Complex Adaptive System of Systems (CASoS) Engineering Initiative
http://www.sandia.gov/casos

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Loki-Infect 3

A Portable Networked Agent Model for Designing Community-Level Containment Strategies

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Modeling for Public Health Action: From Epidemiology to Operations
Centers for Disease Control and Prevention
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Previous Work with Loki-Infect

- Loki-Infect versions 1 and 2 have been used in a variety of infectious disease modeling studies:
  - **Glass et al. (2006):** determined the critical importance of children in influenza epidemic propagation. Closing schools and social distancing of children reduced infections by 90%.
  - **Davey et al. (2008):** evaluated thresholds for rescinding community mitigation strategies.
  - **Glass & Glass (2008):** surveyed children and teenagers found teens had most contacts that could serve as influenza transmission ‘backbone’.
  - **Davey & Glass (2008):** a systematic evaluation of feasible mitigation strategies at wide range of pandemic severities and found critical enablers of success—rapid, stringent, regional implementation with high compliance.
  - **Perlroth et al. (2009):** evaluated cost-effectiveness of mitigation strategies, finding that the addition of school closure to adult and child social distancing and antiviral treatment and prophylaxis is not cost-effective for viral strains with low infectivity (Ro 1.6 and below) and low case fatality rates (1% and below).

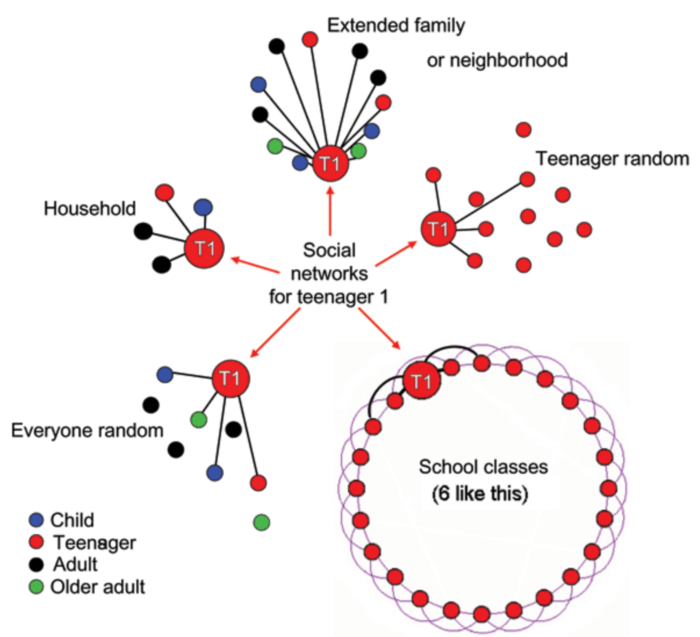
Objectives for Loki-Infect 3

- Loki-Infect 3 is a **desktop application** intended for use by **community-level** decision makers.
- It allows rapid construction of small-scale studies of emerging or hypothetical infectious diseases in their communities and evaluation of the potential effectiveness of various containment strategies.
- It was designed with an emphasis on modularity, portability, and ease of use.
- Our goal is to make this program freely available to community workers across the world.

