INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

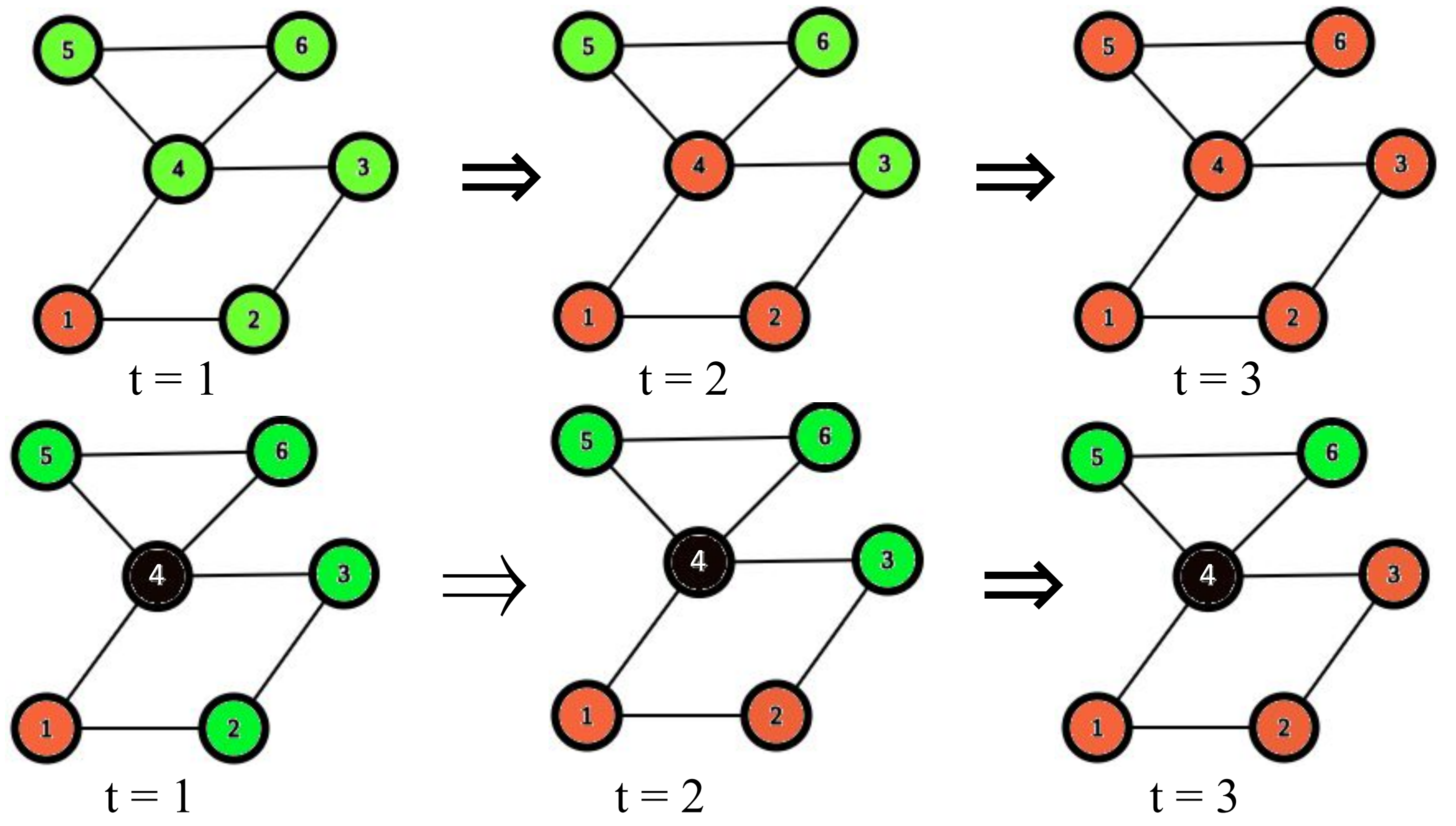
R&D SHOWCASE 2021
Technology, Social Impact

An Efficient Algorithm for Percolation Centrality Computation in Parallel

Introduction

When analyzing a contagion spreading over a network it is important to identify, and take preventive measures at, not only the nodes that are high risk but those that contribute most towards the transmission of the contagion. Percolation centrality is a measure that takes into account both the position of a node in the network and the extent of its percolation. We propose-

- An O(|V||E|) algorithm to compute the source-destination version of Percolation centrality, improving over the existing $O(|V|^3)$ algorithm.
- A graph decomposition into biconnected components in order to perform the computation in parallel.



