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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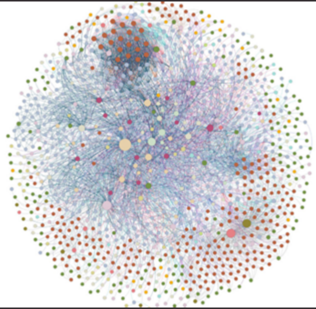
Objective

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



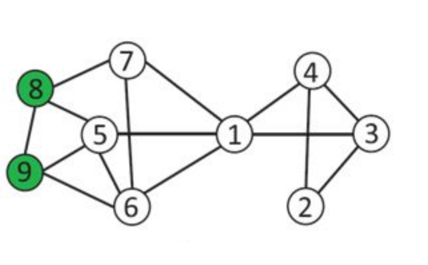
Individual-level intervention (vaccination) policies

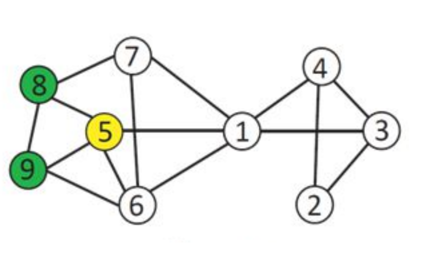
COVASIM by IDM

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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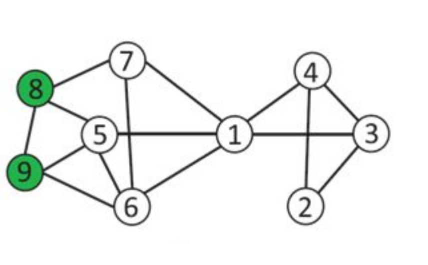

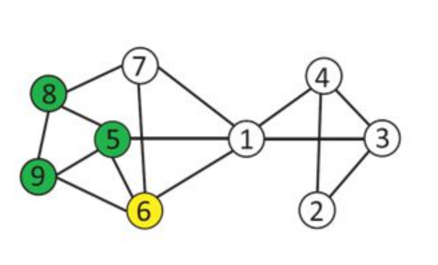

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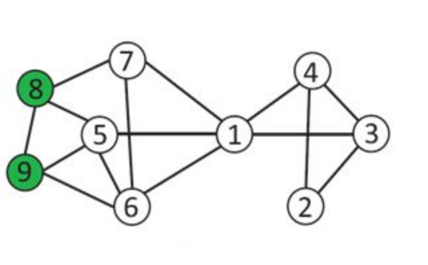

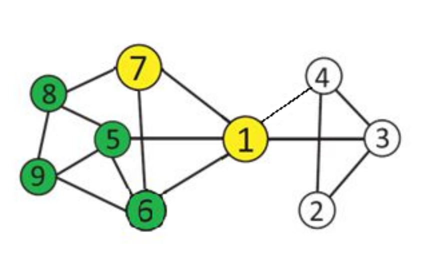

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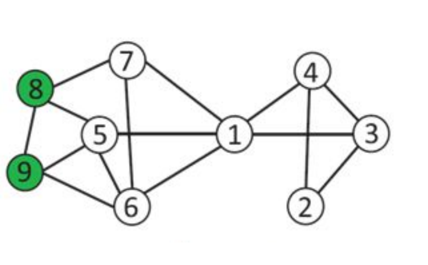
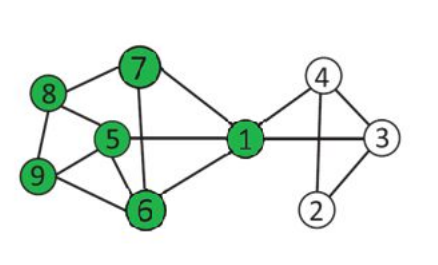
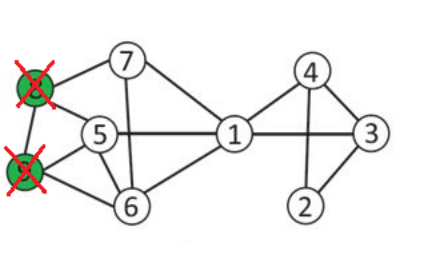


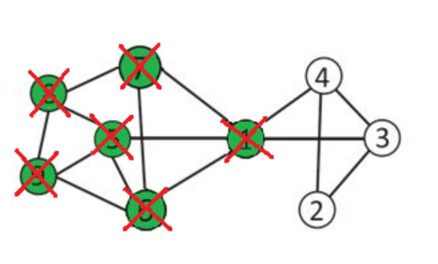


PREEMPT [2]: EpiControl using Inf-Max

- **Input**: Graph $G(V, E, w)$, Diffusion model, initial infected set B
- **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.

