An Integrated Epidemic Simulation Workflow for Submodular Intervention Strategies

epiDAMIK 4.0: The 4th International workshop on Epidemiology meets Data Mining and Knowledge discovery

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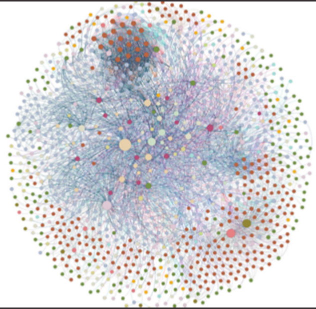
August 15, 2021

WASHINGTON STATE UNIVERSITY

Pacific Northwest NATIONAL LABORATORY

Objective

Incorporate network-based intervention policies at the most granular level into an infectious disease simulation workflows.



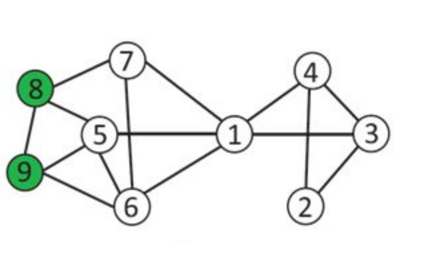
Individual-level intervention (vaccination) policies

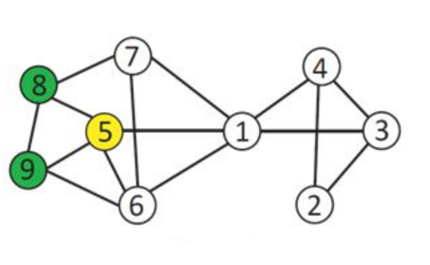
COVASIM by IDM

Agent-based Covid-19 Simulator

Influence Maximization[1]

- **Input**: Graph $G(V, E, w)$, Diffusion model
- **Objective**: identify a set of k nodes to activate so that expected influence spread is maximized
- **Solution**: approx. solution based on the greedy algorithm gurantees a $(1 - 1/e - \epsilon)$ bound using submodular optmization.





[1]Kempe et. al., SIGKDD 2003

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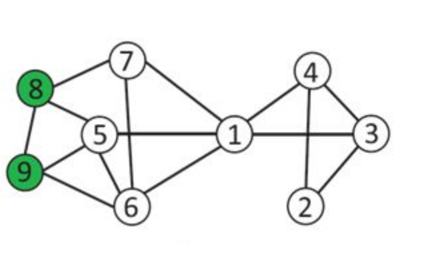

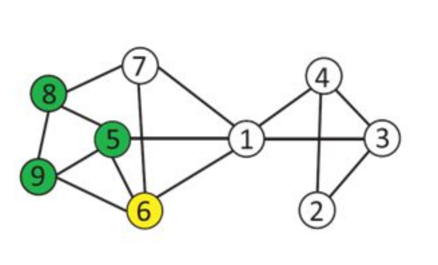

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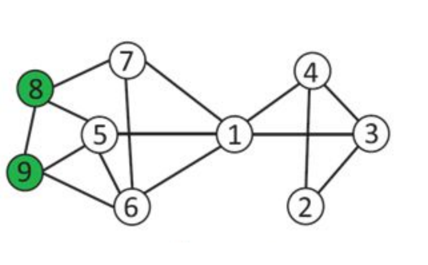

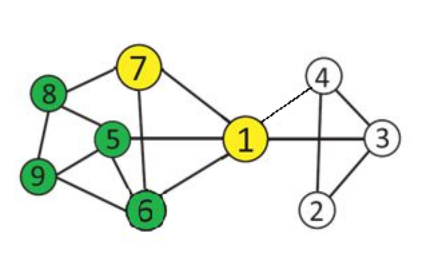

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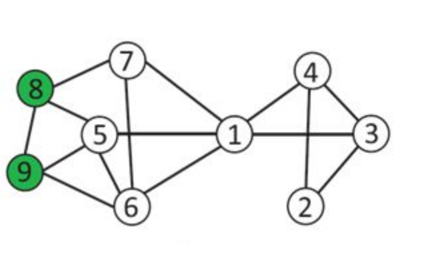
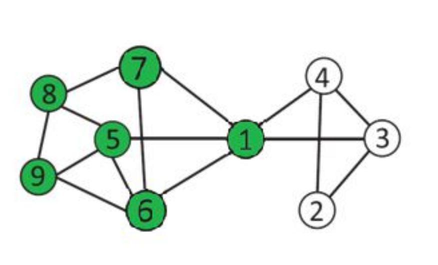
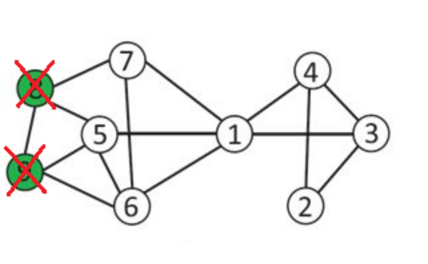
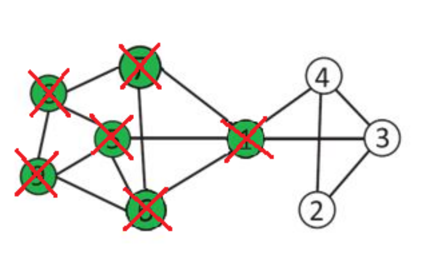




