Understanding the Impact of Geo-Social Human Interaction Patterns on Effective Vaccination Strategies

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Outline

- The past and current research
- Current public health practice for infectious disease control
- An innovative framework in terms of an effective disease control strategy
- A large-scale location-based network approach in an urban environment

Geovisual Analytics

- Visual analytics is defined as the science of analytical reasoning facilitated by interactive visual interfaces (Thomas and Cook 2005).

- Geovisual analytics focuses on visual interfaces to information containing a geospatial component.

Visual Representation

Computational Approach
(e.g., spatial statistics,
data mining)

Major Tasks:

Data Exploration

Predictive Analysis

Decision Making

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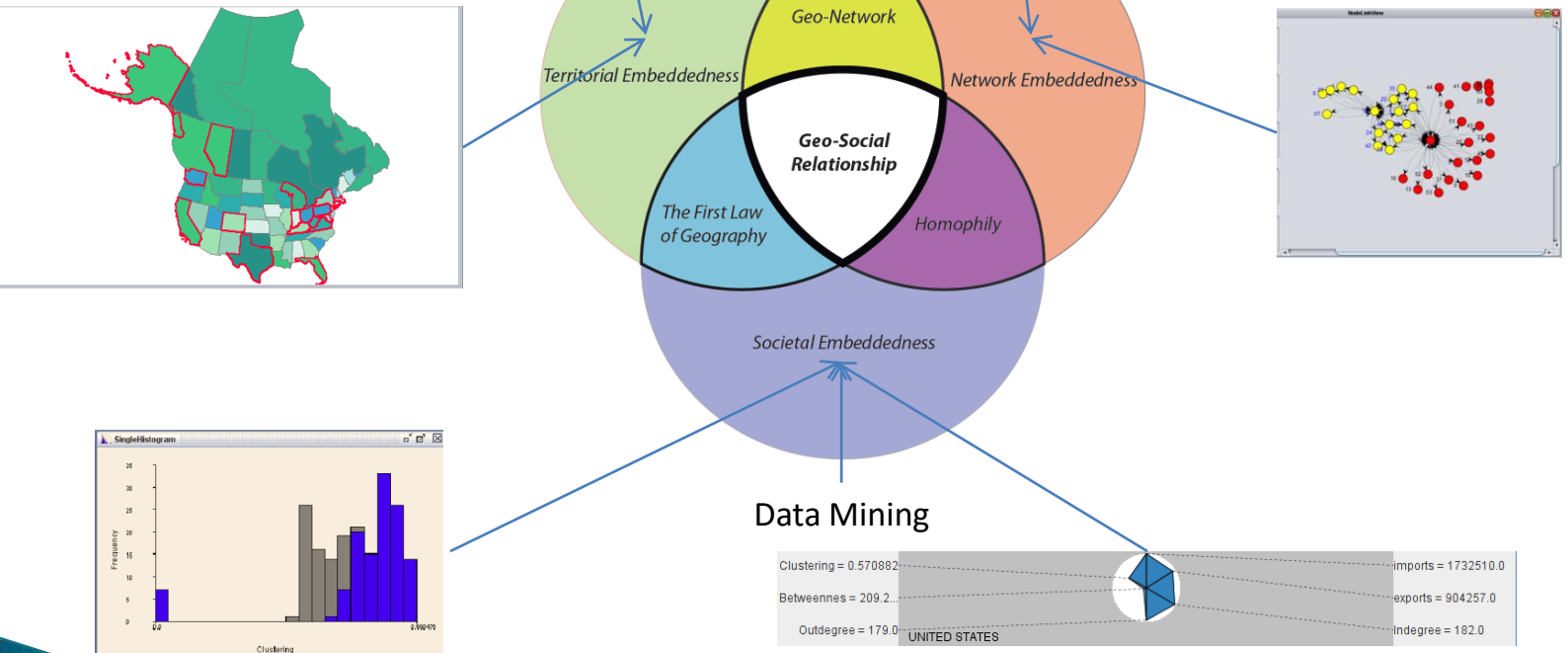
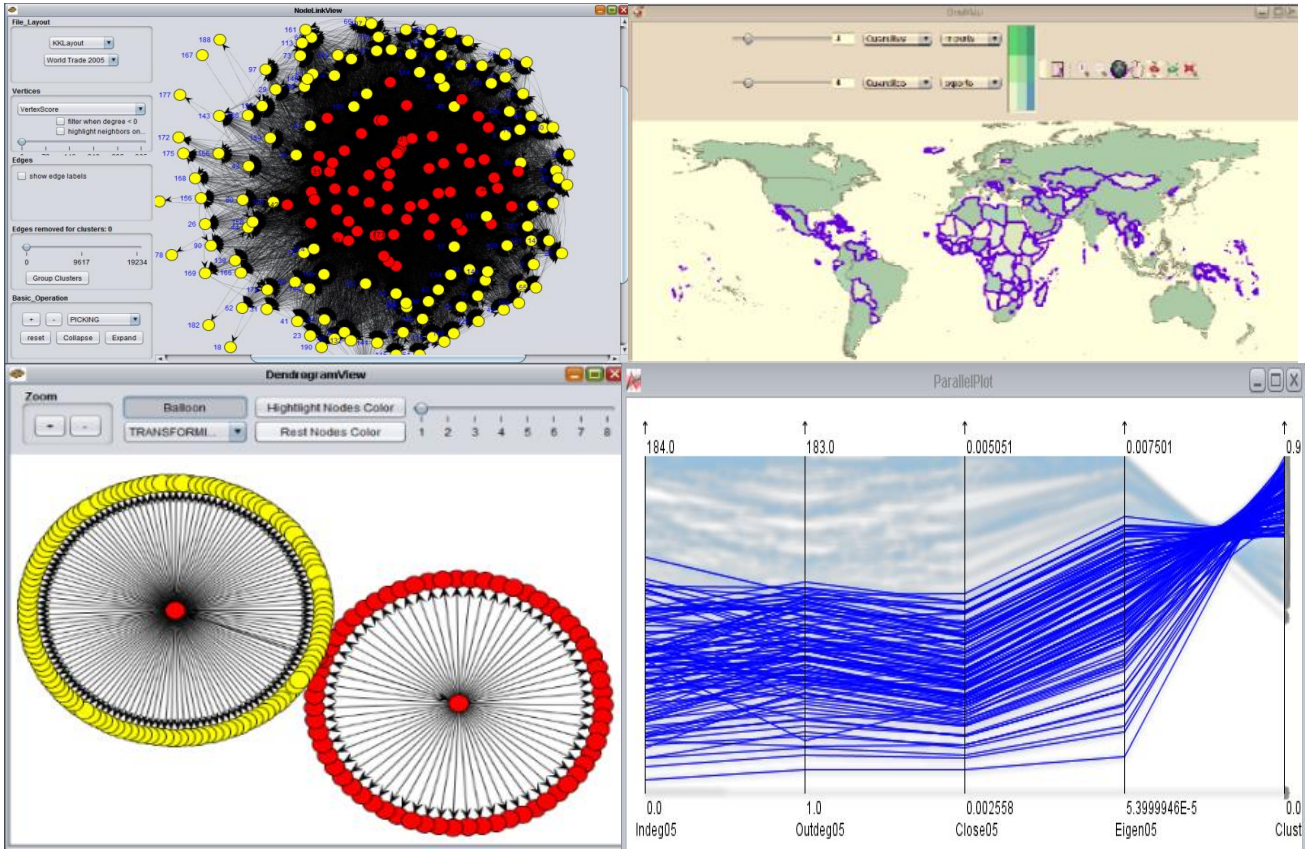
GeoSocial Visual Analytics



Luo W, MacEachren AM. 2014 Geo-Social Visual Analytics. *Journal of Spatial Information Science.* 8.