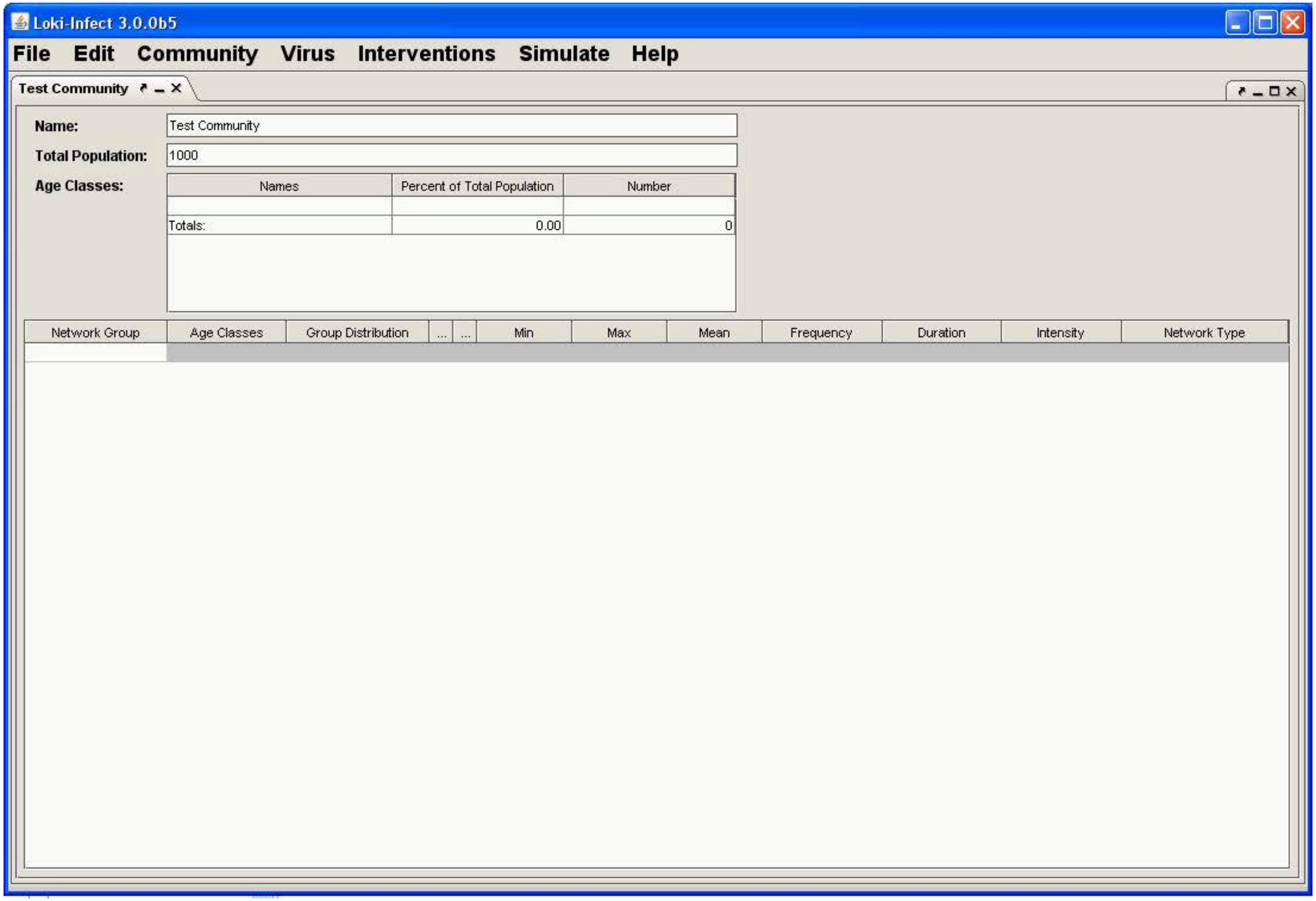
Loki-Infect Graphical User Interface allows users to easily create a propagation network

