Modeling Ebola: System, Agent, and Spatial Models

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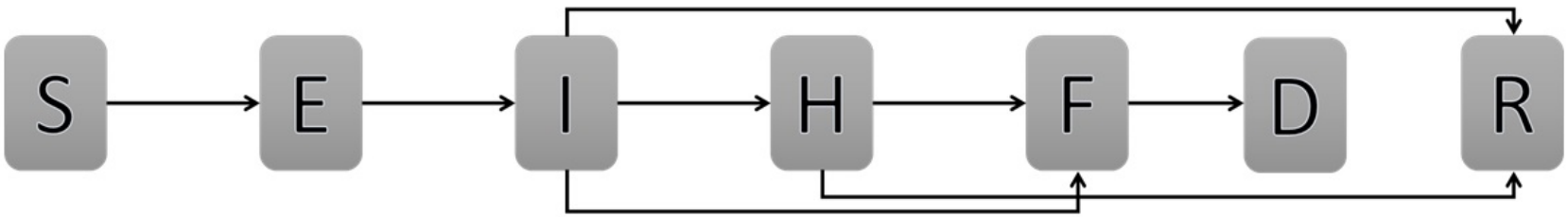
Overview

1. Introduction
2. Models
    - System-based
    - Agent-based
    - Spatial agent-based
3. Summary

Introduction

- Ebola was discovered in 1976
- Early symptoms: headache, fatigue, joint pain
- Later symptoms: abdominal pain, diarrhea, vomiting, rashes
- Diseases like HIV and malaria have the same symptoms
- The virus is contracted through direct contact with bodily fluids and secretion
- Incubation period may last up to two weeks
- Serious outbreaks in Liberia, Sierra Leone, and Guinea (2014)

Compartment Model of the Ebola Epidemic in Liberia



S: Susceptible
E: Exposed
I: Infectious
H: Hospitalized
F: Funeral
R: Recovered
D: Dead

Assumptions

- Focus on Liberia in 2014-2015
- Closed system
- Everyone who dies has a traditional funeral

System Dynamics Differential Equations

$$\frac{dS}{dt} = -\frac{\beta_I SI + \beta_H SH + \beta_F SF}{N}$$

$$\frac{dE}{dt} = \frac{\beta_I SI + \beta_H SH + \beta_F SF}{N} - \gamma_P E$$

$$\frac{dI}{dt} = \gamma_P E - [\gamma_H \theta + \gamma_I (1-\theta)(1-\delta_1) + \gamma_D (1-\theta)\delta_1] I$$

$$\frac{dH}{dt} = \gamma_H \theta I - [\gamma_{HF} \delta_2 + \gamma_{IH}(1-\delta_2)] H$$

$$\frac{dF}{dt} = \gamma_D (1-\theta)\delta_1 I + \gamma_{DH}\delta_2 H - \gamma_F F$$

$$\frac{dR}{dt} = \gamma_I (1-\theta)(1-\delta_1) I + \gamma_{HR}(1-\delta_2) H$$