GeoSocialApp with international trade data



Luo W, Yin PF, Di Q, Hardisty F, and MacEachren AM. 2014 A Geovisual Analytic Approach to Understanding Spatial-Social Relationships in the International Trade Network. *PLoS ONE* 9(2): e88666.

GS-EpiViz with human interaction data in a high school

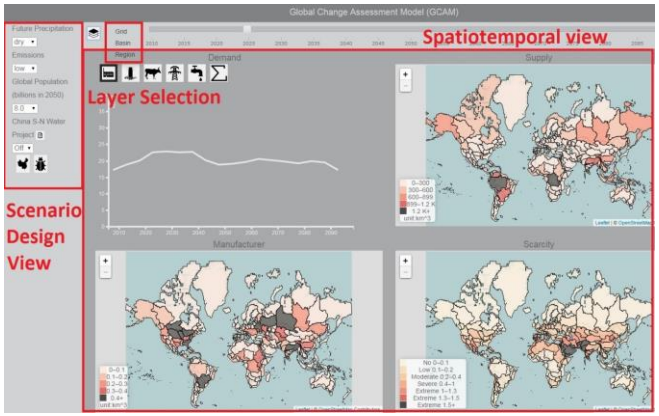
Within-classroom interaction

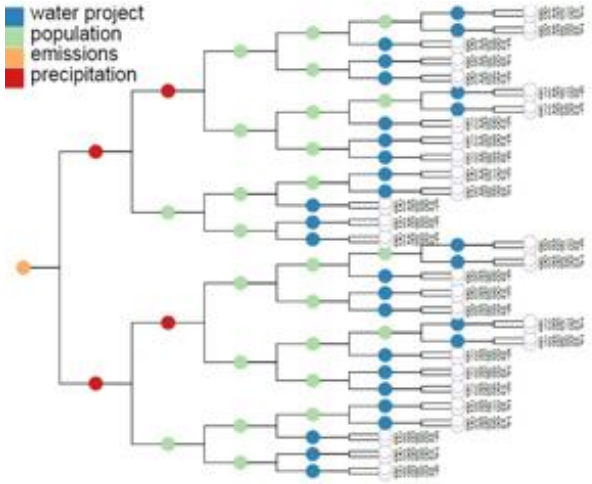
Between-classroom interaction

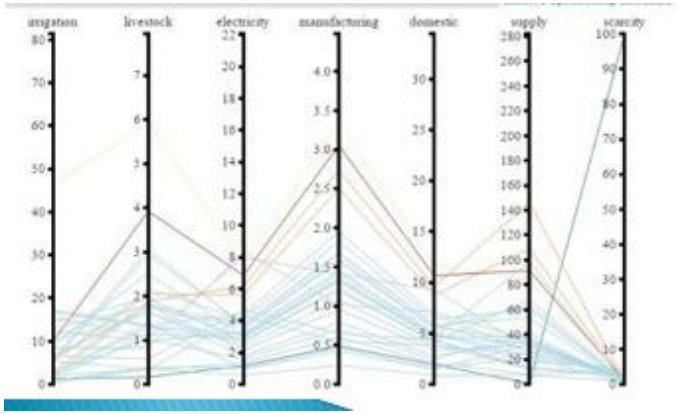
Disease control design Panel

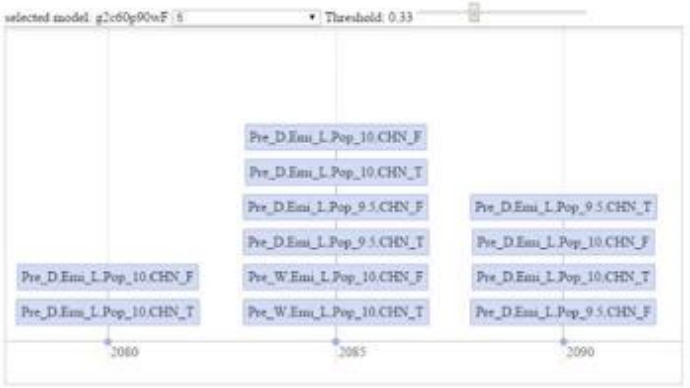
Luo W 2016 Visual Analytics of Geo-Social Interaction Patterns for Epidemic Control. *International Journal of Health Geographics.* 15(28)

Global Change Assessment Model Viz









Luo W, Steptoe M, Chang Z, Link R, Clarke L, and Maciejewski R. 2017 The Impact of Spatial Scales on the Inter-Comparison of Climate Scenarios. *IEEE Computer Graphics & Applications Special Issue: Geographic Data Science.* 37(5).

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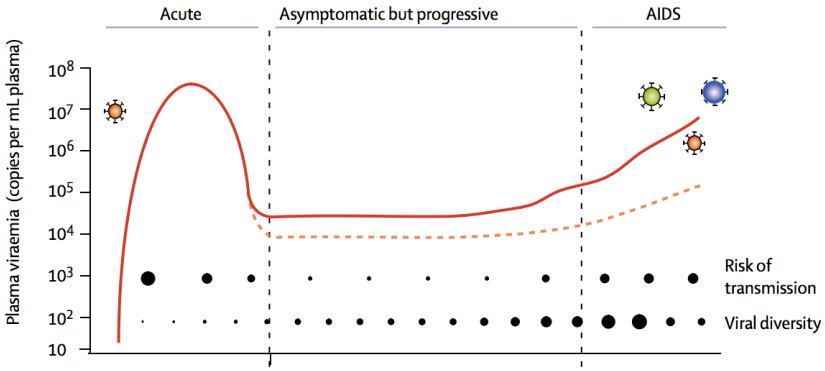
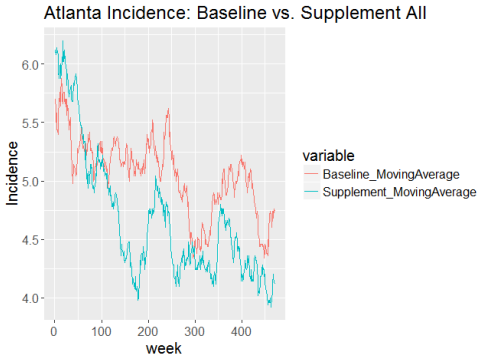
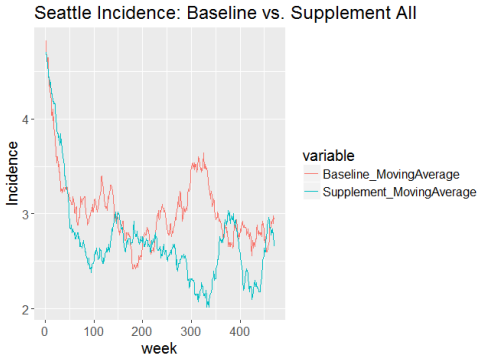
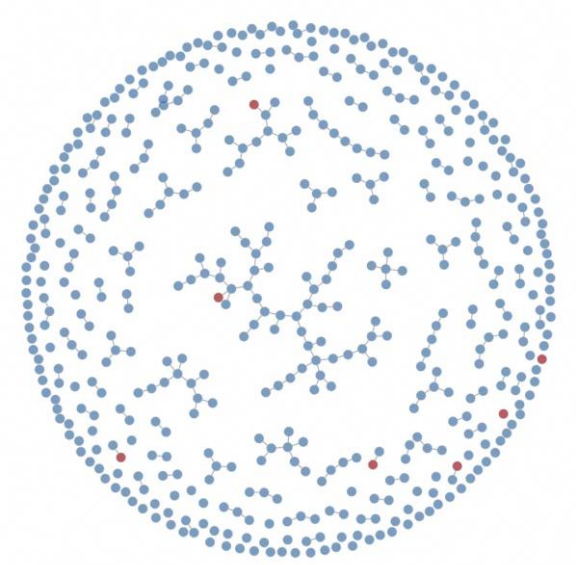
Identifying Effective Strategies for HIV Self-Testing among Men who Have Sex with Men in Atlanta and Seattle









Luo W, Katz D, Hamilton D, McKennie J, Jenness S, Goodreau S, Stekler J, Rosenberg E, Sullivan P., and Cassels S. (2018) Development of an Agent-based Model to Investigate the Impact of HIV Self-testing Programs for Men Who Have Sex with Men in Atlanta and Seattle. *JMIR Public Health Surveill.* 2018;4(2):e58.

