Modeling Ebola Outbreak in Africa

Dr. Kevin Shinpaugh

On Behalf of the VBI Ebola Response Team
The Virginia Bioinformatics Institute addresses critical challenges related to the integrative life sciences, especially those posed to human health, habitat and wellbeing. VBI research programs emphasize information biology, a unifying informatics-driven approach for studying biological systems from molecules and simple organisms to the microbiome and policy considerations in massive human-created networks.
Shadowfax

A heterogeneous computing environment for data intensive computations

- ~3,300 Cores, > 14TB RAM (Dell/Intel)
- ~27,000 GPU cores (nVidia)
- 8 FPGA hybrid core systems (Convey)
- 2 Large memory systems
- > 1 PB GPFS storage
- Database and portals at edge
Constructing synthetic social contact networks

- **Disaggregated Population Generator**
- **Disaggregated Synthetic Population**
- **Activity, Locations, & Route Assignment**
- **Synthetic Social Contact Network**

**Population Information**
- **Age**: 26, 26, 7, 12
- **Income Status**: Yes, Yes, 50, 50
- **Other**: Yes, Student

**Social Networks**

**Census Population**

**Map of Washington, DC**

**Home**

**Work**

**Lunch**

**Daycare**

**Social Networks**

**Synthetic Population**

**Location Assignment**

**Edges**
- **Activity Types**: Shop, Work, School
- **Location Information**: Location, Land Use, Business Type

**Edge Labels**
- **Activity Types**: Shop, Work, School
- **Location Information**: Location, Land Use, Business Type
Cyber-Infrastructure for Epidemics

Data Grid
- Local clusters and databases, Amazon cloud

Indemics
- Interactive modeling environment.
- Very general class of diffusion, interventions.
- Relational database and query language to specify interventions.

EpiSimdemics
- Agent Based Model
- Dynamic Interventions
- Dynamic Social Network
- Slow Compared to EpiFast

EpiFast
- Percolation Based Model
- Static Social Network
- Static Interventions
- Faster than EpiSimdemics

Simifrastructure: Service-Oriented HPC Architecture
- Middleware
- Computation Grid
- Stimulation Grid
- Data Grid

Data Management
- Data Retrieval
- Data Augmentation
- Digital Library
- Data Warehouse
- Data Creator
- Pass to Broker

Generic GUIs provide user interface
- Service Broker
  - Receives Requests from all sources and Organizes them and negotiates with other “Brokers” to fulfill the requests as Efficiently as Possible.

Model Broker
- Compute Broker

Clouds and Grids
- Local Resources
- National Resources

Digital Library
- Pass to Broker
- Data Grid
- Data Broker

Web Services
- Compute Broker
- Model Broker
- Service Broker
- Data Broker
- Data Grid
- Data Warehouse
- Data Creator
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EpiSimdemics Scaling

Model 280 million people on 352k cores for 120 days: 12 seconds

- System: NCSA Blue Waters
- 352k Cray XE6 core modules
- US Population: 280 million
- Simulated time: 120 days
- Walltime: 12 seconds

Projected Global Population time: 6 minutes
October Data

<table>
<thead>
<tr>
<th></th>
<th>Cases</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guinea</td>
<td>1906</td>
<td>997</td>
</tr>
<tr>
<td>Liberia</td>
<td>6248</td>
<td>2705</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>5235</td>
<td>1500</td>
</tr>
<tr>
<td>Total</td>
<td>13,411</td>
<td>5210</td>
</tr>
</tbody>
</table>

- Data from WHO, MoH Liberia, and MoH Sierra Leone, available at https://github.com/cmrivers/ebola
- MoH and WHO have reasonable agreement
Forecast from October

Overall: 1.7

<table>
<thead>
<tr>
<th></th>
<th>8/10 to 8/16</th>
<th>8/17 to 8/23</th>
<th>8/24 to 8/30</th>
<th>8/31 to 9/6</th>
<th>9/8 to 9/13</th>
<th>9/14 to 9/20</th>
<th>9/21 to 9/27</th>
<th>9/28 to 10/4</th>
<th>10/5 to 10/11</th>
<th>10/12 to 10/18</th>
<th>10/19 to 10/25</th>
<th>10/26 to 11/01</th>
<th>11/02 to 11/08</th>
<th>11/09 to 11/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>231</td>
<td>442</td>
<td>559</td>
<td>783</td>
<td>681</td>
<td>959</td>
<td>917</td>
<td>915</td>
<td>904*</td>
<td>917*</td>
<td>1198*</td>
<td>3171</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecast</td>
<td>329</td>
<td>393</td>
<td>469</td>
<td>560</td>
<td>693</td>
<td>830</td>
<td>994</td>
<td>119</td>
<td>1426</td>
<td>1708</td>
<td>2045</td>
<td>2447</td>
<td>2929</td>
<td>3505</td>
</tr>
</tbody>
</table>

* Liberian reporting shows anomalies, may be over-capacity
## Countries with Widespread Transmission

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Cases (Suspected, Probable, and Confirmed)</th>
<th>Laboratory-Confirmed Cases</th>
<th>Total Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guinea</td>
<td>3429</td>
<td>3011</td>
<td>2263</td>
</tr>
<tr>
<td>Liberia</td>
<td>9602</td>
<td>3151</td>
<td>4301</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>11841</td>
<td>8520</td>
<td>3747</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24872</strong></td>
<td><strong>14682</strong></td>
<td><strong>10311</strong></td>
</tr>
</tbody>
</table>

Sierra Leone - Prevalence

Number of people needing care (SL)

<table>
<thead>
<tr>
<th>Date</th>
<th>People in H + I</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/2</td>
<td>112</td>
</tr>
<tr>
<td>2/9</td>
<td>92</td>
</tr>
<tr>
<td>2/16</td>
<td>76</td>
</tr>
<tr>
<td>2/23</td>
<td>63</td>
</tr>
<tr>
<td>3/02</td>
<td>51</td>
</tr>
<tr>
<td>3/09</td>
<td>42</td>
</tr>
</tbody>
</table>
Stages of Response

• **Investigation**: How bad is this going to get? Could it be bad here in the US? What long-term planning can we do?