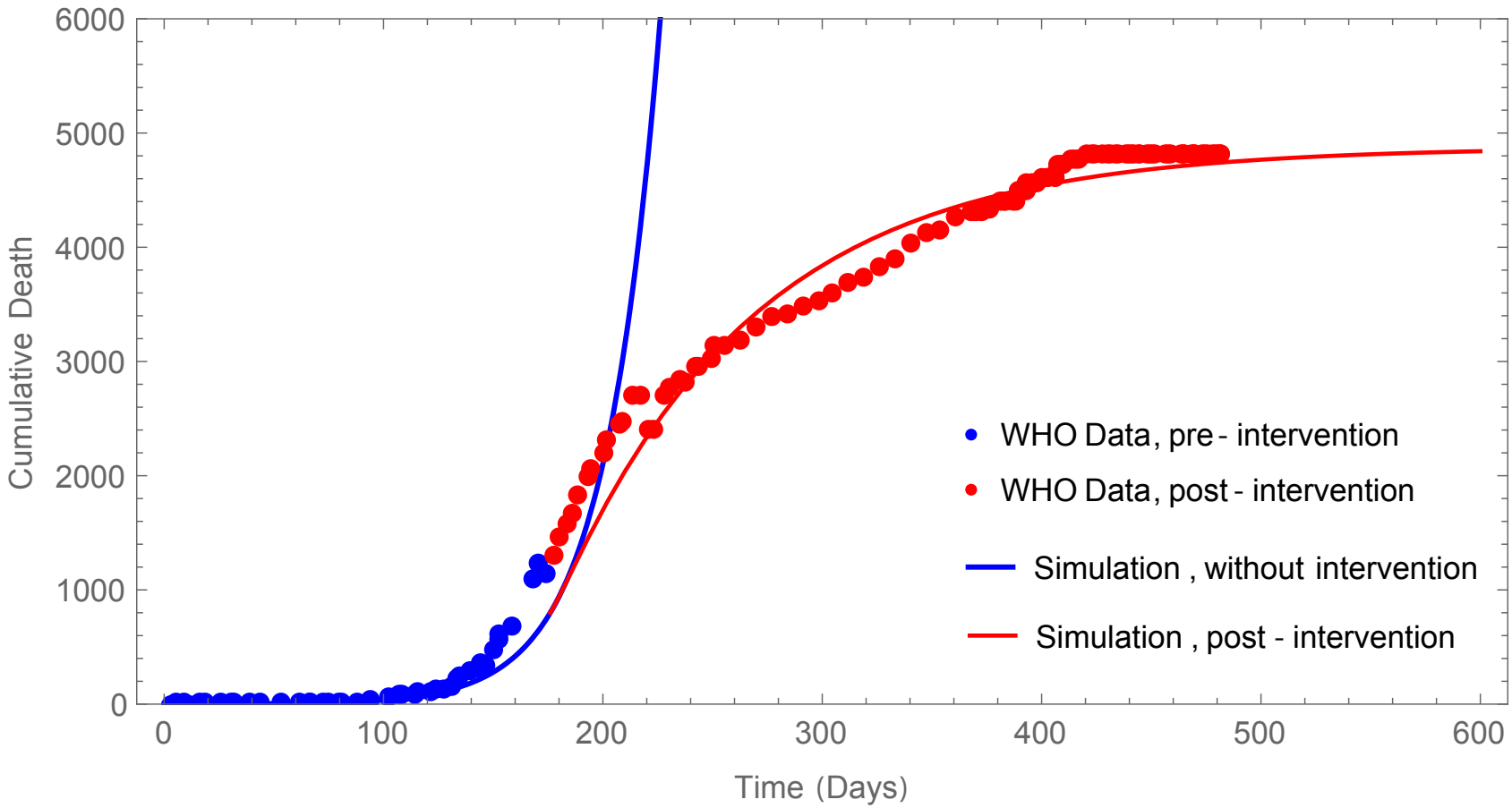
$$\frac{dD}{dt} = \gamma_F F$$

Model Parameters for Ebola Epidemic in Liberia

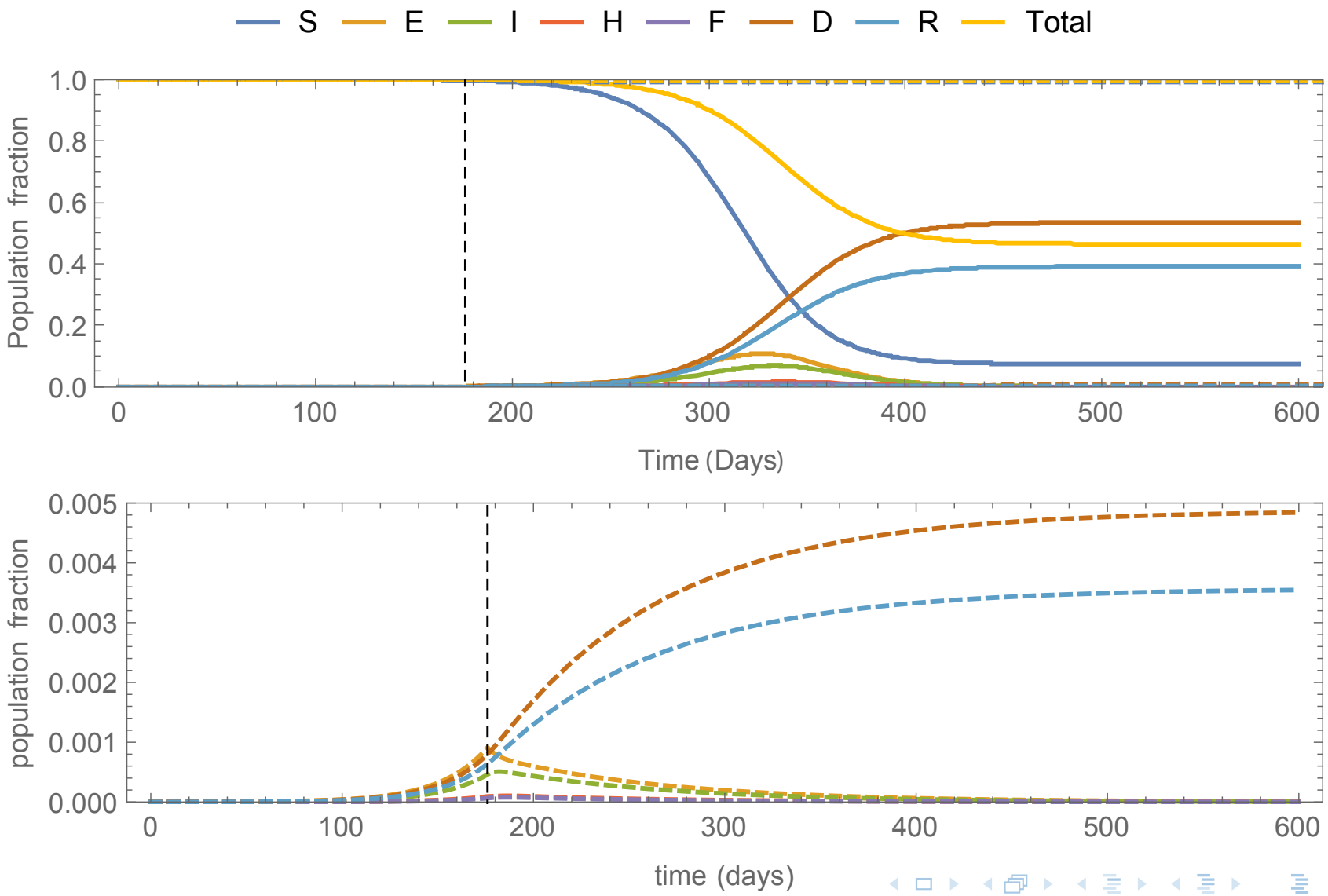
Parameter	Value
Incubation Period (t_P)	11 days
Duration of Traditional Funeral (t_F)	2.00 days
Time from Infection to Recovery (t_I)	10.00 days
Time from Infection to Death (t_D)	8.00 days
Case Fatality Rate, Unhospitalized (δ_1)	0.500
Case Fatality Rate, Hospitalized (δ_2)	0.500