Representation of a Community

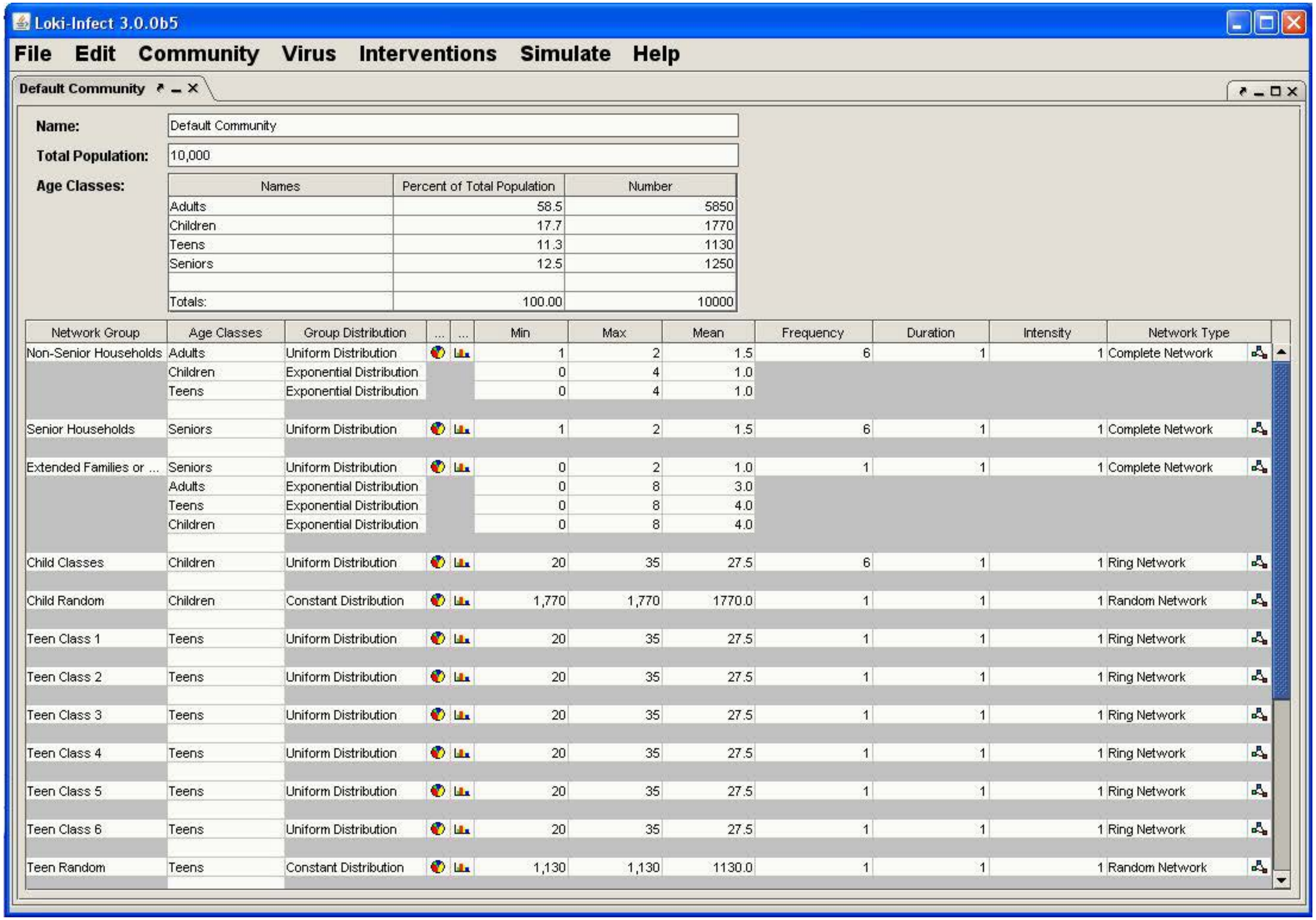
- A community is described by a set of **layers**, such as a family layer, a friend layer, or a classroom layer.
- Each layer contains a number of **groups**, which represent, e.g., individual families, friendship groups, or classrooms.
- A person is represented by a **node**, which can be a member of multiple different groups.



Users can begin with a blank community, building it from scratch to suit their needs...



Or users can begin with a predefined community that reflects basic contact networks for a model 10000-member community