• **Recognition**: Can vaccine help now? What else can we do?

• **Engagement**: Where should we direct the resources? How can we prepare for further spread?
Preparing the Agent-based Model

https://www.youtube.com/watch?v=eWm2wFJVduw
Planning a Larger Response

- **Question**: How many treatment centers needed, can they make a difference?
- **Response**: First couple months of efforts in Monrovia alone, need more than just beds.
Where to place new ETUs

MapOptimizer versus Location Allocation based on Ebola Burden (12 new ETUs)

<table>
<thead>
<tr>
<th>ETUs</th>
<th>Cases</th>
<th>Long</th>
<th>Lat</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Monrovia</td>
<td>1,442</td>
<td>-10.7698</td>
<td>6.2867</td>
</tr>
<tr>
<td>Barwiwen</td>
<td>79</td>
<td>-9.6478</td>
<td>8.1533</td>
</tr>
<tr>
<td>Big Gbarta</td>
<td>218</td>
<td>-9.2951</td>
<td>6.7108</td>
</tr>
<tr>
<td>Boni</td>
<td>1</td>
<td>-10.8207</td>
<td>6.8663</td>
</tr>
<tr>
<td>Bong Mines</td>
<td>152</td>
<td>-10.3568</td>
<td>6.8073</td>
</tr>
<tr>
<td>Buchanan</td>
<td>187</td>
<td>-10.0442</td>
<td>5.8834</td>
</tr>
<tr>
<td>Fenuloti</td>
<td>103</td>
<td>-9.6912</td>
<td>6.6790</td>
</tr>
<tr>
<td>Foya</td>
<td>108</td>
<td>-10.2130</td>
<td>8.3632</td>
</tr>
<tr>
<td>Gbami</td>
<td>533</td>
<td>-9.4812</td>
<td>7.0084</td>
</tr>
<tr>
<td>Gbonota</td>
<td>70</td>
<td>-9.7798</td>
<td>7.1134</td>
</tr>
<tr>
<td>Harbel City</td>
<td>368</td>
<td>-10.3430</td>
<td>6.2709</td>
</tr>
<tr>
<td>Jebli</td>
<td>54</td>
<td>-8.4210</td>
<td>7.0482</td>
</tr>
<tr>
<td>Kakata</td>
<td>440</td>
<td>-10.3518</td>
<td>6.5313</td>
</tr>
<tr>
<td>Peter's Town</td>
<td>125</td>
<td>-10.0865</td>
<td>6.6011</td>
</tr>
<tr>
<td>Sacleapea</td>
<td>128</td>
<td>-8.8418</td>
<td>6.9562</td>
</tr>
<tr>
<td>Sanniquellie</td>
<td>117</td>
<td>-8.7069</td>
<td>7.3634</td>
</tr>
<tr>
<td>Sinje</td>
<td>0</td>
<td>-11.1305</td>
<td>6.8129</td>
</tr>
<tr>
<td>Totota</td>
<td>283</td>
<td>-9.9418</td>
<td>6.8106</td>
</tr>
<tr>
<td>Vahun</td>
<td>30</td>
<td>-10.4997</td>
<td>8.0624</td>
</tr>
</tbody>
</table>

Legend
- Facility Already Built
- Location Allocation
- MapOptimizer

Work done at NDSSL - Virginia Tech

Notes:
- Based on County Level ODE Model
- No demand on Sinje
- Minimal Demand on Boni

Sources:
- Pop: LandScan 2013
- Roads: LISSGIS (Etherton)
- Rivers: DIVA-GIS
Incorporate Regional Travel

- **Question**: Where will it be next?

**Response**: Need to calibrate the spatial spread using mobility data (seasonality?)
Current Status

• Moved from Operational Support role
• How can models be improved
• Integration of new data sources
• Design for future outbreak planning
• Hypothetical scenarios – vaccines
Agent-based Current Effort

• Spatial spread calibration
  – Incorporate degraded road network to help guide fitting to current data
  – Guide with more spatially explicit initial infected seeds and interventions
  – Incorporate road degradation for rainy season

• Planned Experiments:
  – Impact of hospitals with geo-spatial disease
    • Study design / implementation under construction
  – Vaccination campaign effectiveness
    • Framework under development
Comparison – 10k doses

6 weeks after start of campaign

3 months after start of campaign
Conclusions

• Ebola in West Africa can be defeated
  – Success in Liberia, promising progress in Sierra Leone and Guinea
• Team Science necessary to respond to the breadth and depth of questions / problems
• Conducting Research while responding to a sensitive event is challenging
Acknowledgements

Many thanks to Bryan Lewis the VBI Ebola Response Team for supporting this *intense* work

VBI: Students, Postdocs, Research Staff, Admin support, IT team, and many others

Collaborators: Kathy Alexander – VT Wildlife, DTRA Reachback and CB staff, Deen Disraelly et al – IDA, DHS – BARDA staff

Special thanks to NDSSL Public Health team
Questions??

Check out VBI’s Ebola resource page:  
http://www.vbi.vt.edu/ebola

Many thanks to all the folks on the VBI Ebola Team for supporting this *intense* work