PREEMPT [2]: EpiControl using Inf-Max

- **Input**: Graph $G(V, E, w)$, Diffusion model
- **Objective**: identify a set of k nodes to vaccinate so that expected disease spread is minimized or lives saved is maximized.
  Number of lives saved:
  $$\lambda_{G_i}(B, S) = \sigma_{G_i}(B, \emptyset) - \sigma_{G_i}(B, S).$$





[2] Minutoli et. al., SC 2020

Covasim [3]

- Stochastic agent-based simulator that is used to simulate the spread of the Covid-19 disease.
- Builds synthetic populations as a network based on real-world demographic data:
  - Every agent is a node in the network
  - Nodes are connected based on if they interact with each other (inside a household, school, work, and out in the community)
  - The edge weights are the probabilities of the source nodes infecting the destination nodes given that the source nodes themselves are infected.
- Supports highly customizable intervention (vaccination) policies.

[3] Cliff C Kerr, Robyn M Stuart, Dina Mistry, Romesh G Abeysuriya, Gregory Hart,Katherine Rosenfeld, Prashanth Selvaraj, Rafael C Nunez, Brittany Hagedorn,Lauren George, et al. Covasim: an agent-based model of covid-19 dynamics andinterventions.medRxiv, 2020.

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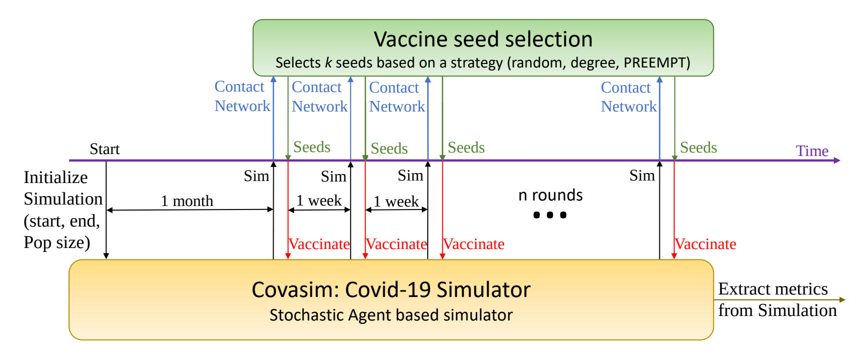
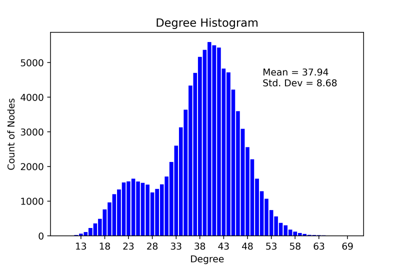
Integrated Workflow



The simulation is allowed to simulate the start of the pandemic unhindered for a month followed by regular vaccination rounds of certain batch sizes every week. Nodes to be vaccinated are specified by a seed selection strategy, which could internally implement various strategies to identify those seeds.

Input

- Simulated location: India
- $|V| = 100,000$
- $|E| = 3,793,826$
- Duration of each run of the simulation: 170 days (over 5 months) – starting on January 1st and ending on June 19th.



Evaluation Metrics

- the number of *cumulative infections*
- The number of *new infections per day*
- The number of *cumulative deaths*

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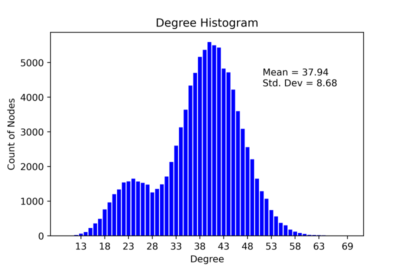