Parameter	Pre-intervention (Mar 2014 to Sept 2014)	Post-intervention (Sept 2014 to July 2015)
Contact Rate, Community (β_I)	0.148 (0.0953)	0.0446 (0.0338)
Contact Rate, Hospital (β_H)	0.235 (0.143)	0.0877 (0.0563)
Contact Rate, Funeral (β_F)	0.465 (0.287)	0.283 (0.208)
Time from Infection to Hospitalization (t_H)	4.49 (1.44) days	4.63 (1.43) days
Probability a Case is Hospitalized (θ)	0.248 (0.142)	0.233 (0.145)

World Health Organization Data vs. Systems Model



System Model Results: With and Without Intervention

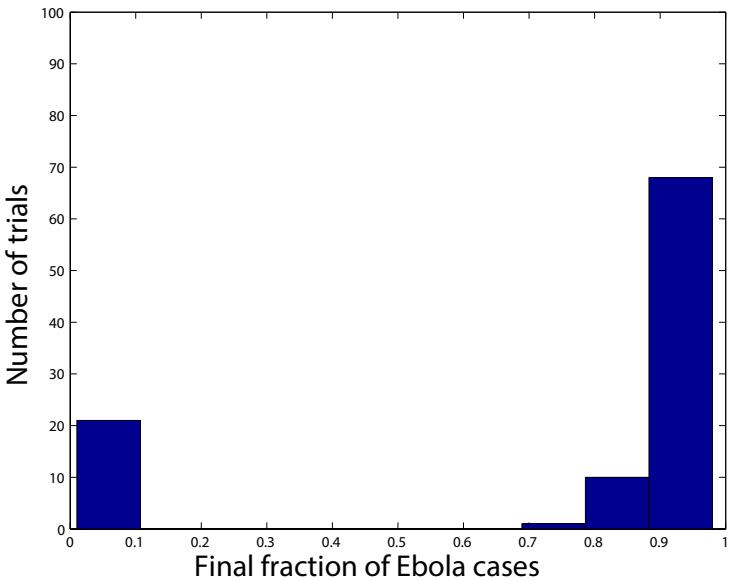


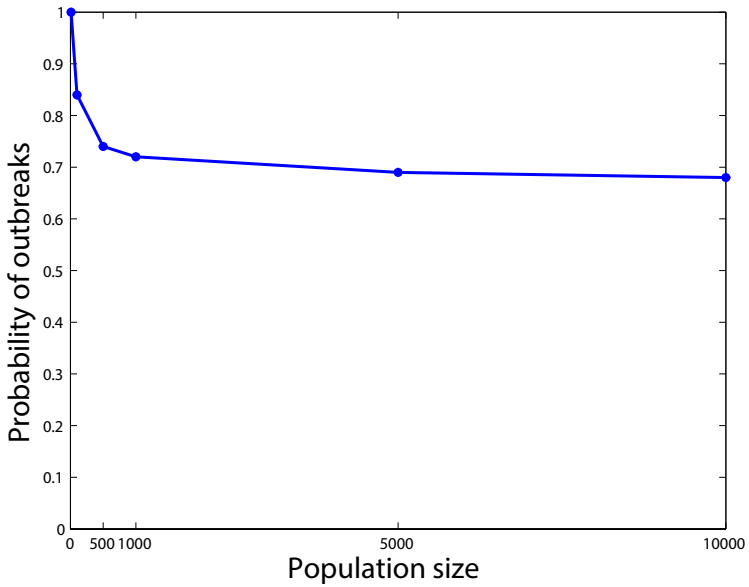
Agent-based model

- System $\Longrightarrow$ agent
- Compartment $\Longrightarrow$ state
- Deterministic $\Longrightarrow$ probabilistic
- Simulation:
  - 1000 individuals; 1 exposed
  - 300 days
  - 100 repetitions