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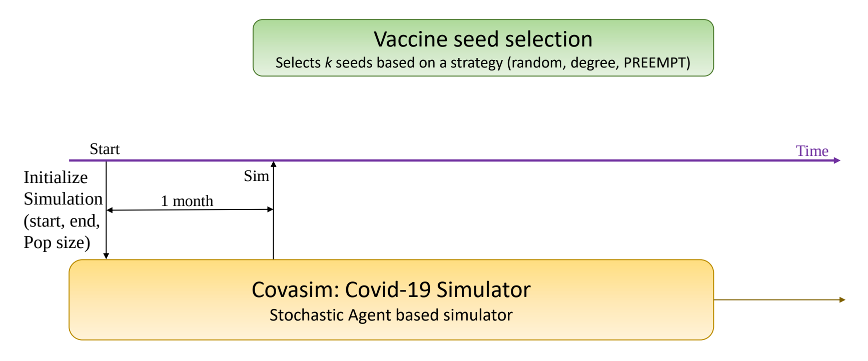
Epidemic Simulation + Intervention



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.

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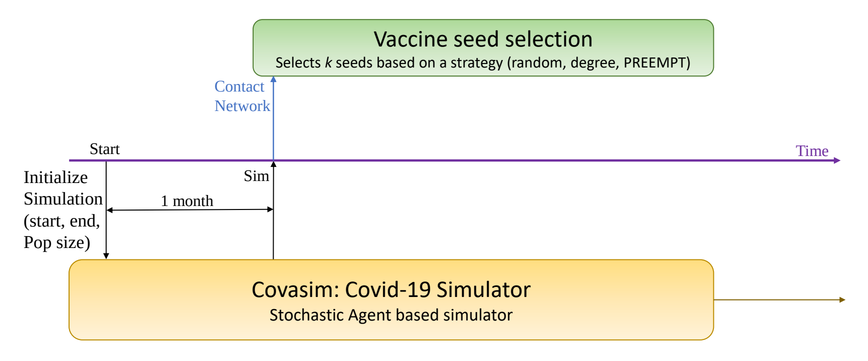

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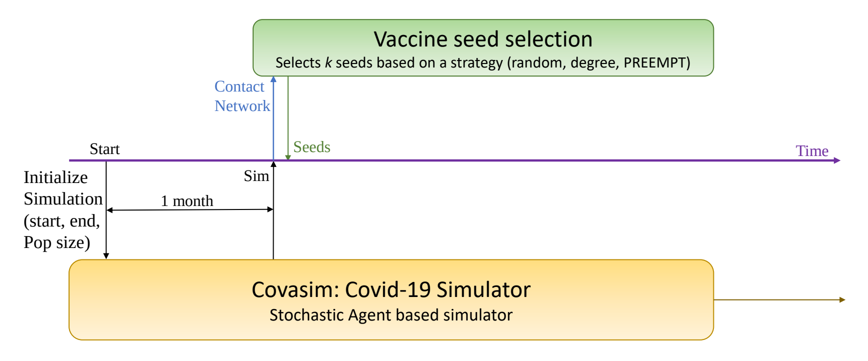

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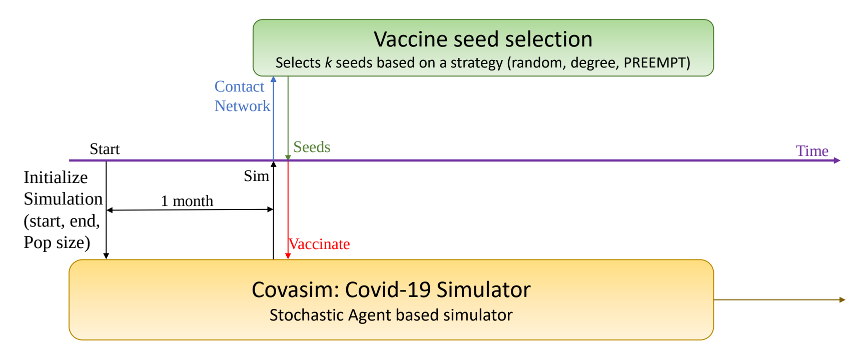

