We use Blue Waters to analyze risk of infection spread due to movement of passengers during air travel.
OUTLINE

• Introduction
• Modeling Passenger Movement
• Performance Optimizations
• Modeling Infection Spread
• Conclusions
INTRODUCTION
MOTIVATION

- Air travel is an important factor in infection spread
- There had been calls to ban flights from Ebola infected areas
  - This can have large human and economic impact
  - Fine-tuned policy prescriptions can be as effective
    - Reassures the public that action is being taken
    - Avoids negative human and economic impacts
PROJECT GOALS

• Analyze the impact of different policies on spread of diseases through air-travel
  • Example: Different boarding procedures

• Why it matters
  • Provides insight to decision makers on policy or procedural choices that can reduce risk of infection spread without disrupting air travel
CURRENT MODELS

• Typically focused on scientific understanding, rather than policy analysis
  • Predictions are difficulty due to inherent uncertainties

• Usually at an aggregate level, which makes evaluation of impact of new policies difficult

• Example: Inaccurate predictions on Ebola
  • Predicted millions infected by early 2015 and hundreds of thousands dead
OUR MODELING APPROACH

• Use fine-scale model of human movement in planes to determine response to policies

• Parameterize sources of uncertainty
  • A parameter sweep over this space generates feasible scenarios

• Key challenge
  • Large parameter space leads to high computational cost

• Why Blue Waters
  • It provides the computational power to produce solutions in a national emergency
Air-travel policies to reduce infection spread

- Airport layout
- On-ground procedures
- Boarding and deplaning
- In-flight procedures

Human movement in flights and airports

Validation and model refinement

Phylogeography global model

Susceptible – infective stochastic model

# infected per airport

Probability of Infection

Probability of Infection vs. Days post onset of symptoms

Number of contacts
QUESTIONS ANSWERED

• Can simple policies reduce infection risk without causing major disruptions?
  • Change plane type
  • Change boarding and disembarkation procedures
  • Change airport layout and procedures

• Broader impacts

The way airlines board planes affects how easily bugs are spread among passengers

The way we board planes could actually be spreading diseases
MODELING PASSENGER MOVEMENT
SELF PROPELLED ENTITY DYNAMICS MODEL

- Social dynamics is motivated by Molecular Dynamics, and treats entities as particles
  - Individuals experience self propulsion that induces them to move toward their desired goal
  - They experience repulsive forces from other persons and surfaces
- We add human behavioral characteristics to social dynamics
- Parameterize the sources of uncertainty and carry out a parameter sweep to identify their robustness under a variety of possible scenarios
BOARDING STRATEGIES

Number of contacts

- Random
- Two Sections
- Three Sections
- Column Wise

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PERFORMANCE OPTIMIZATIONS
CONVENTIONAL OPTIMIZATIONS

- Blue Waters team helped reduce parallel IO bottleneck, leading to a factor two performance gain.

Parallel parameter sweep with ~68K combinations
**TYPES OF PARAMETER SWEEP**

<table>
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<tr>
<th>Type</th>
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<th>Convergence check</th>
<th>Factor 2(^d) gap between convergence checks</th>
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SPED model in this part of our study uses 5 parameters
- 5-D Lattice and 5-D Scrambled Halton Low Discrepancy Sequence (LDS) parameter sweeps used for infection spread analysis
CONVERGENCE FOR LATTICE SWEEP

Histogram for subgrid of size $5^5$

Histogram for subgrid of size $9^5$

Histogram for $17^5$ grid
CONVERGENCE FOR LDS SWEEP

Histogram for subgrid of size $5^5$

Histogram for subgrid of size $9^5$

Histogram for $17^5$ grid

Histogram for $32768$ ($2^{15}$) points

Histogram for $262144$ ($2^{18}$) points

Histogram for $17^5$ points
LOAD IMBALANCE IN LATTICE VS. LDS SWEEPS

Load imbalance across processes is defined as

\[ \frac{|\text{MaximumLoad} - \text{AverageLoad}|}{\text{AverageLoad}} \]

0 when load is perfectly balanced

- Lattice sweep is well balanced
- LDS has a poor balance with 1000 and 1024 processes
- LDS performs better than Lattice for 1003 processes
  - 1003 is divisible by 17 (parameter values)

Load imbalance for Lattice and LDS sweep of the entire data set 17^5 (without convergence checks) using cyclic distribution

1000 and 1024 are products of primes used in the LDS
LOAD BALANCING LDS

With convergence checks

Cyclic Distribution

- Cyclic: Load is not well balanced in the initial stages even with 1003 processes
- Block: Does not work well for small number of samples
- Dynamic: Master-worker based dynamic load balancing works best overall but is not scalable
MODELING INFECTION SPREAD
Since $R_0$ for Ebola is around 2, that means a typical infective individual will produce on average two new secondary cases thus, replacing him or herself, producing additional case, and eventually leading to large outbreak in the population.

- Probability of infection transmission modeled as a function of distance to infected person, exposure time, and infectivity
IMPACT OF BOARDING STRATEGIES

- Boarding Boeing 757-200
  - One passenger at the first day of infection
  - Infection probability = 0.06
  - Contact radius = 1.2 m
- Strategies that prevent clustering in the cabin reduce infection likelihood
LONG VS SHORT CONTACT RADIUS

- Infection contact radius
  - Ebola: 1.2 m
  - SARS: 2.1 m
- Model includes airport gates
CONCLUSIONS
COMPUTATIONAL OPTIMIZATIONS

- Parameter sweep with LDS is more efficient than with lattice
  - Better coverage of parameter sweep and faster convergence
  - It made feasible analysis that was not feasible earlier

- Load imbalance is a potential problem with LDS and is related to its number-theoretic properties
  - Identified techniques, that can lead to good load balancing under different applications scenarios

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SUMMARY OF APPLICATION RESULTS

- Identified procedures that can lead to decrease in contacts
  - Random boarding leads to lower risk of infection spread
  - Boarding has a higher impact than deplaning
  - Smaller planes are better than larger ones

- Use of better procedures and smaller planes could have reduced Ebola risk by 87% without travel restrictions

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FUTURE DIRECTIONS

• Extend this approach
  • Assimilate data into simulation model
  • Use domain adaptation to model related situations
  • Consider the consequences of air travel

Zika importation risk prediction
• Identify human mobility from social media data and link with metapopulation epidemic model
• Fine-grained results predict locations within Miami with granularity of the order of a square mile

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