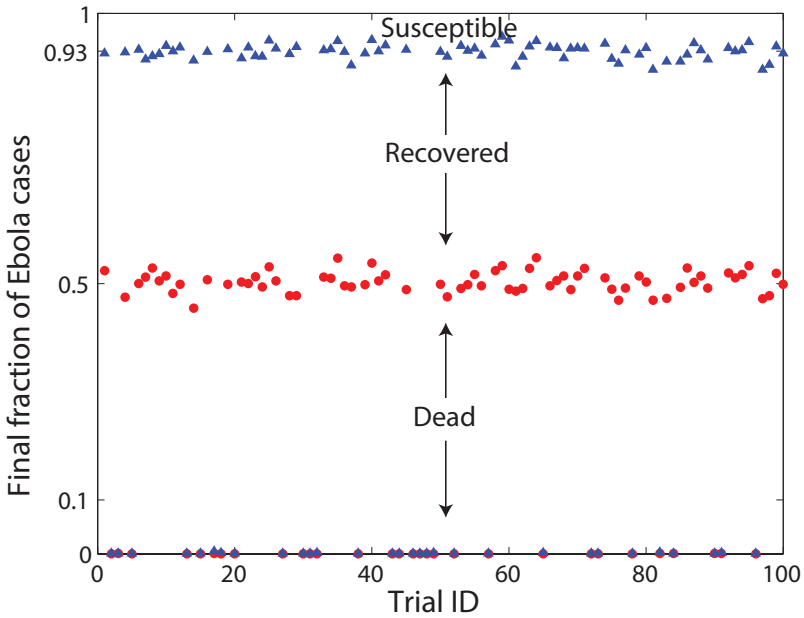
Probability of having an outbreak

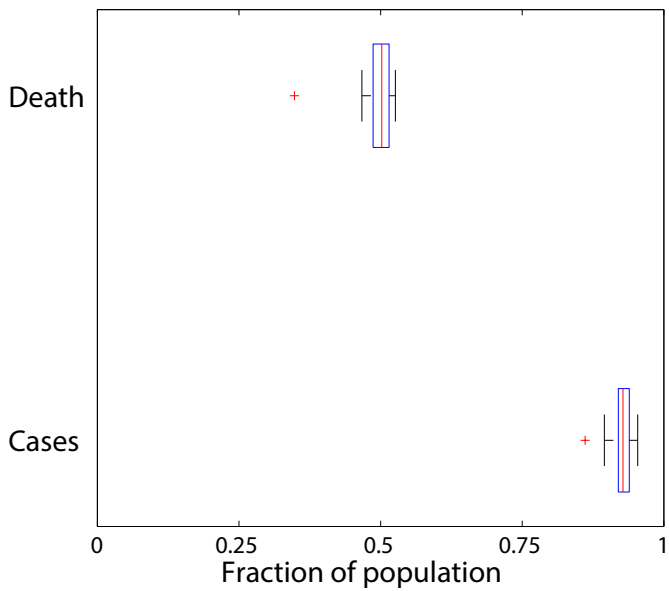
outbreak: 2% of population contracts disease