Name: Default Community

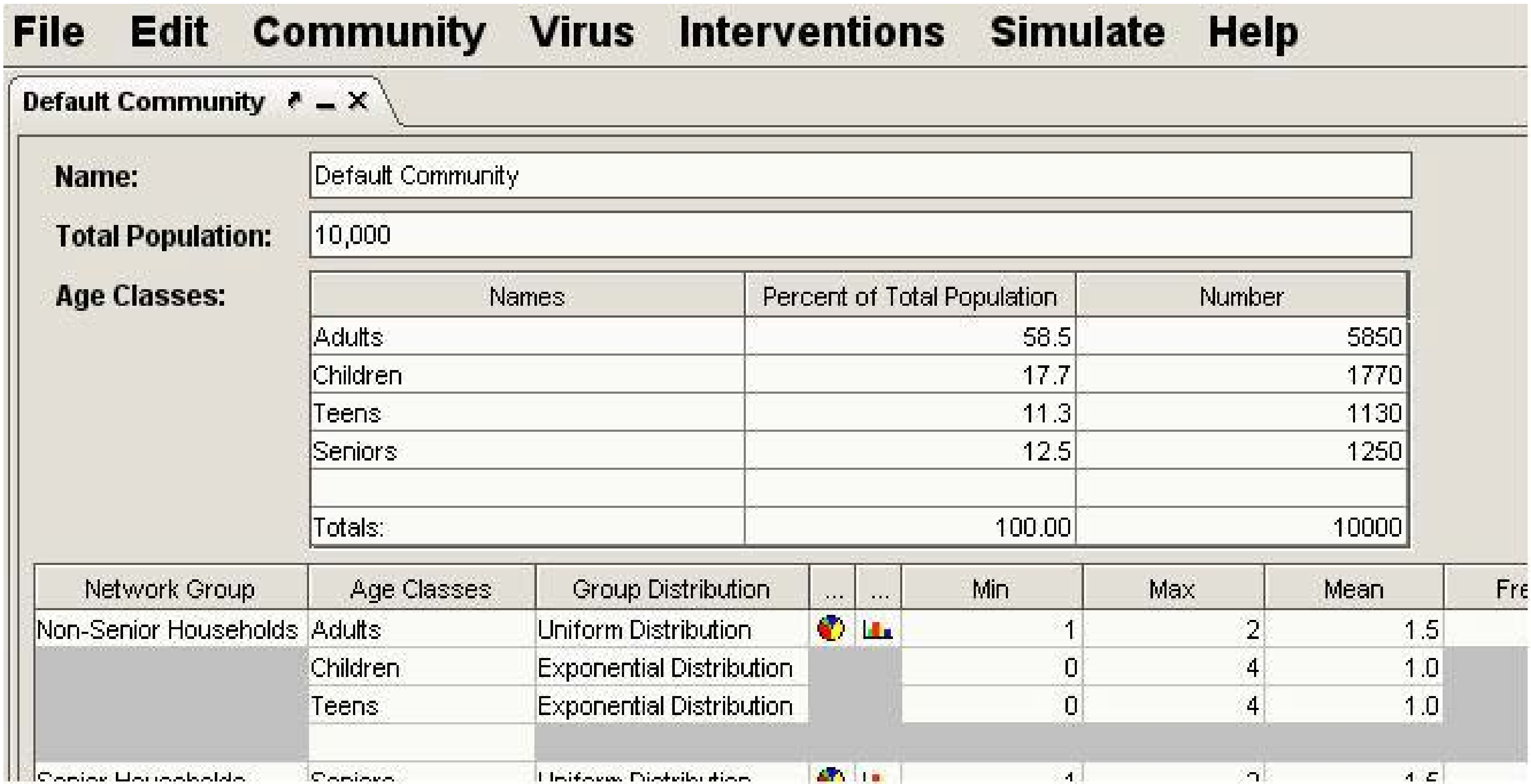
Total Population: 10,000

Age Classes:

Names	Percent of Total Population	Number
Adults	58.5	5850
Children	17.7	1770
Teens	11.3	1130
Seniors	12.5	1250
Totals:	100.00	10000

Network Group	Age Classes	Group Distribution	...	...	Min	Max	Mean	Frequency	Duration	Intensity	Network Type
Non-Senior Households	Adults	Uniform Distribution			1	2	1.5	6	1	1	Complete Network
	Children	Exponential Distribution			0	4	1.0				
	Teens	Exponential Distribution			0	4	1.0				
Senior Households	Seniors	Uniform Distribution			1	2	1.5	6	1	1	Complete Network
Extended Families or ...	Seniors	Uniform Distribution			0	2	1.0	1	1	1	Complete Network
	Adults	Exponential Distribution			0	8	3.0				
	Teens	Exponential Distribution			0	8	4.0				
	Children	Exponential Distribution			0	8	4.0				
Child Classes	Children	Uniform Distribution			20	35	27.5	6	1	1	Ring Network
Child Random	Children	Constant Distribution			1,770	1,770	1770.0	1	1	1	Random Network
Teen Class 1	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Class 2	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Class 3	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Class 4	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Class 5	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Class 6	Teens	Uniform Distribution			20	35	27.5	1	1	1	Ring Network
Teen Random	Teens	Constant Distribution			1,130	1,130	1130.0	1	1	1	Random Network

Individual cells can be edited to update the entire population, or only a portion of it



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	Teens	Exponential Distribution			0	4	1.0	

Members of a layer and how they're distributed in groups in the layer can be configured

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Additional layers over the population can be constructed