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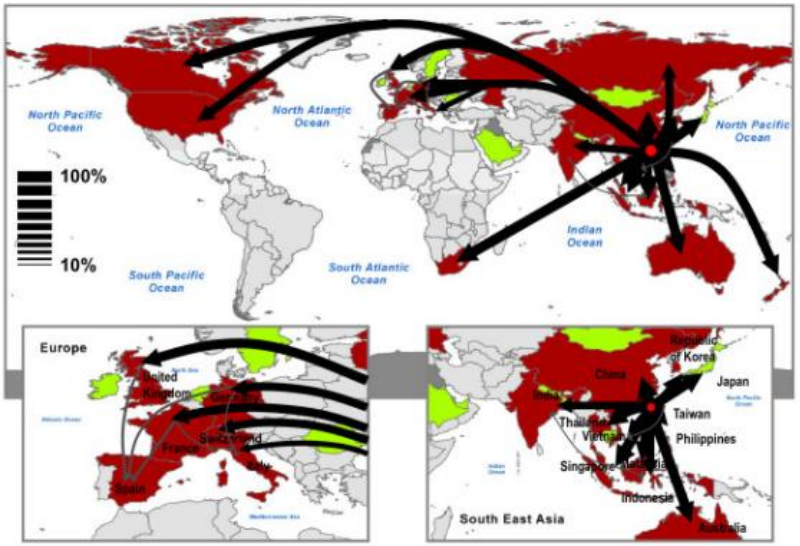
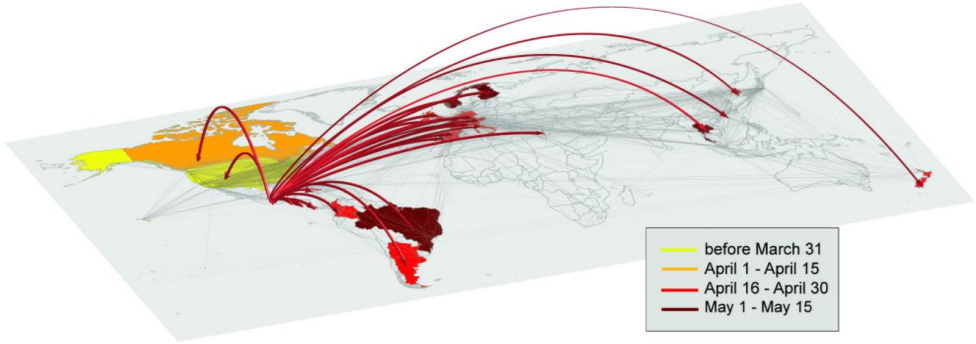
An innovative framework in terms of an effective disease control strategy

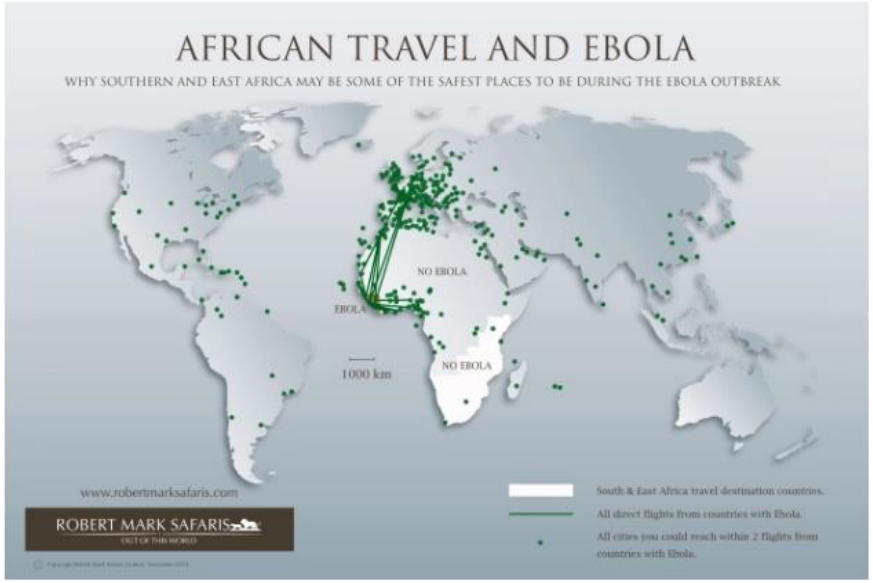
Human Travel and Disease Outbreak



2002-2003 SARS (Colizza et al., 2007)



2009 H1N1 pandemic from GLEAMviz.org



2014-2016 Ebola from ebola-map

Contact Tracing

- Contact Tracing: identification and diagnosis of people who may have come into contact with an infected person.
  - 2014 Ebola outbreak in West Africa (WHO and CDC, 2015).
  - Limitation:
    - Resource intensive process even if following a few cases.

Ring Prophylaxis

- Ring prophylaxis: geographically targeted containment via applying a certain distance threshold (e.g., 5 km) by means of prophylaxis (e.g., travel restriction, vaccination).
  - 2009 H1N1 outbreaks (Lee et al., 2010).
  - Limitations:
    - How to determine an appropriate containment size?
    - Hard to capture spatial heterogeneity of human mobility patterns responsible for transmission processes.

Overarching Goal

- Develop theory and methodology to contain air-borne infectious disease transmission from a geo-social perspective.

Research Objectives

Objective 1

Develop a geosocial theoretical framework for infectious disease control (Luo 2016).

GeoSocial Control

Objective 2

Develop a large-scale location-based network approach in high performance computing (Luo et al., 2018).