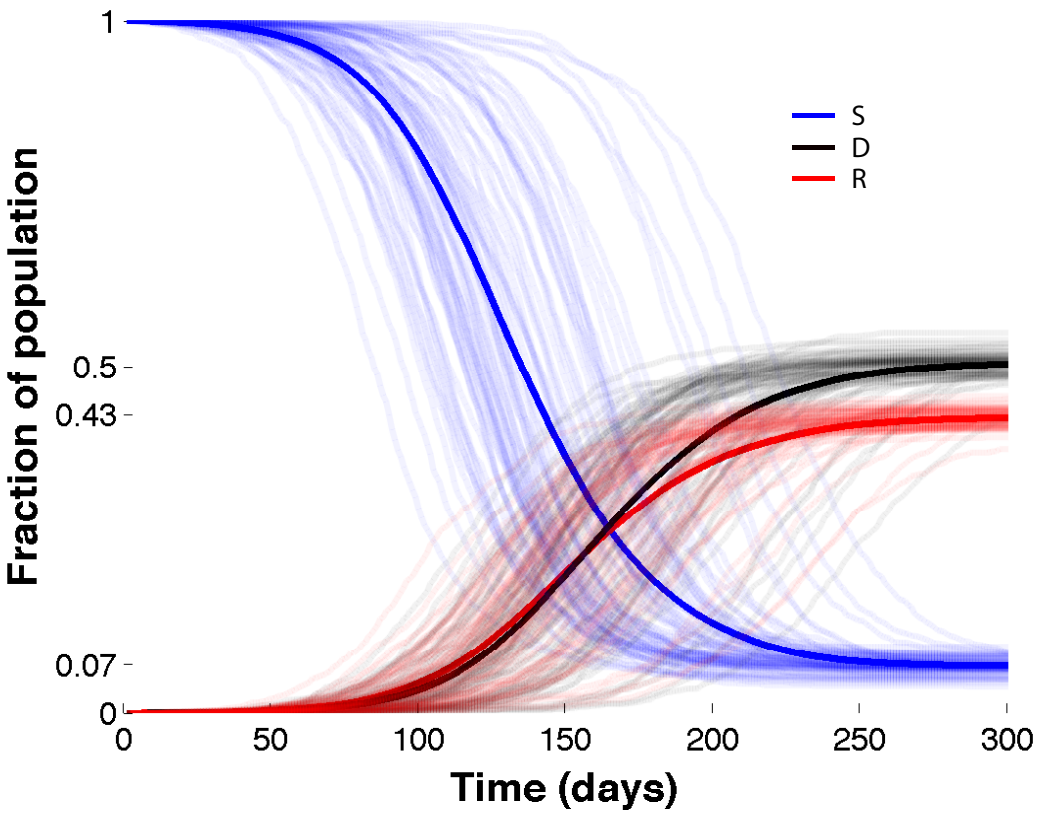


Effects of Ebola outbreak

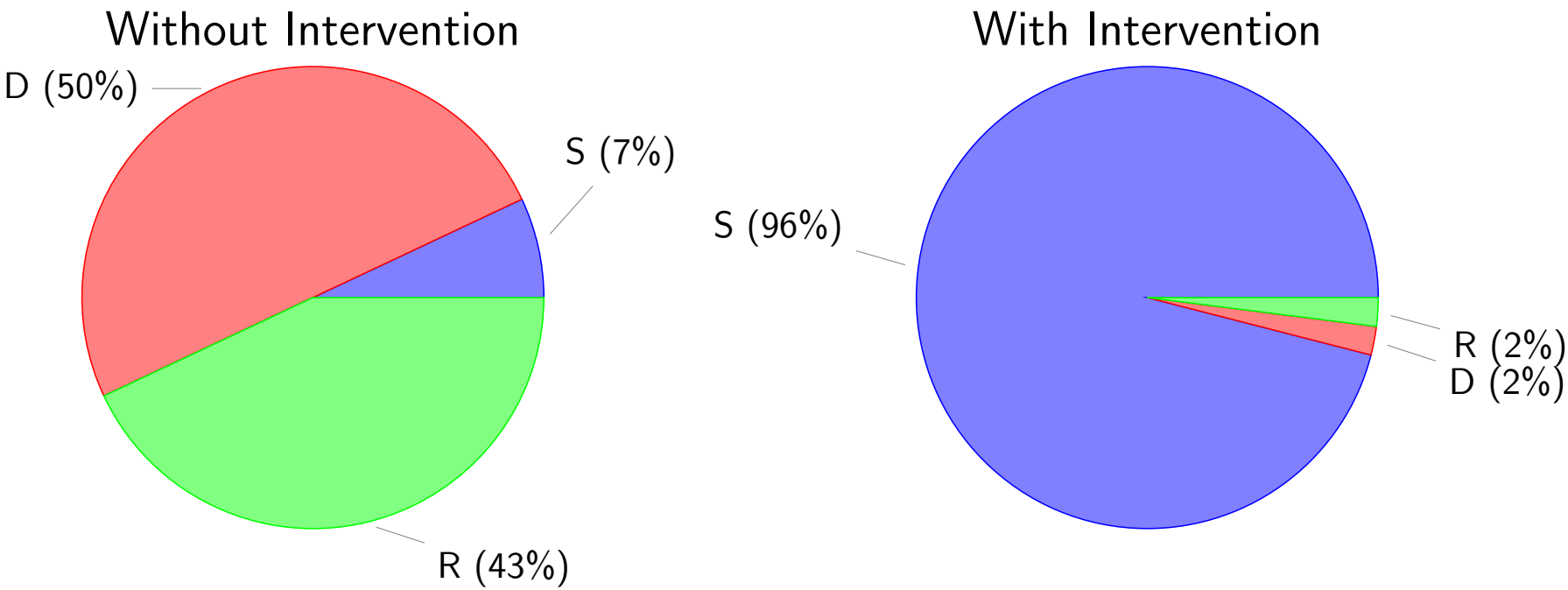




Trajectories of S, D and R

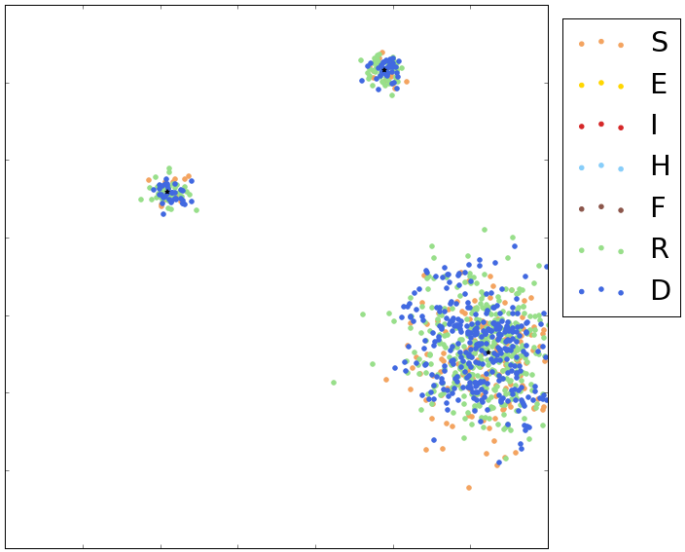


Results of Intervention

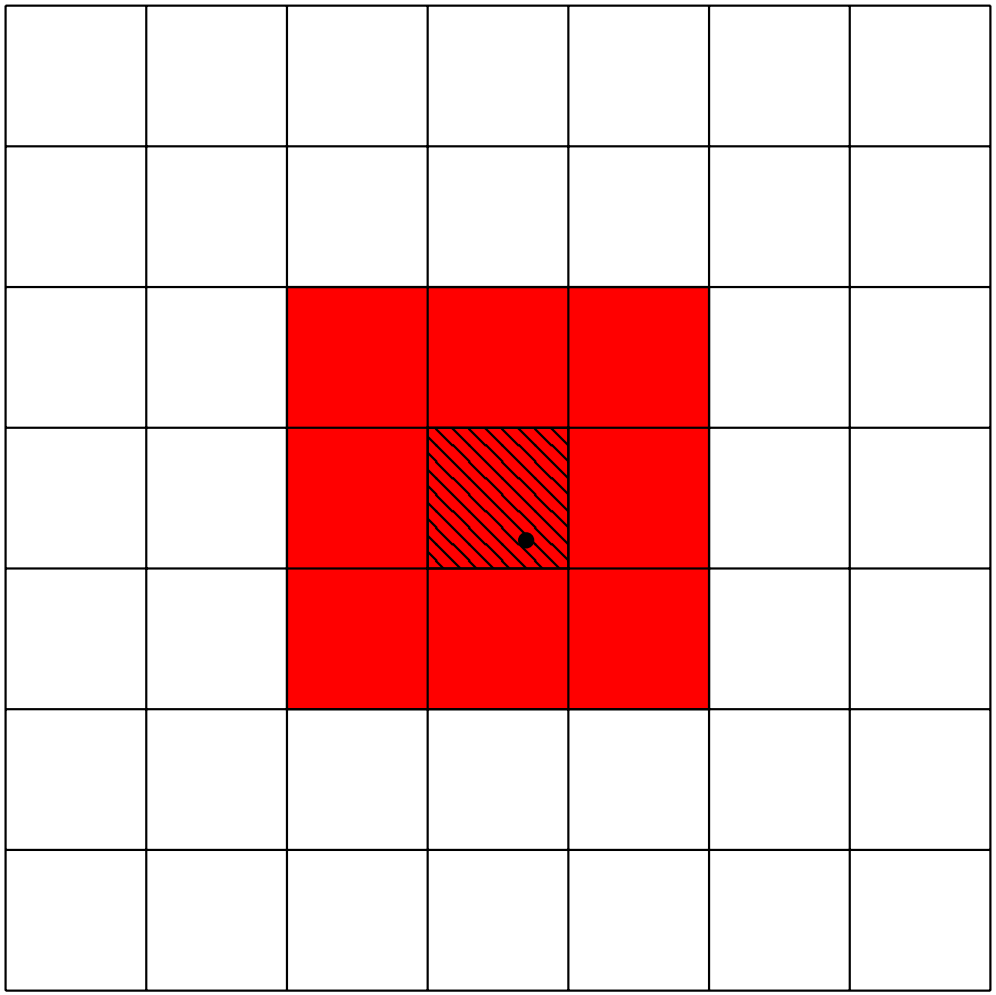


Spatial Agent-Based Model: Overview

- Importance of incorporating the spatial information
  - Distinct contact rates within households, communities and funerals
  - Different travel patterns for cities and villages
- Initialization: an example
- Regions of infection spread
- Available travel routes
- Differences:
  - Hospitalized people are quarantined
  - Transition time between states