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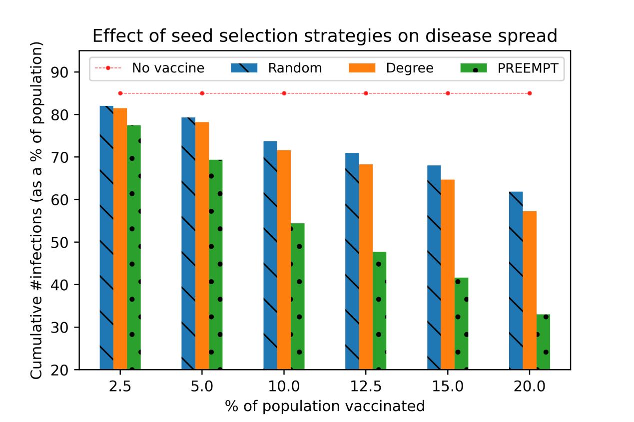
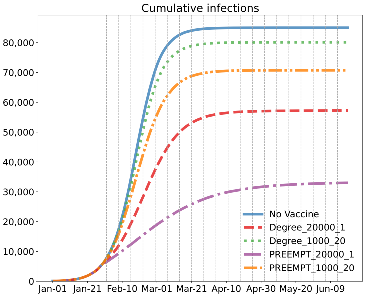
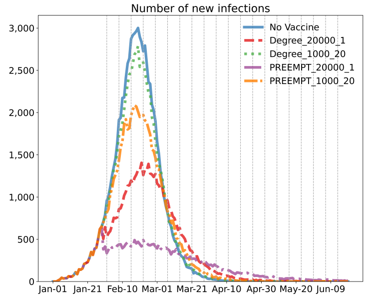
Effect of seed selection strategies

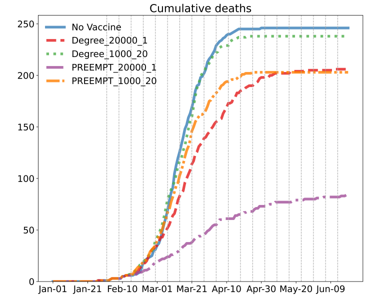


The x-axis represents the % of population vaccinated at a single round, on the 31st day of the simulation. The y-axis represents the cumulative #infections after 5+ months of simulation as a % of the population infected.

Effect of vaccinating in batches of uniform size

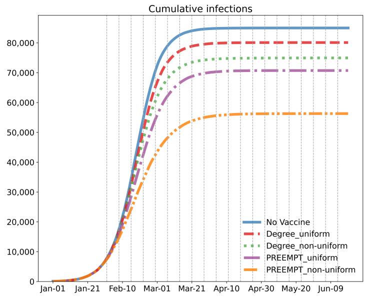


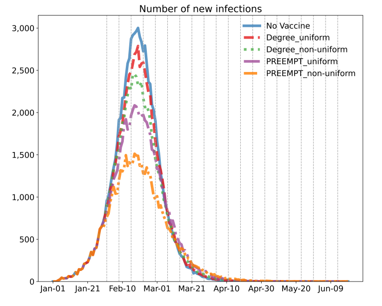


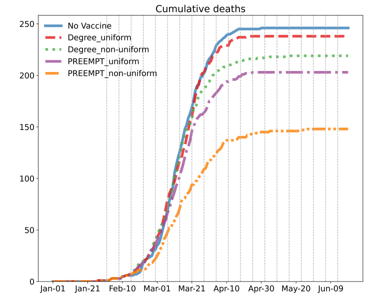


For every curve labeled as 'X_Y_Z', 'X' stands for the seed selection strategy; 'Y' stands for the (uniform) batch size used at each round; and 'Z' stands for the number of rounds. Every vertical dashed line represents a vaccination round. Also shown for comparative reference, is the 'No vaccine' curve that corresponds to zero vaccines given out at each round. We use 20,000 as the total number of vaccines.

Effect of vaccinating in batches of non-uniform sizes







The plots are labeled as ‘X_Y’ where ‘X’ stands for the seed selection strategy and ‘Y’ represents the two batching strategies—*uniform* or *non-uniform*. The uniform strategy applies 1,000 vaccines per round. The non-uniform strategy uses 2,000 vaccines in each of the first 5 rounds; 1,000 vaccines in each of the next 5 rounds; and 500 vaccines per round in the final 10 rounds. Also shown is the ‘No vaccine’ curve for reference.

Summary

- Key contribution - Provide a framework[4] that integrates epidemic simulation with graph-theoretic/network science-based interventions.
- Demonstrated effectiveness of Inf-Max based intervention strategies for epidemic control over simpler heuristics like degree.
- In addition to a *carefully selected* subset of seeds, our experiments also demonstrate that the *timing* of these vaccination matter—i.e., giving more vaccines early on could save more lives in the long run.

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Acknowledgments

- Funds:
  - U.S. DOE ExaGraph project at the Pacific Northwest National Laboratory (PNNL) [5]
  - National Science Foundation (NSF) grants CCF 1815467 and OAC 1910213 to Washington State University.
- The developers at IDM, Seattle for guidance while using Covasim.

[5] PNNL is operated by Battelle Memorial Institute under Contract DE-AC06- 76RL01830

Thank You