Urban Environment

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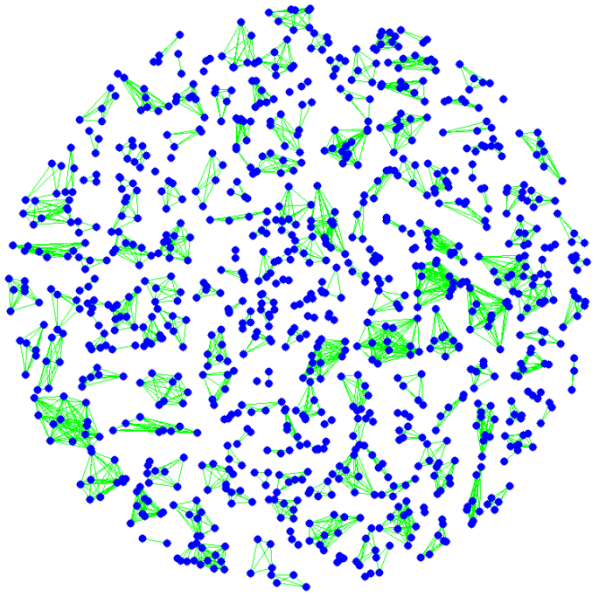
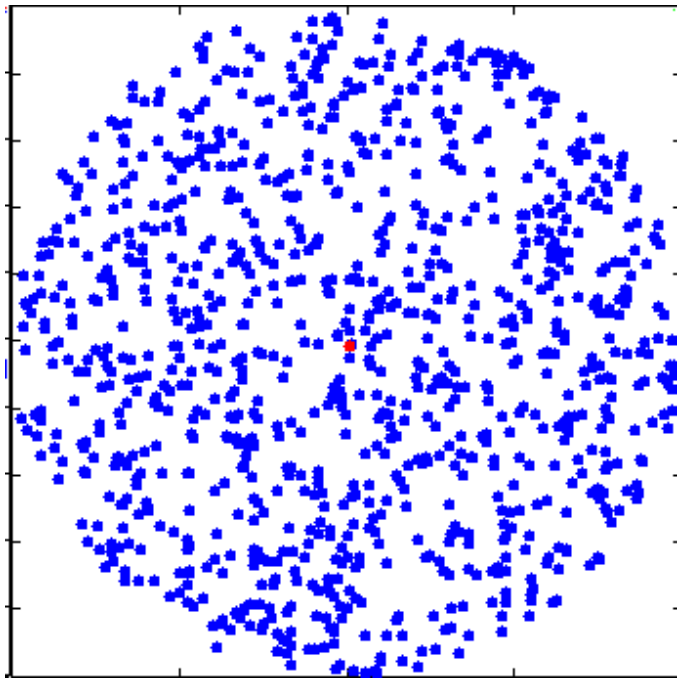
Agent-Based Epidemic Model



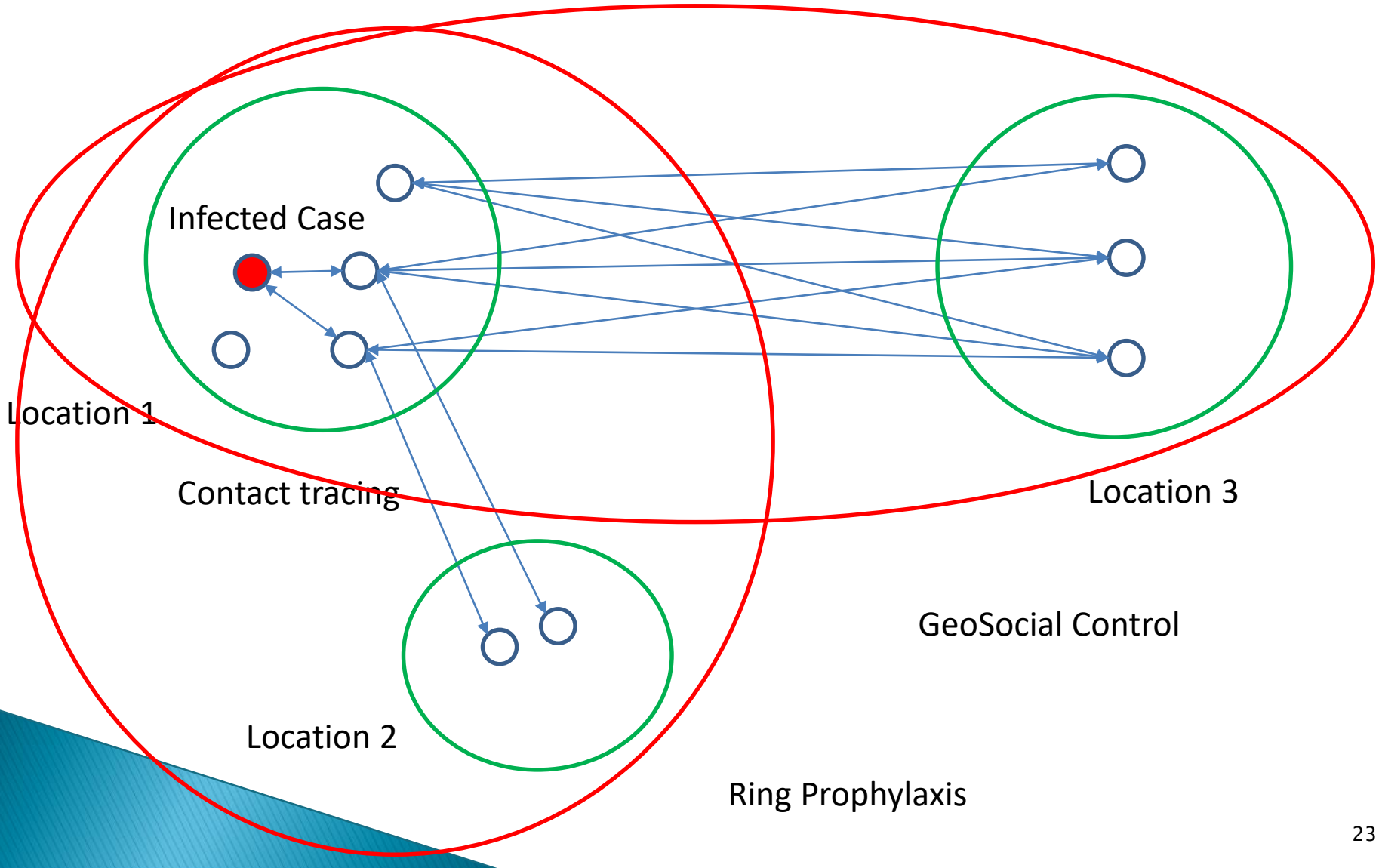
Human Interaction Network



susceptible infectious recovered

Epidemic Simulation based on SIR Model

Contact Tracing vs. Ring Prophylaxis vs. GeoSocial Control



Pros: GeoSocial Control

- It is easier to target critical locations first rather than prioritizing individuals.
- It is infeasible to capture all of contacts of infections, but the information to estimate population flows among locations is widely available (e.g., travel survey, twitter).
- It can capture the mixed interactions of the social and spatial relationships among individuals that determine infectious disease transmission.