Network Group	Age Classes	Group Distribution	...	...	Min	Max	Mean
Non-Senior Households	Adults	Uniform Distribution			1	2	1.5
	Children	Exponential Distribution			0	4	1.0
	Teens	Exponential Distribution			0	4	1.0
Senior Households	Seniors	Uniform Distribution			1	2	1.5
Extended Families or ...	Seniors	Uniform Distribution			0	2	1.0
	Adults	Exponential Distribution			0	8	3.0
	Teens	Exponential Distribution			0	8	4.0
	Children	Exponential Distribution			0	8	4.0
Child Classes	Children	Uniform Distribution			20	35	27.5

Graphs of the distributions of groups upon constructing a given layer can be requested by clicking the appropriate icon

Network Group	Age Classes	Group Distribution	...	...	Min	Max	Mean	Frequency	Duration	Intensity	Network Type
Non-Senior Households	Adults	Uniform Distribution			1	2	1.5	6	1	1	Complete Network
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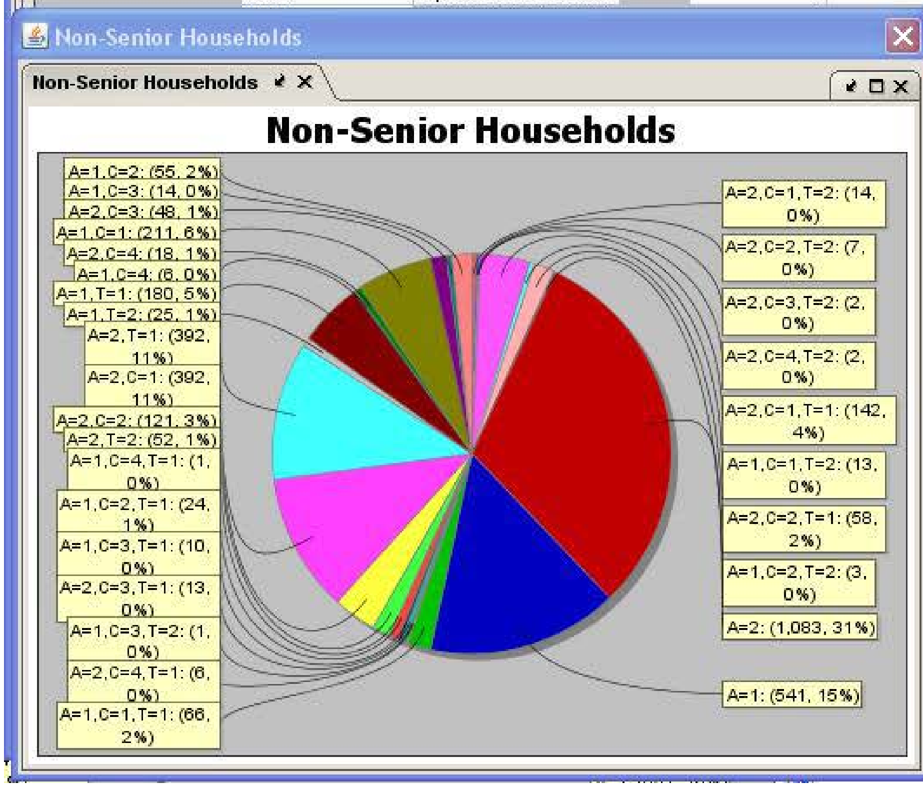
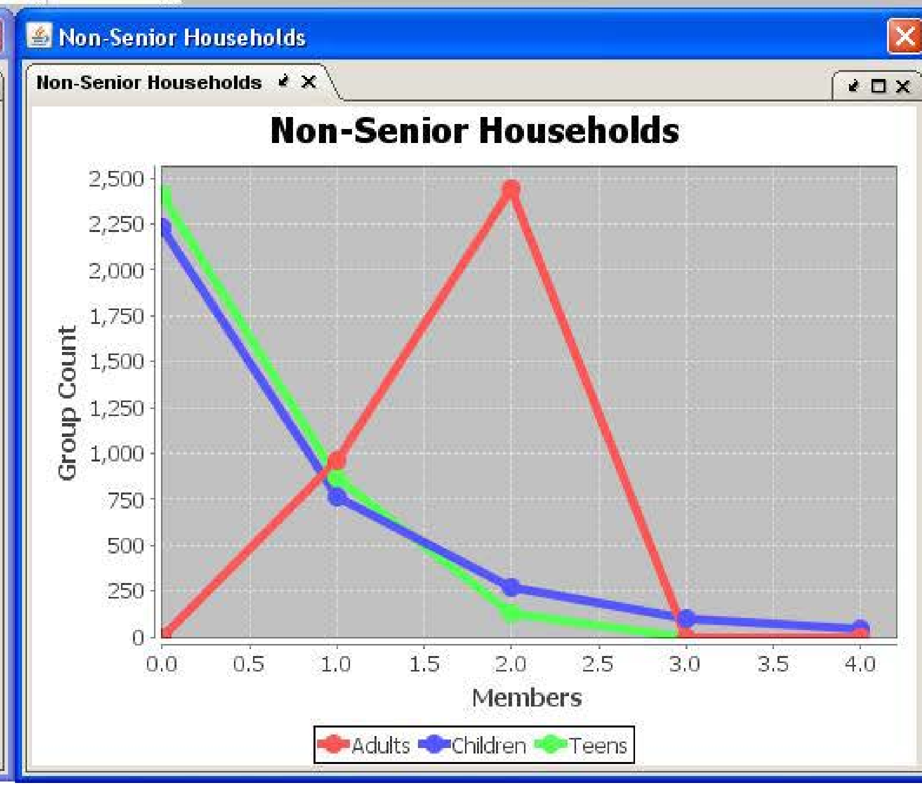
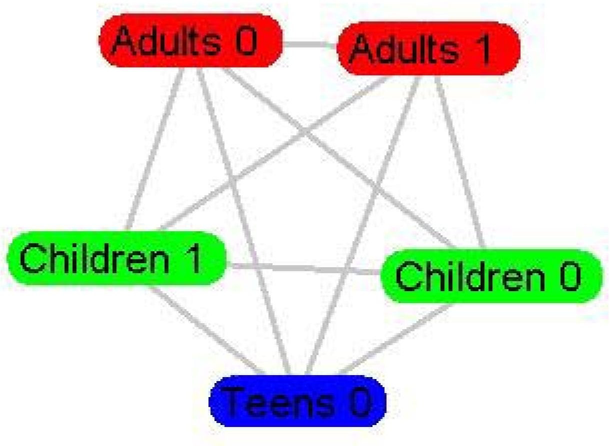