Red denotes a fully percolated node while green denotes an unpercolated one. Suppose the contagion spreads one unit at each timestep, node 4 shows high percolation centrality and should be shielded (black) to prevent spread.

Problem Definition

Percolation centrality $[PC^t(v)]$:

$$PC^t(v) = \frac{1}{\sum_{s \neq v \neq r} R\left[x_s^t - x_r^t\right]} C^t(v)$$

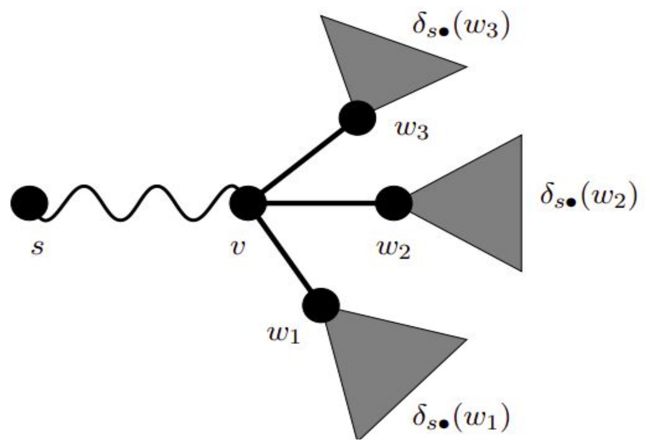
$$C^t(v) = \sum_{s \neq v \neq r} \frac{\sigma_{s,r}(v)}{\sigma_{s,r}} R\left[x_s^t - x_r^t\right]$$

x_u^t : percolation of node u at instant t.
$\sigma_{s,r}$: no. of shortest paths from s to r.
$\sigma_{s,r}(v)$: no. of shortest paths from s to r and passing through v.
R denotes the ramp function, R(x) = x if x > 0, else R(x) = 0.

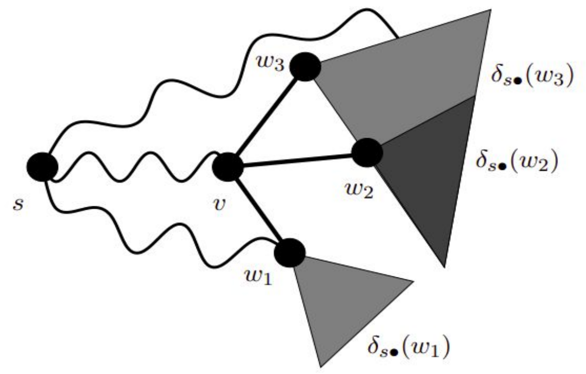
Applications

- Viral or bacterial infection can spread over social networks of people, known as contact networks.
- The spread of diseases or computer viruses also fall under such networks.
- Rumours or news about business offers and deals can also spread via social networks of people.

Quadratic Runtime for Sparse Graphs



Phase 1 : DAG of shortest paths for a node as source is generated.

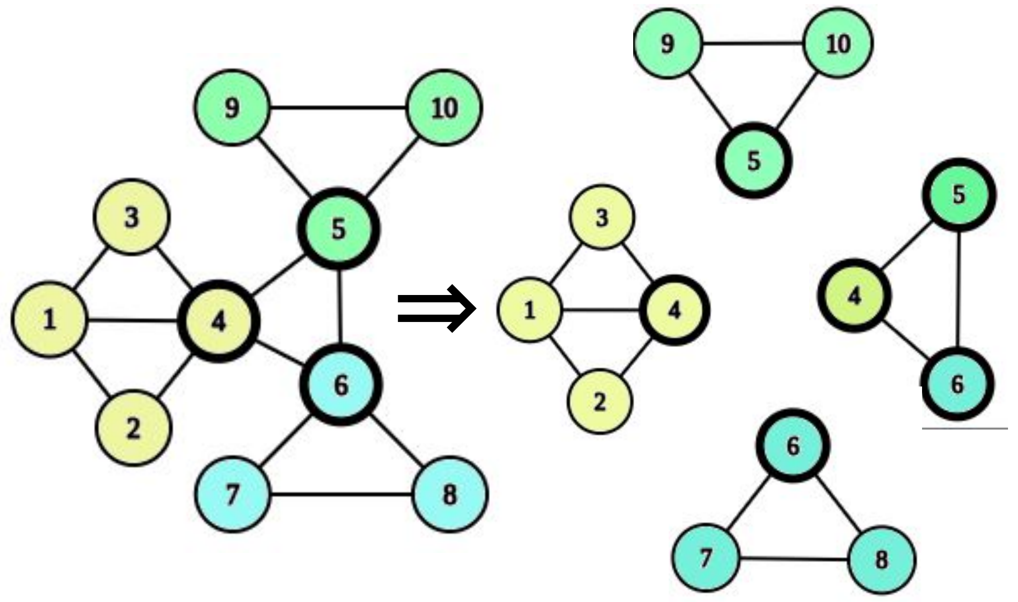


Phase 2 : fractions of the dependencies on successors are propagated up along the edges of DAG.