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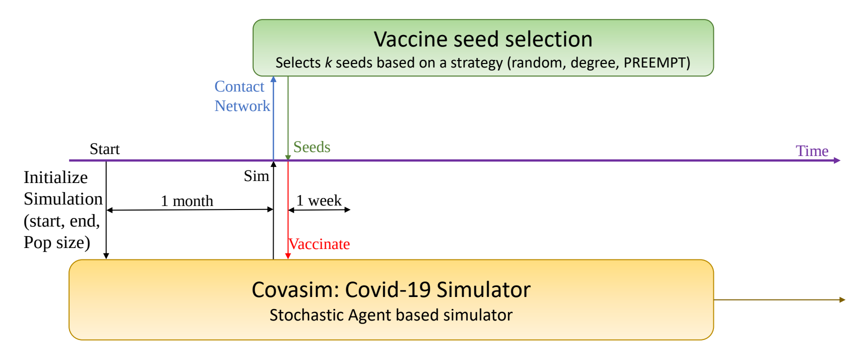

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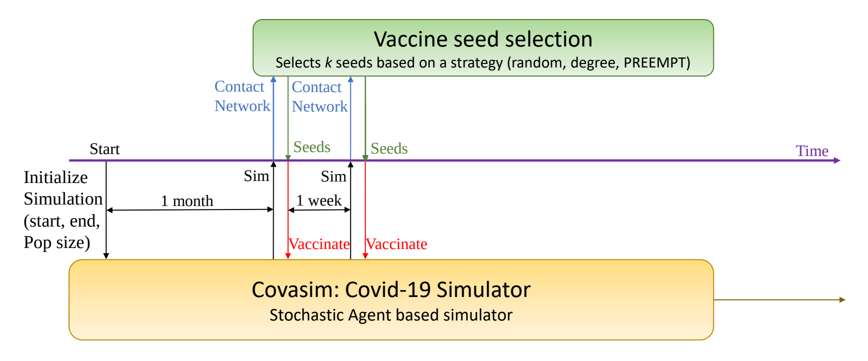

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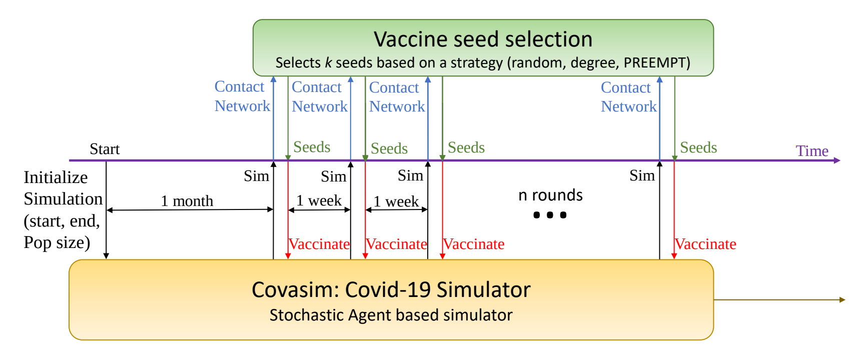

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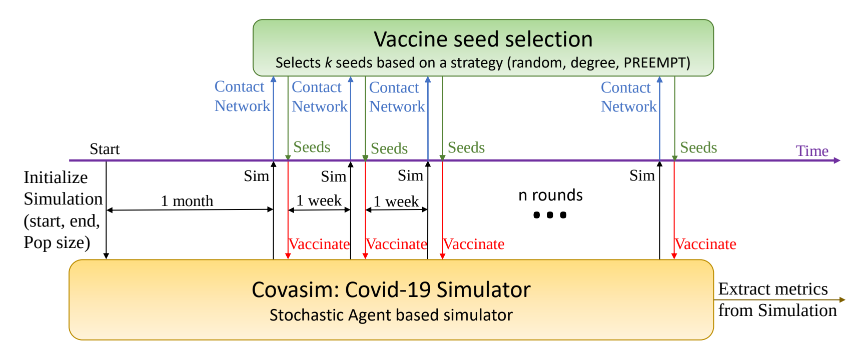

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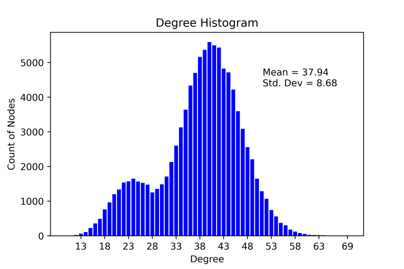
Input