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Geographical Tracing

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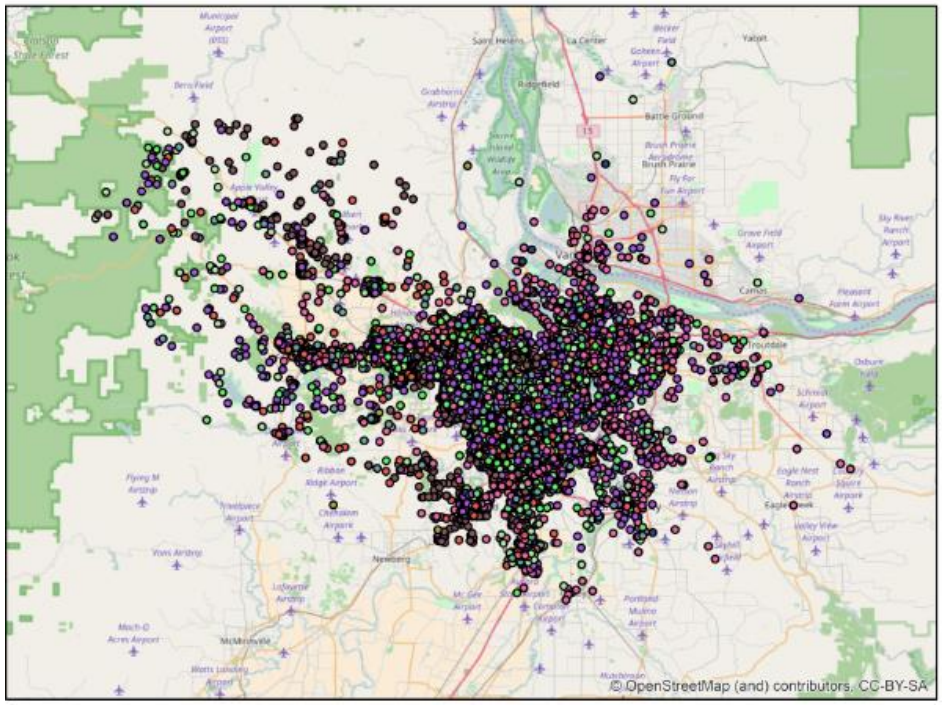
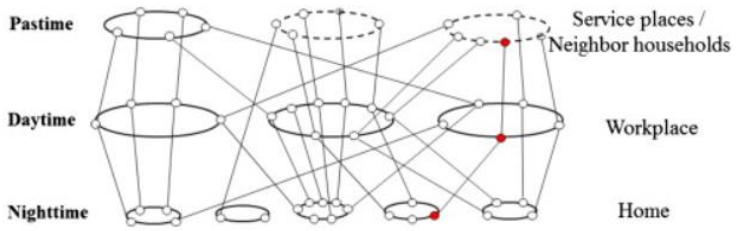
Urban Environment

Luo W, Gao P, and Cassel S. Understanding the Impact of Geo-Social Human Interaction Patterns on Effective Vaccination Strategies in an Urbanized Area. (2018). *Computers. Environment and Urban Systems* 72?

Human Interaction and Mobility in an Urbanized Area



Human Activities at Portland



(Mao, 2014)

Network Measures	Number
Total population	1,575,861
Total contacts	19,481,626
Total locations	1,517,302
Total flows	6,539,119

http://ndssl.vbi.vt.edu/synthetic-data/

Challenges

- Human interaction patterns in urban environments are characterized by the complexity of spatially heterogeneous population distribution and movement.

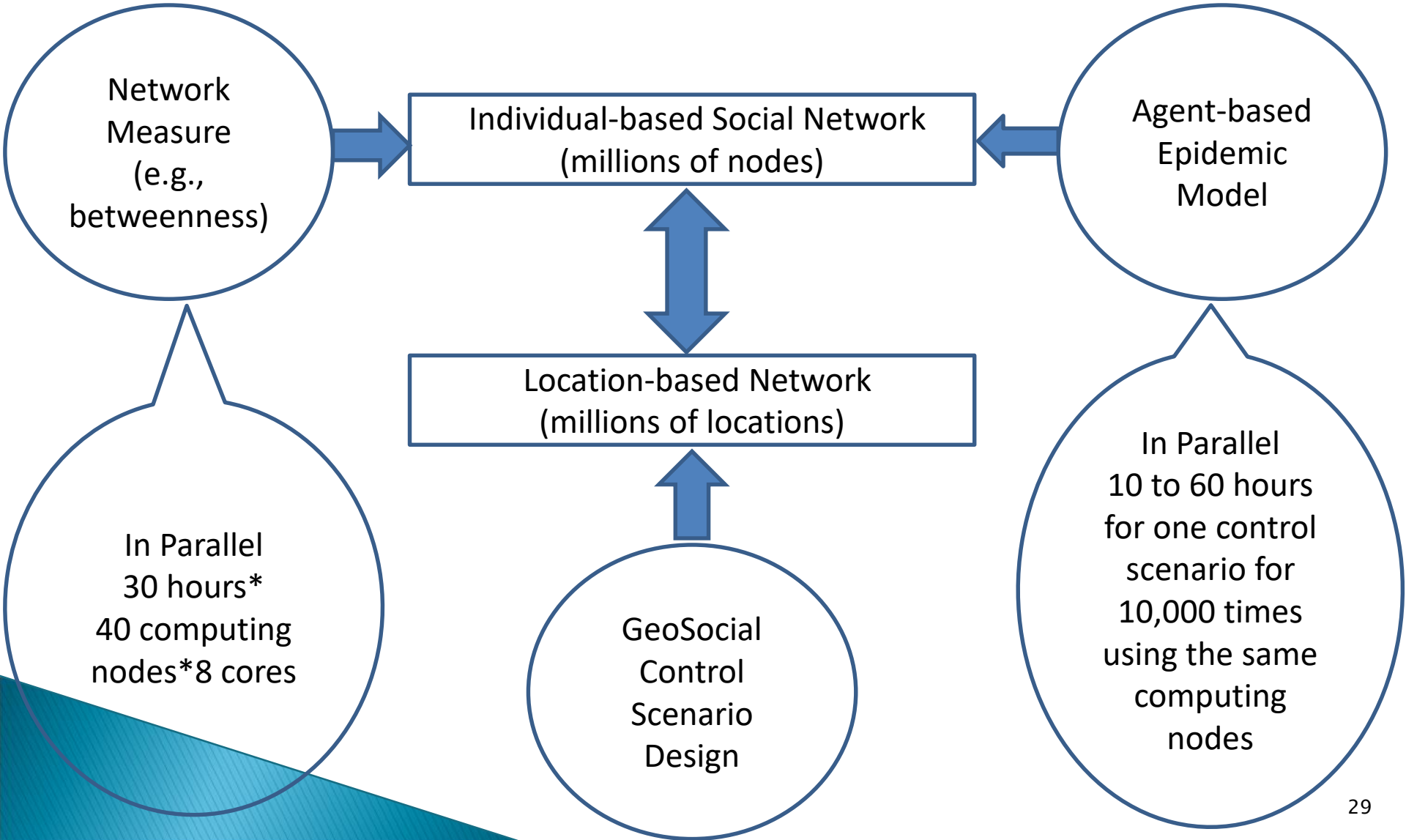
- Massive interactions with millions of locations and connections make network analysis and modeling challenging.

Research Questions

- How does the spatially heterogeneous population distribution and movement impact the geosocial control effectiveness?

- How does the size of the containment area impact the geosocial control effectiveness?

Method

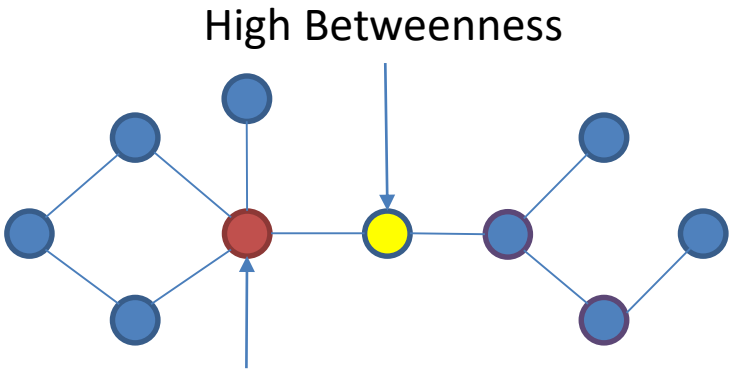

Network Measure (e.g., betweenness)
Individual-based Social Network (millions of nodes)
Agent-based Epidemic Model
Location-based Network (millions of locations)
In Parallel 30 hours* 40 computing nodes*8 cores
GeoSocial Control Scenario Design
In Parallel 10 to 60 hours for one control scenario for 10,000 times using the same computing nodes