Regions of Infection Spread



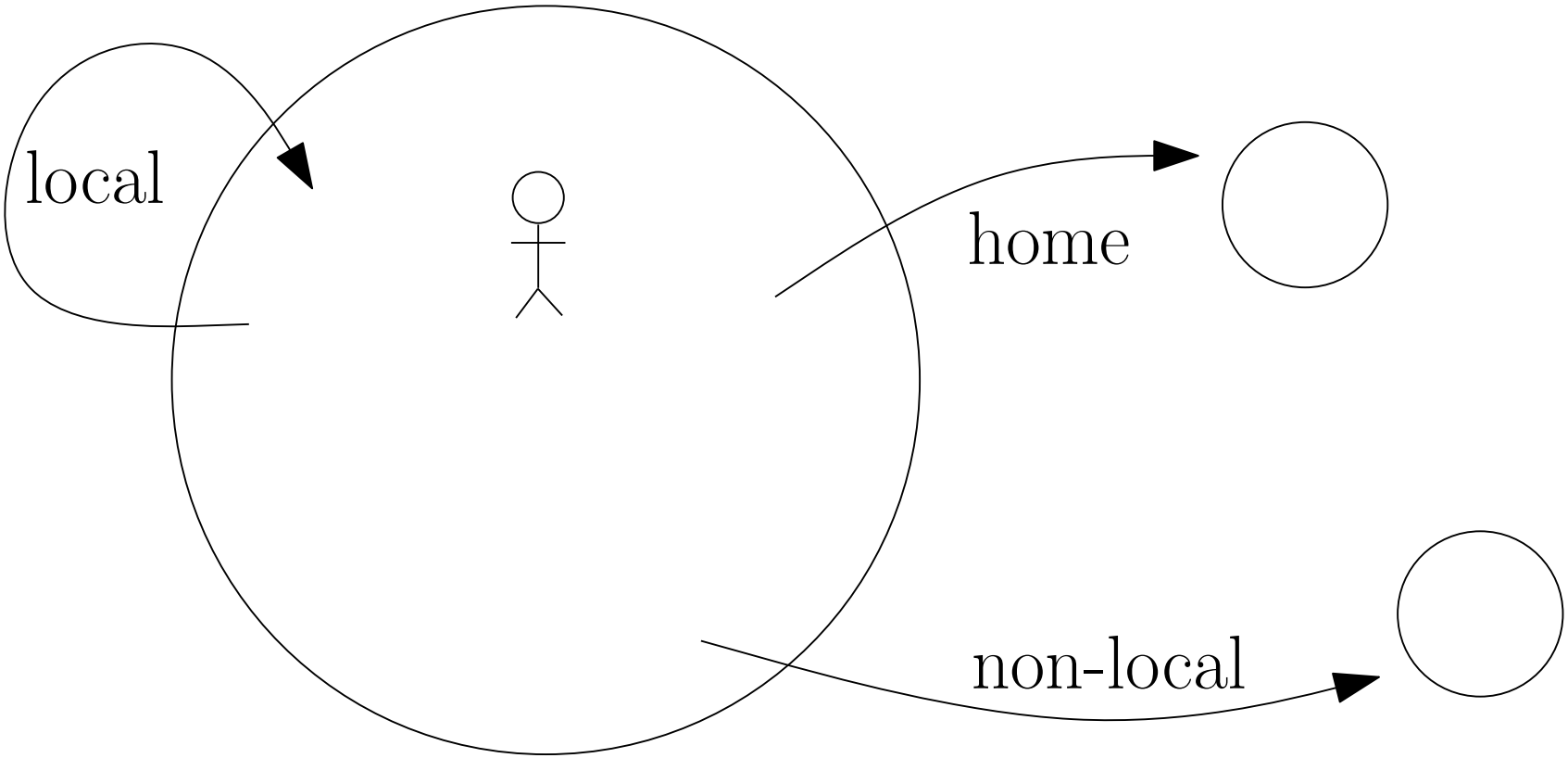
funeralized

infected

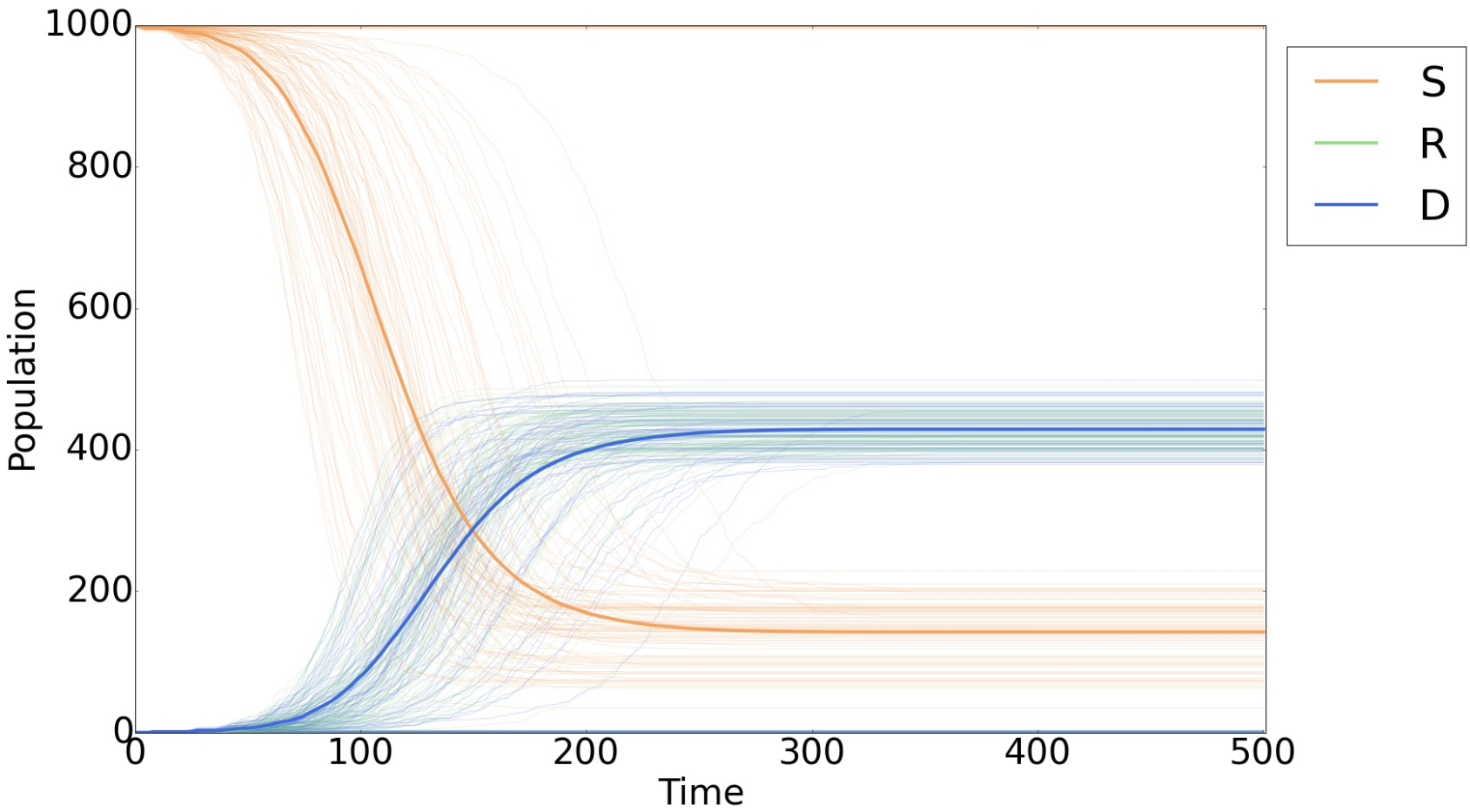