- 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*
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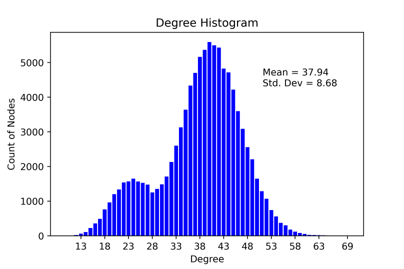

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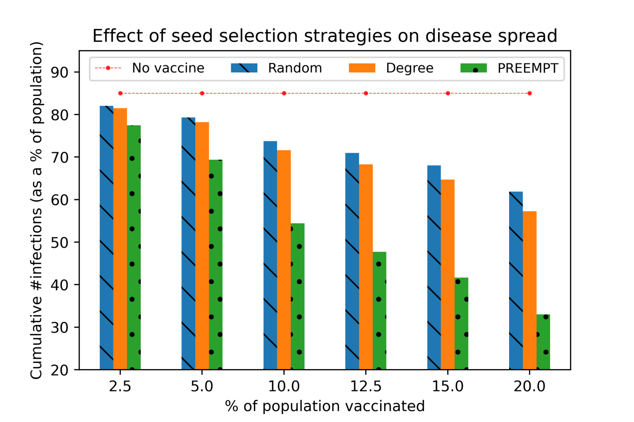
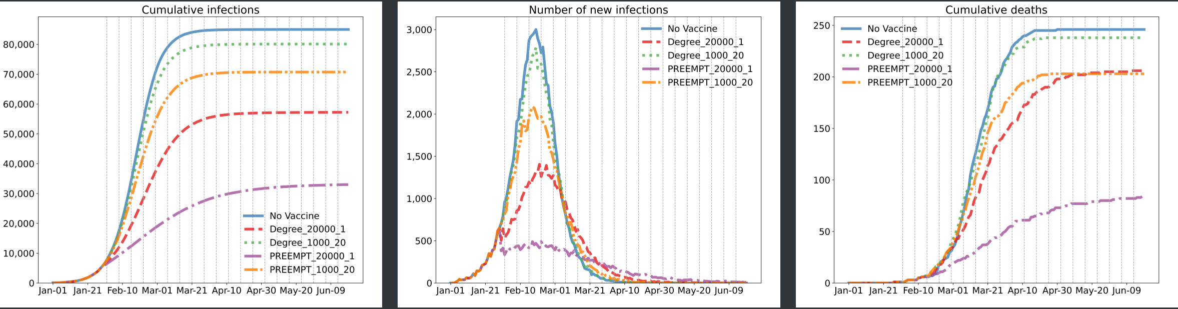
Effect of seed selection strategies



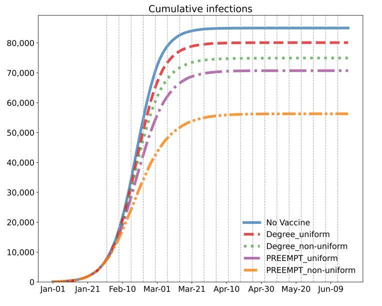
The x-axis represents the % of population vaccinated at a single round, on the 31st day of the simulation. The y-axis represents the cumulative #infections after 5+ months of simulation as a % of the population infected.

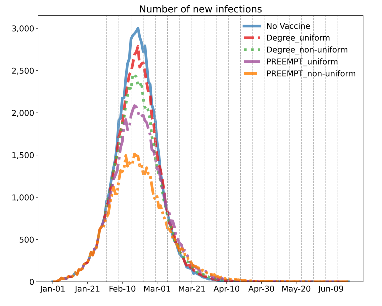
Effect of vaccinating in batches of uniform size

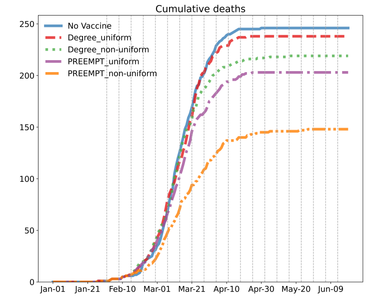


- Single-batch strategy is better than batching, but unrealistic.
- Uniform-batched PREEMPT is comparable to single-batched Degree.

Effect of vaccinating in batches of non-uniform sizes







- Irrespective of batch-size distribution, PREEMPT is better than Degree.
- Top-heavy non-uniform batched PREEMPT is better than uniform batched PREEMPT.

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:
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  - 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