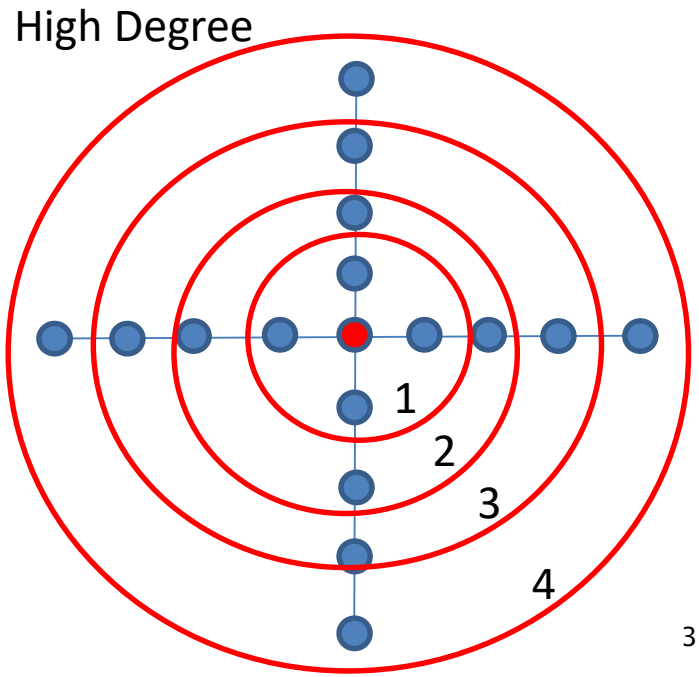
Influenza Parameters

Parameters	Default Values	Data Sources
Length of exposed period	2 days	Heymann (2004)
Length of infectious period	4 days	Heymann (2004)
Basic reproduction rate: R_0	1.6	Mills et al.(2004) and Ferguson et al. (2005)
Infection probability per contact	0.015	Measured based on R_0

Control Scenario Parameters

Parameters	Values
Vaccination strategies	Random-based, degree-based, and betweenness-based
Initial infection locations	1,000 (low population density), 5,000 (medium), and 10,000 (high) individuals in the first order of geographical neighborhood locations
Containment areas	Four different geo-social local containment scales
Number of vaccines	20,000 to 200,000 with an increment of 20,000
Simulation runs	3600 (1*3*100*3*4*10) *10,000 = 360,000,000

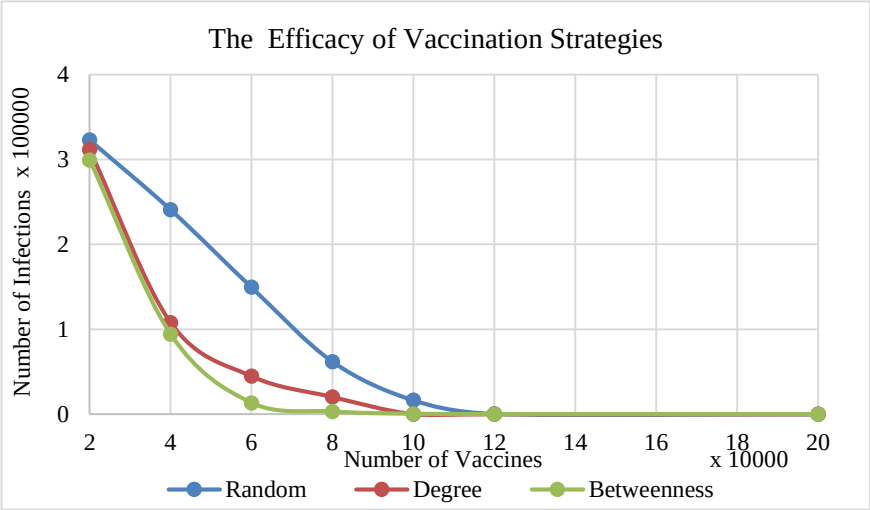




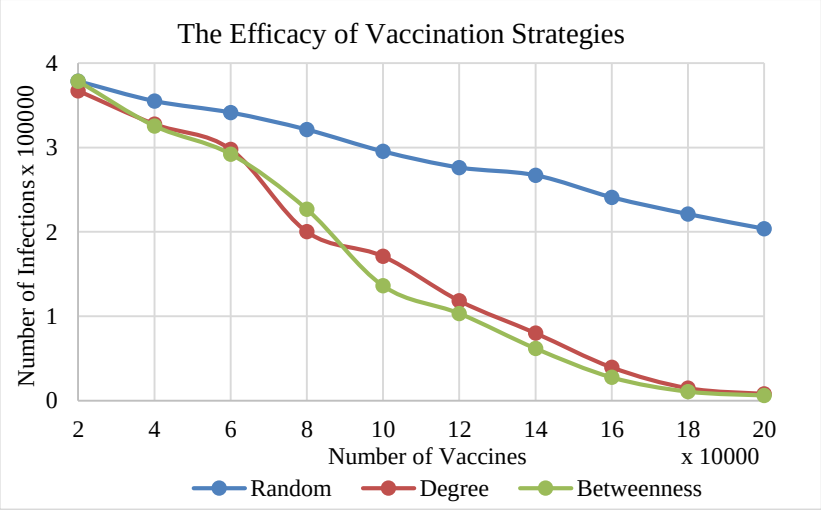
Two Measures of Control Effectiveness

- A lower number of infections.
- How well we can contain the epidemic locally: no infections outside the containment area.

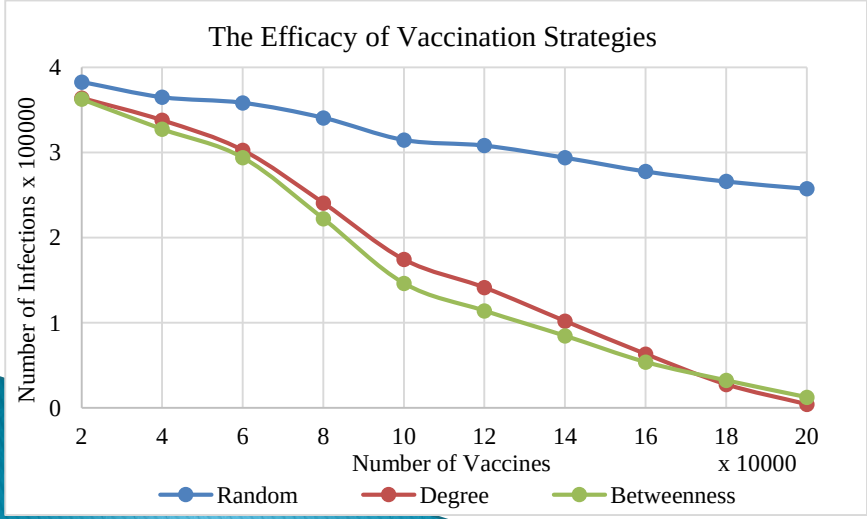
Local Containment Efficacy with Medium Population Density Scenarios



