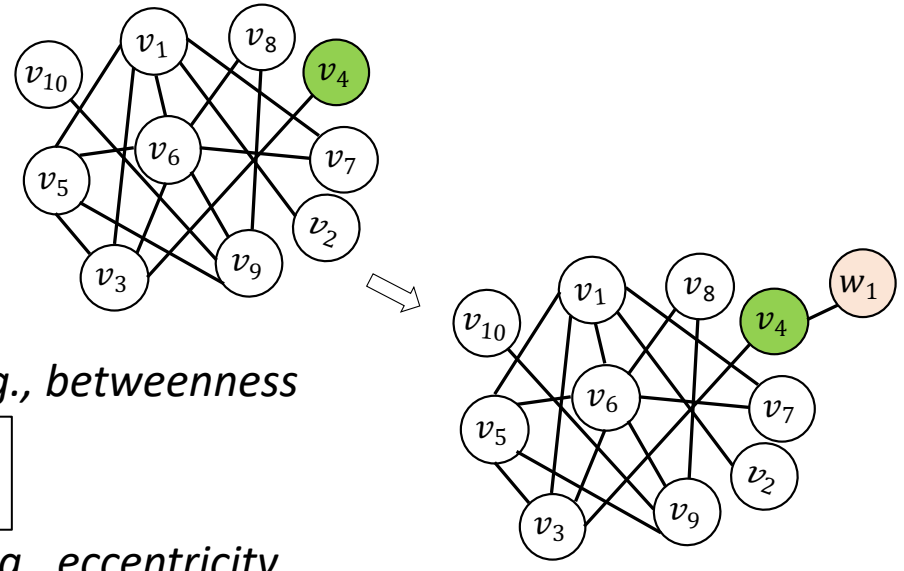
Black-Box Network Insert nodes/edges around target node

Ranking Promotion Non-trivial How to choose a strategy for a centrality measure?

Idea

When inserting nodes into G (by some strategy)

Centrality measures: two groups



- *Value of target node can only be increased (or not changed), e.g., betweenness*

  choose a strategy to ensure target node:
  Maximum Value Increase (Maximum Gain Principle)

- *Value of target node can only be decreased (or not changed), e.g., eccentricity*

  choose a strategy to ensure target node:
  Minimum Value Decrease (Minimum Loss Principle)

Maximum Gain Principle

Goals

Black-Box Network — Insert nodes/edges around target node

Ranking Promotion — Non-trivial — How to choose a strategy for a centrality measure?

Maximum Gain Principle

Choose Multi-Point for betweenness promotion

Three Conditions

Ranking of t is improved by overtaking a vertex in G

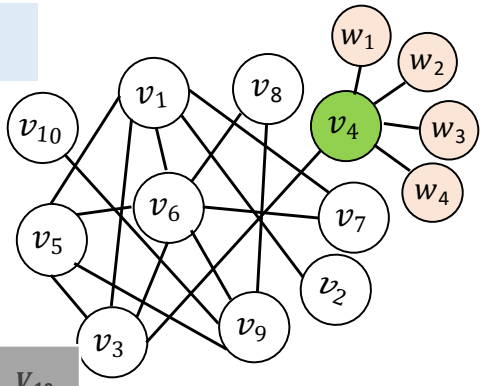
Target t has the maximum increase

t overtakes some v (after inserting $\sqrt{c(v) - c(t)} + 1$ nodes)

increase=42 $\sqrt{4-0}+1 = 3$ nodes

node t has a value no smaller than inserted nodes w

Newly inserted W will not rank higher than t



G	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value	9.5	0	8	0	4	13	0	0	8.5	0
rank	2	6	4	6	5	1	6	6	3	6

G'	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
value'	15.5	0	40	42	8	23	0	0	12.5	0
rank'	4	7	2	1	6	3	7	7	5	7

w_1	w_2	w_3	w_4
0	0	0	0
7	7	7	7

Minimum Loss Principle

Goals

Black-Box Network — Insert nodes/edges around target node

Ranking Promotion — Non-trivial — How to choose a strategy for a centrality measure?

Maximum Gain Principle — Choose Multi-Point for betweenness promotion

Minimum Loss Principle — Choose Double-Line for eccentricity promotion

Three Conditions

Target t has the minimum loss

t overtakes some v (after inserting $certain$ nodes)

node t has a value no smaller than inserted nodes w

Experiments

Datasets

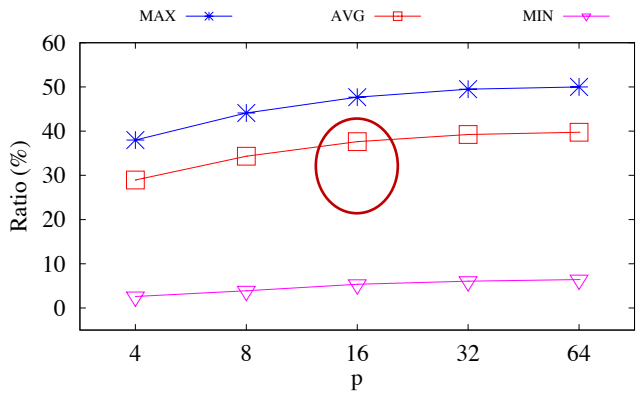
CA-HepPh (HEPP), 11204 nodes, 117619 edges

Maximum Gain Principle

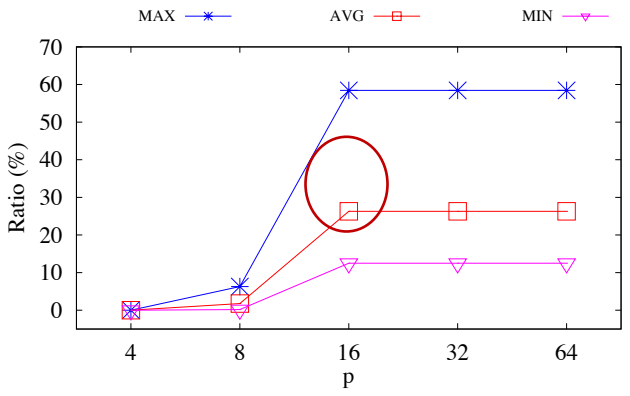
Multi-Point is effective for betweenness promotion

Minimum Loss Principle

Double-Line is effective for eccentricity promotion



Target node improves the ranking by
at least 3,000 on average (betweenness)



Target node improves the ranking by
at least 2,000 on average (eccentricity)

Manipulating Black-Box Networks for Centrality Promotion

- Black-Box Networks
  - Assume that the graph structure is unknown
- Ranking Promotion
  - Maximum Gain or Minimum Loss Principles

Thanks