individual

Available Travel Routes

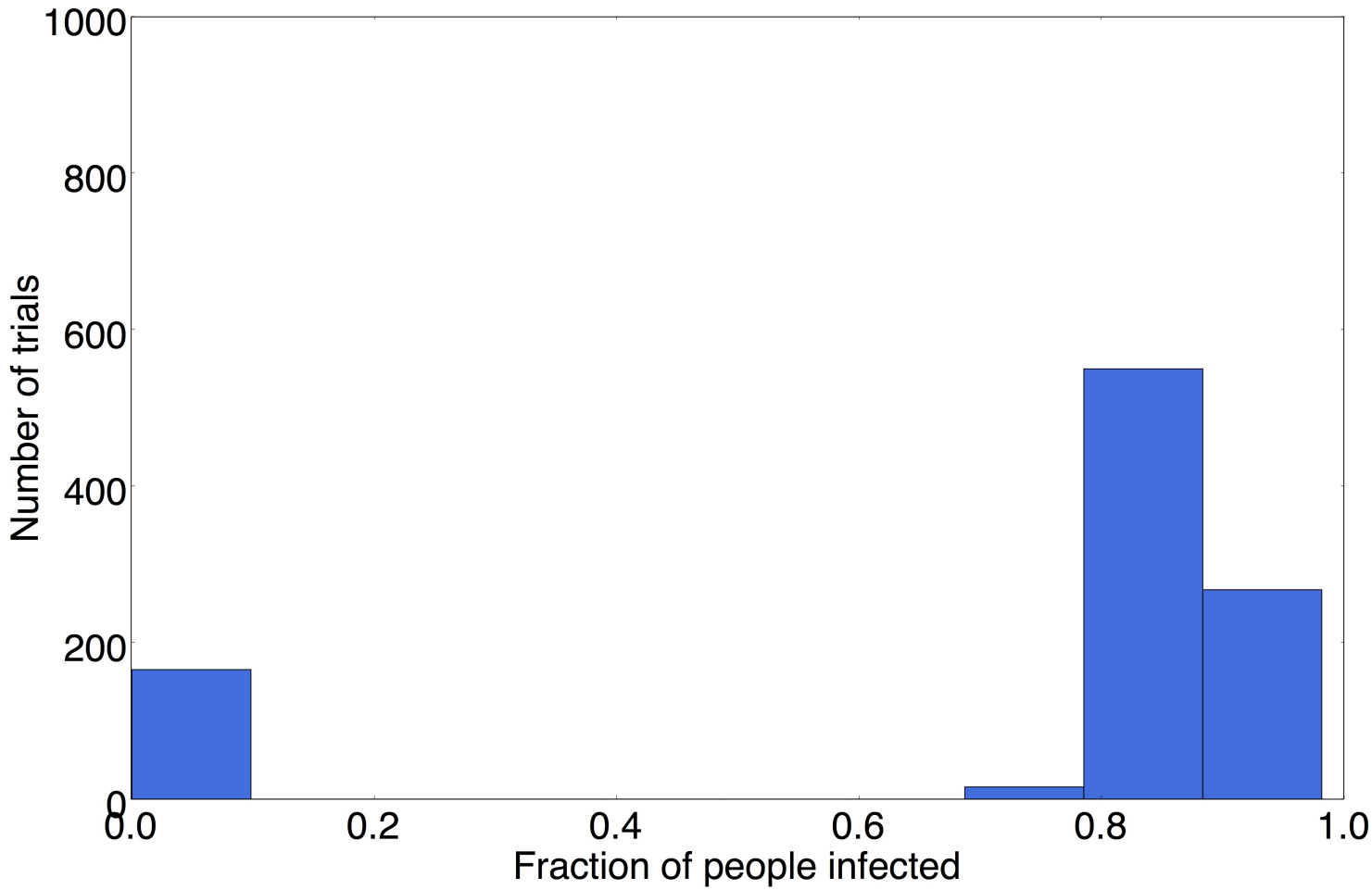
if he travels...