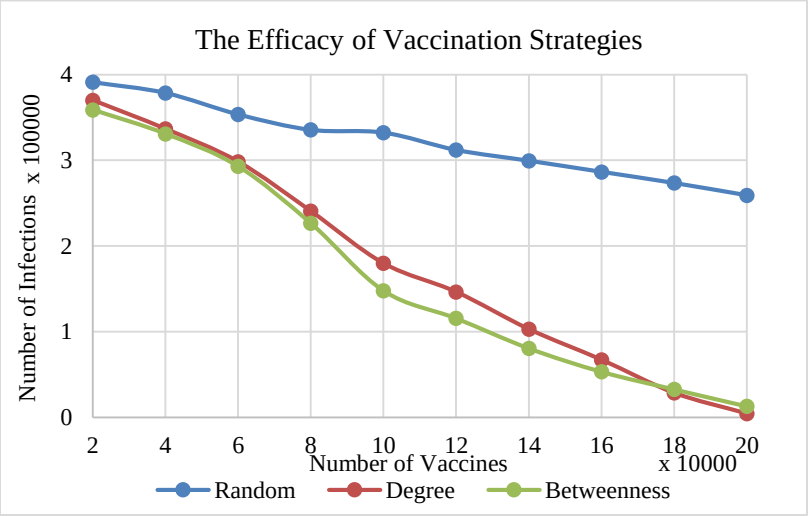
(a) The second level local containment scale



(b) The third level local containment scale

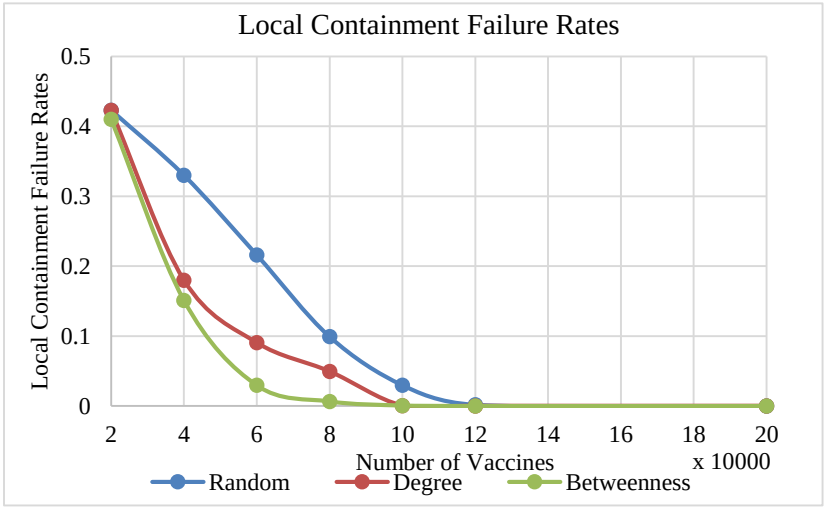


(c) The forth level local containment scale



(d) The fifth level local containment scale

Local Containment Success Rate with Medium Population Density Scenarios



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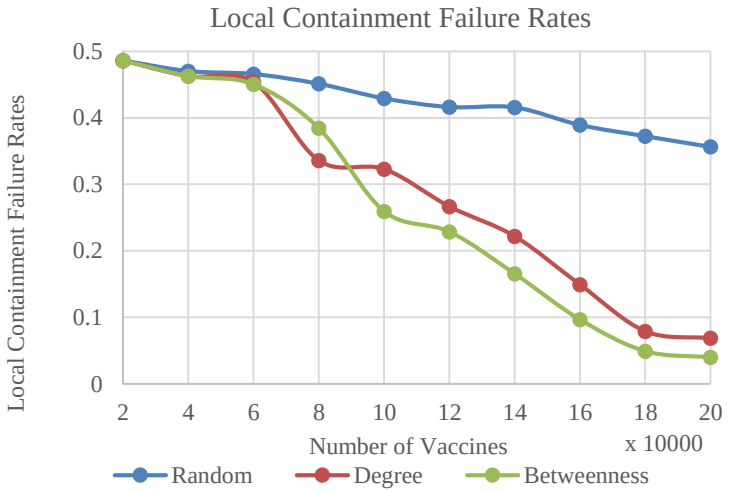
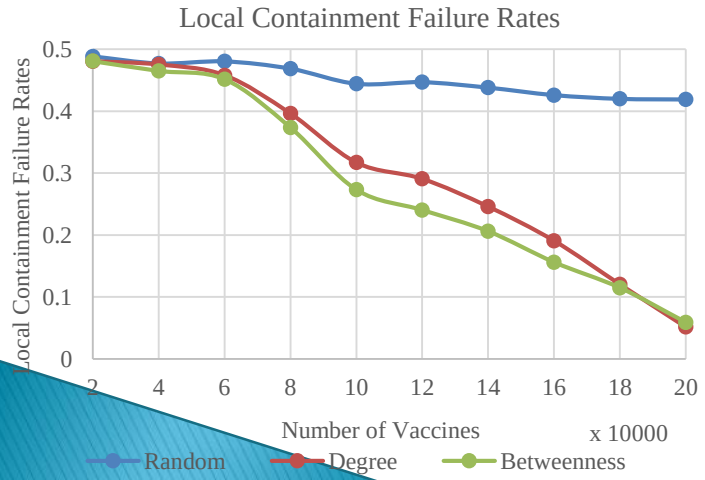
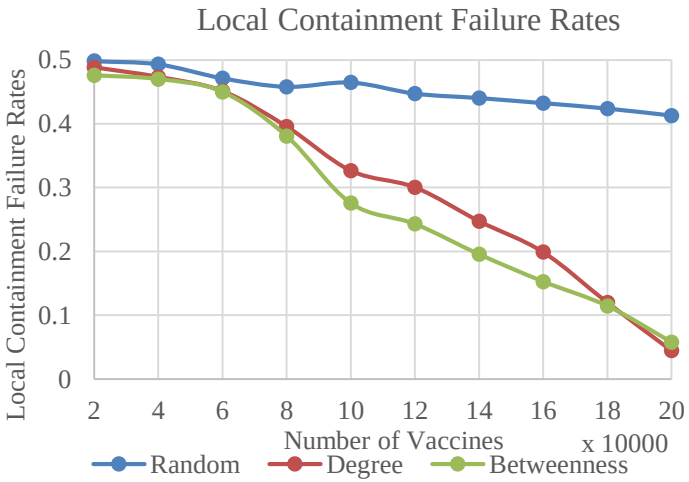


(b) The third level local containment scale

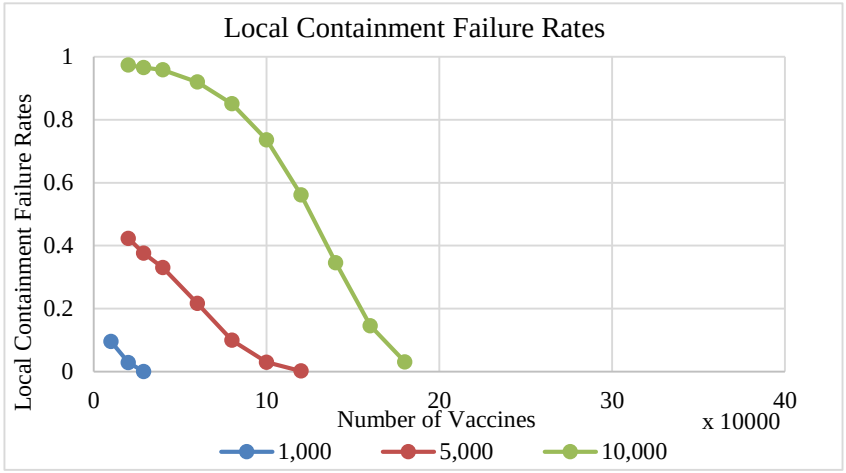


(c) The forth level local containment scale



(d) The fifth level local containment scale

Random-based Vaccination Strategies with Spatially Heterogeneous Population Distribution and Movement