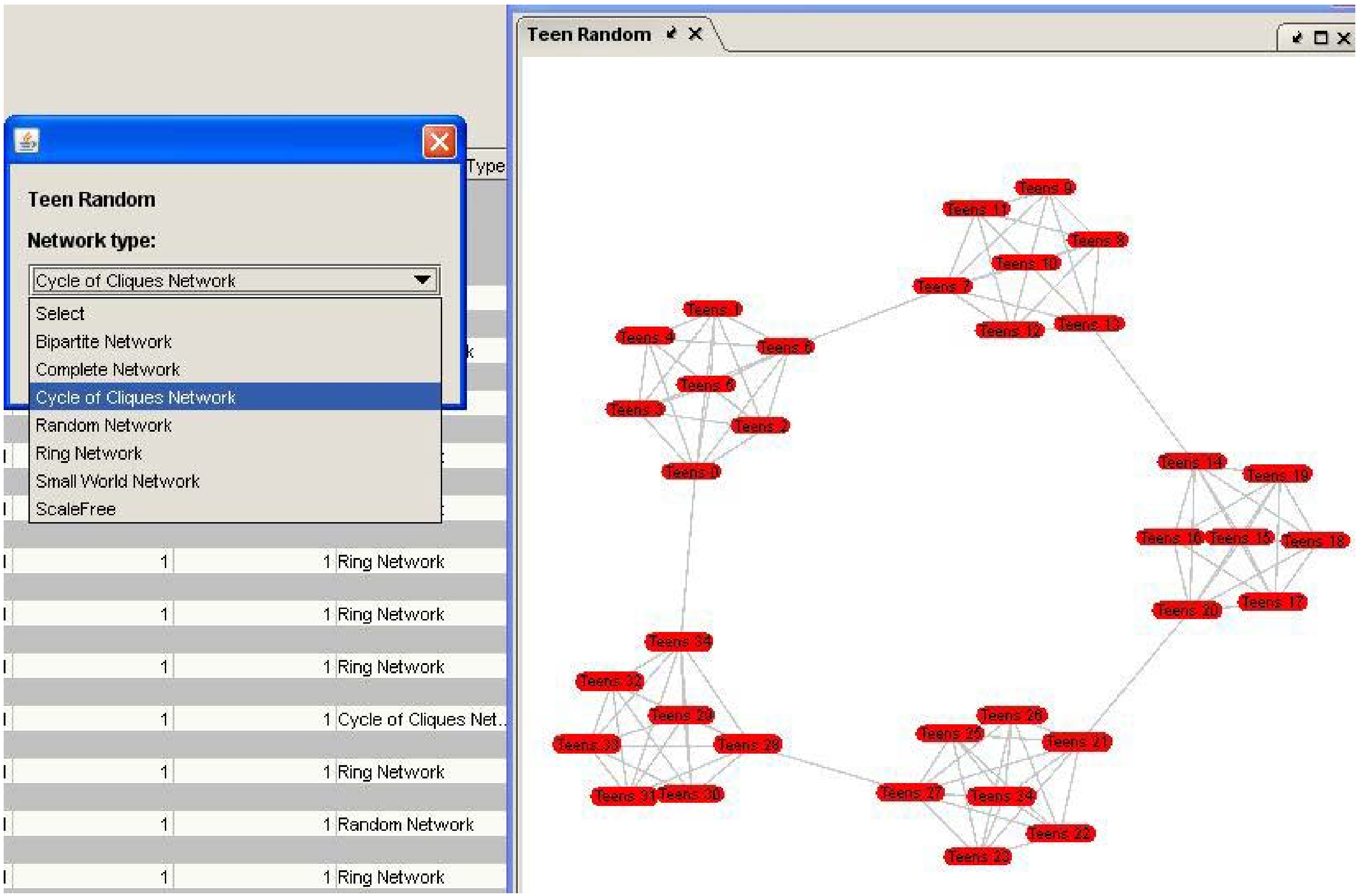
Representation of a Community

- Finally, for each layer in a community, the user provides an idealized network topology (and any parameters for that topology) for each group in the layer.
- Supported topologies include:
  - Scale-Free (Barabási)
  - Random (Erdős–Rényi)
  - Small-World (Strogatz)
  - Ring