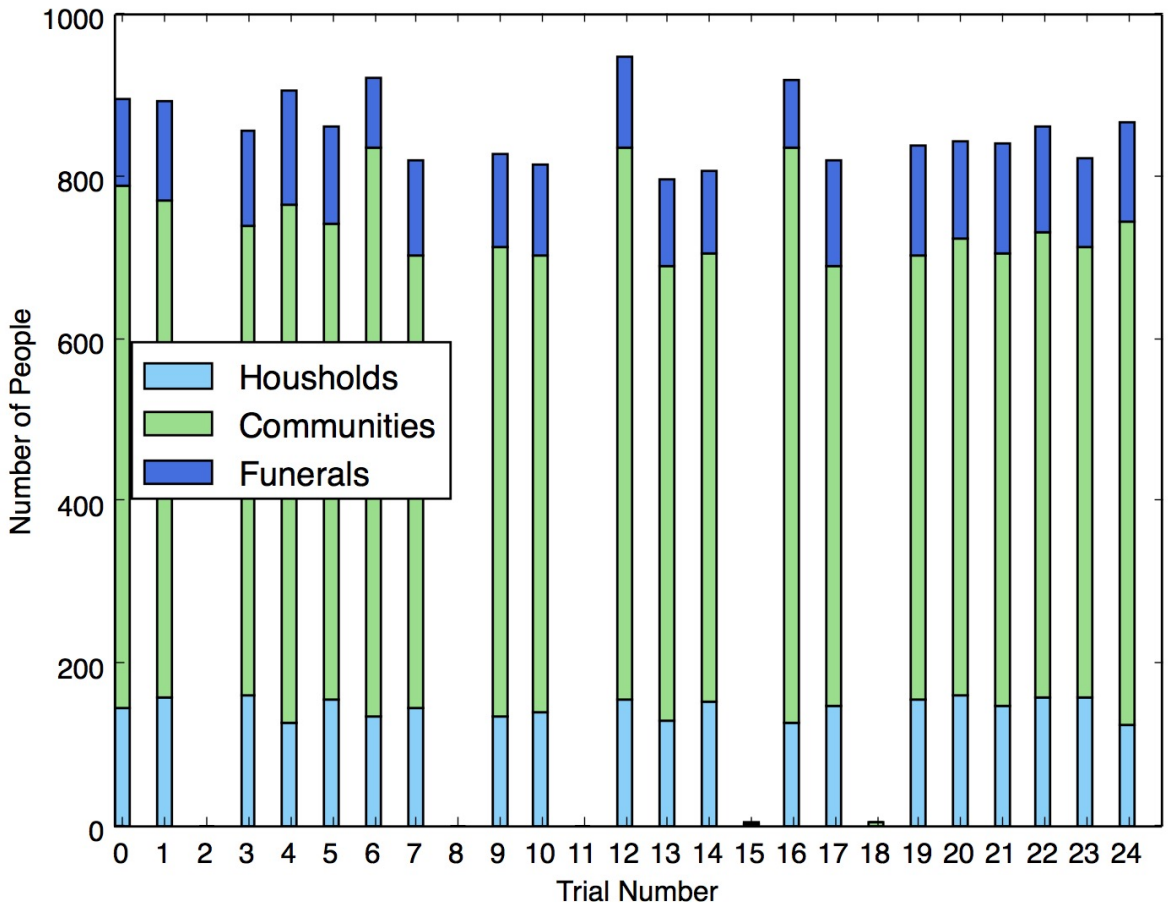
Trajectories of S, R, D: 100 simulations



Probability of an Outbreak



Methods of Infection



Summary

- Deterministic model matches real data of Liberia
- Deterministic and probabilistic approaches give similar results
- Incorporating spatial information allows for less severe outbreaks
- Intervention has a big effect:
  - Over 90% contract the disease
  - About 50% dies due to disease
  - Intervention causes these figures to decrease significantly