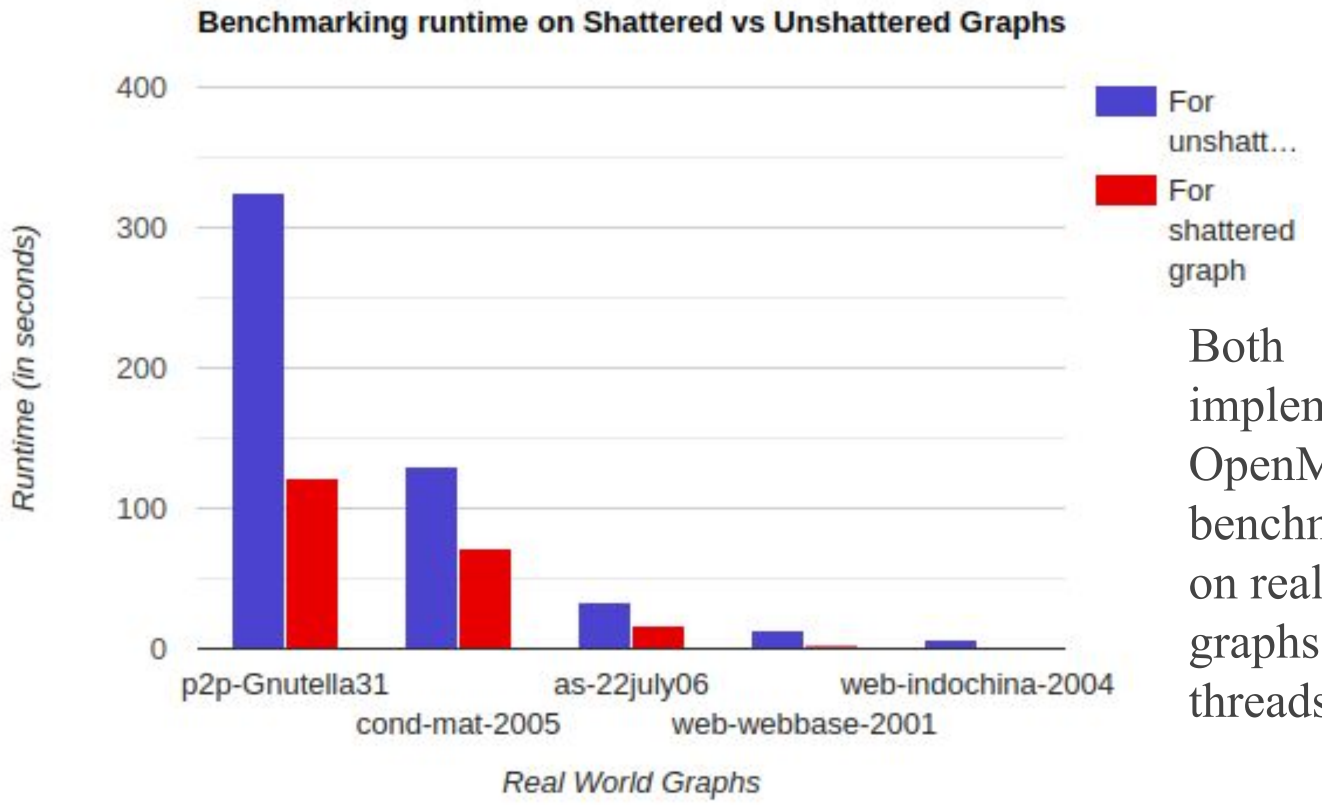
We propose a modified delta (dependency value):

$$\delta^t(s, r|v) = \frac{\sigma(s, r|v)}{\sigma(s, r)} R\left[x_s^t - x_r^t\right]$$

Graph Shattering



- Graph is broken into biconnected components (BCCs).
- An ordered set of percolation values called reach is maintained for each node.
- PC is computed independently for each BCC using a modified version of the O(|V||E|) algorithm.



Both implemented in OpenMP and benchmarked on real-world graphs using 10 threads.

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