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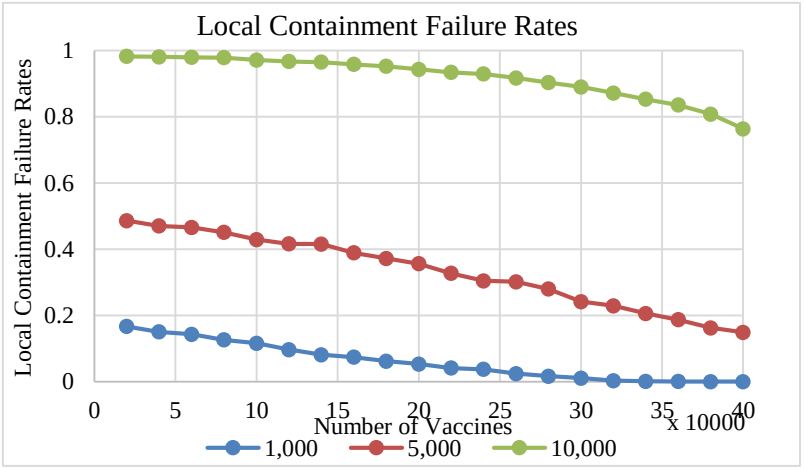
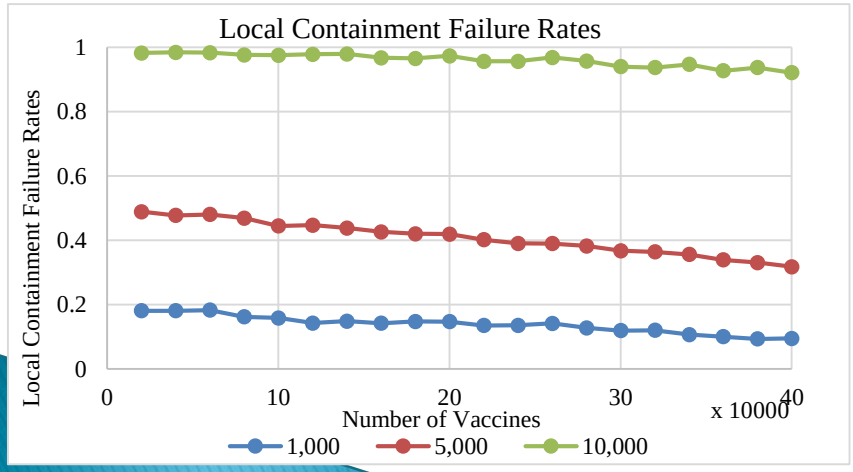
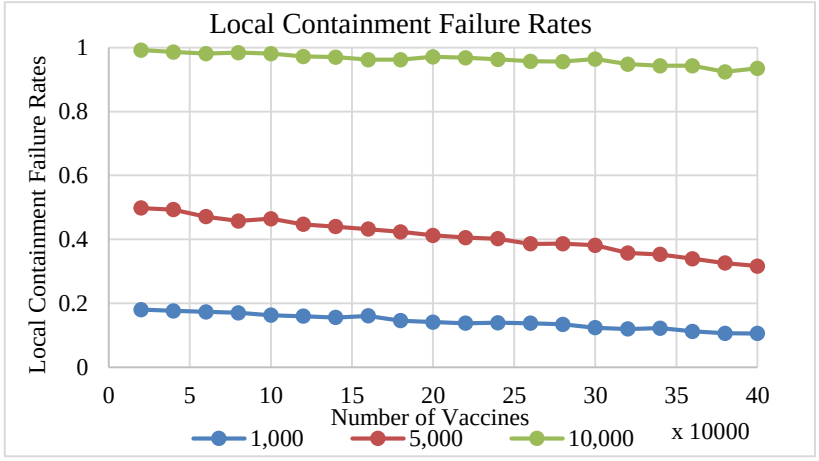


(b) The third level local containment scale



(c) The forth level local containment scale

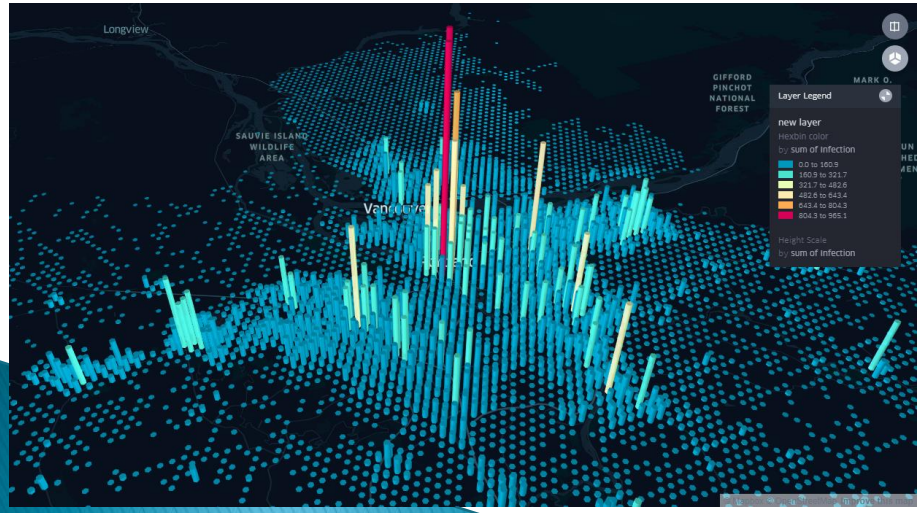


(d) The fifth level local containment scale

Spatial Effectiveness with Medium Population Density Scenarios

(a) The second level local containment scale

(b) The third level local containment scale



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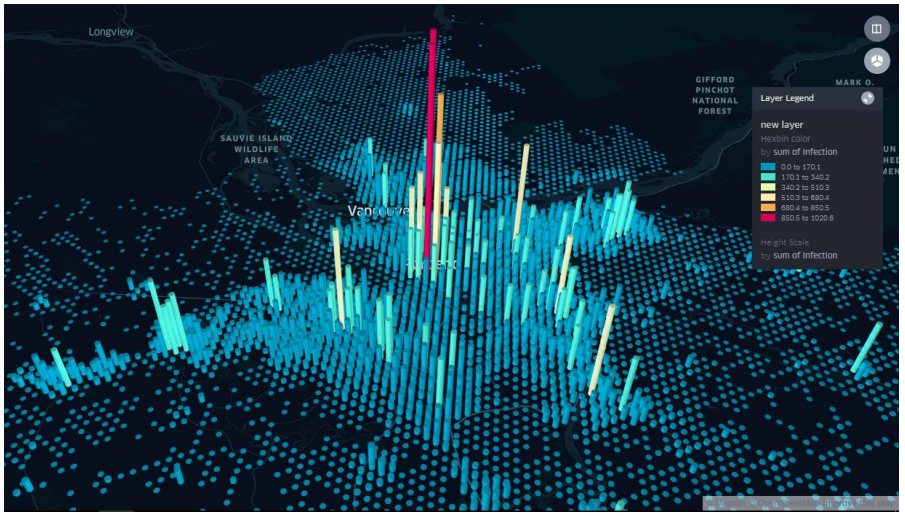

(d) The fifth level local containment scale

Conclusions

- The population density at the source of infections matters.
- An appropriate spatial-social scale can help achieve the best control efficacy with a limited number of vaccines.
- Geosocial control can help geographically optimize the design of control strategies (e.g., travel restrictions) before pandemic outbreaks in an urban environment.

Significance

- Indian Institute of Public Health (IIPH) is implementing geosocial control approach.
- ESRI, the biggest Geographical Information System (GIS) company, is implementing the approach in their software.
- With the available data (i.e., twitter) to estimate human movement patterns, geosocial control make it possible to design the near real-time disease control.

- Thanks.