  - Bipartite
  - Cycles of Cliques



- The resulting community is a network of networks, where each node is a member of multiple different sub-networks.

Example group topology: idealized cycle of cliques



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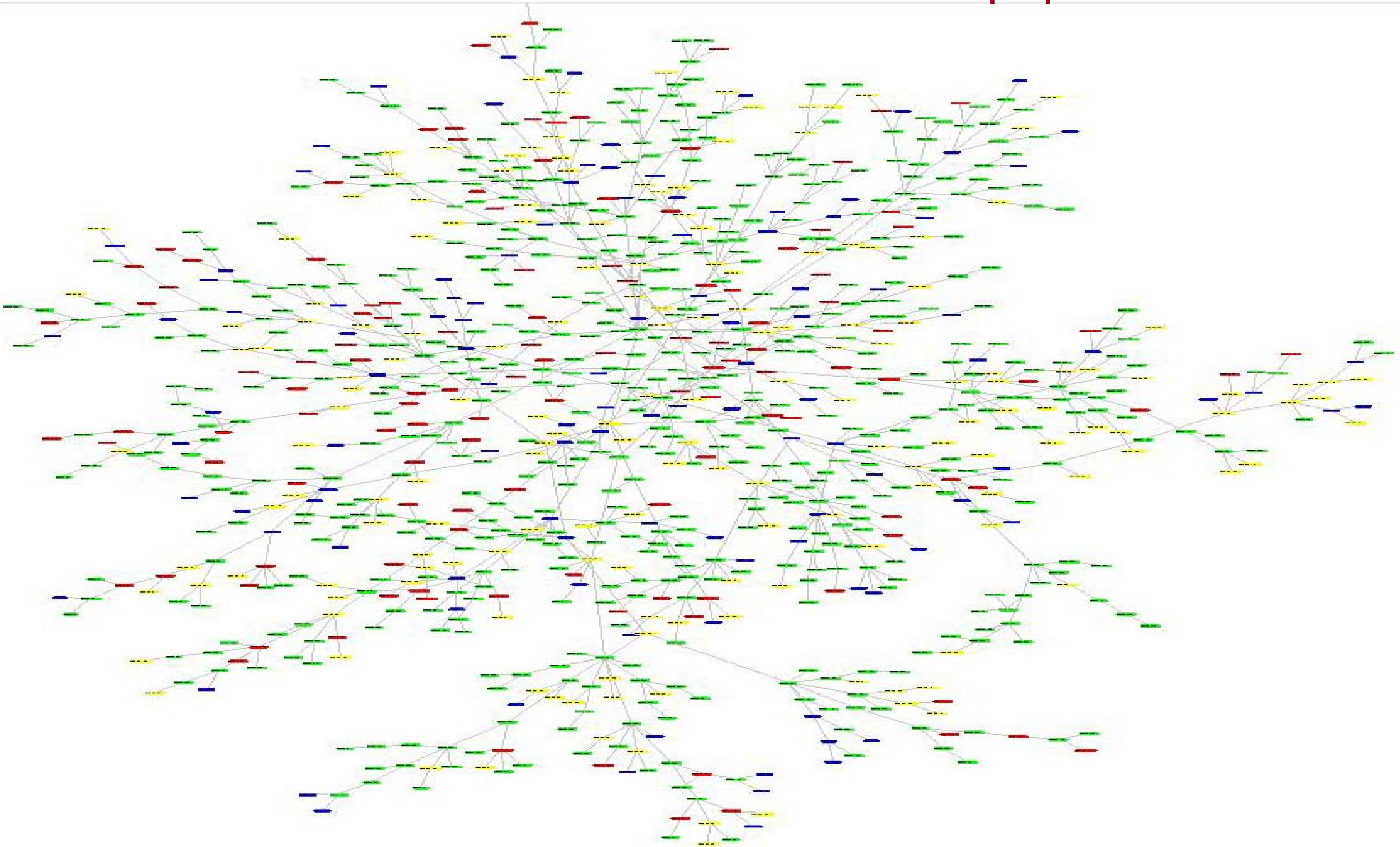
scale-free network over a population of 1000



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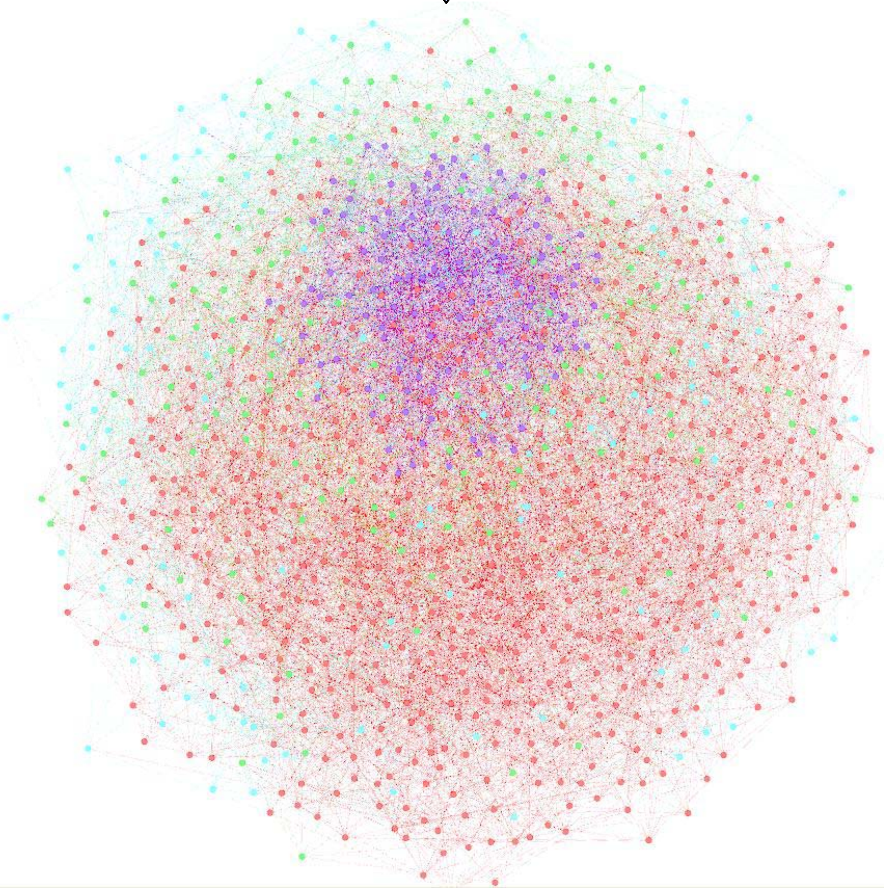
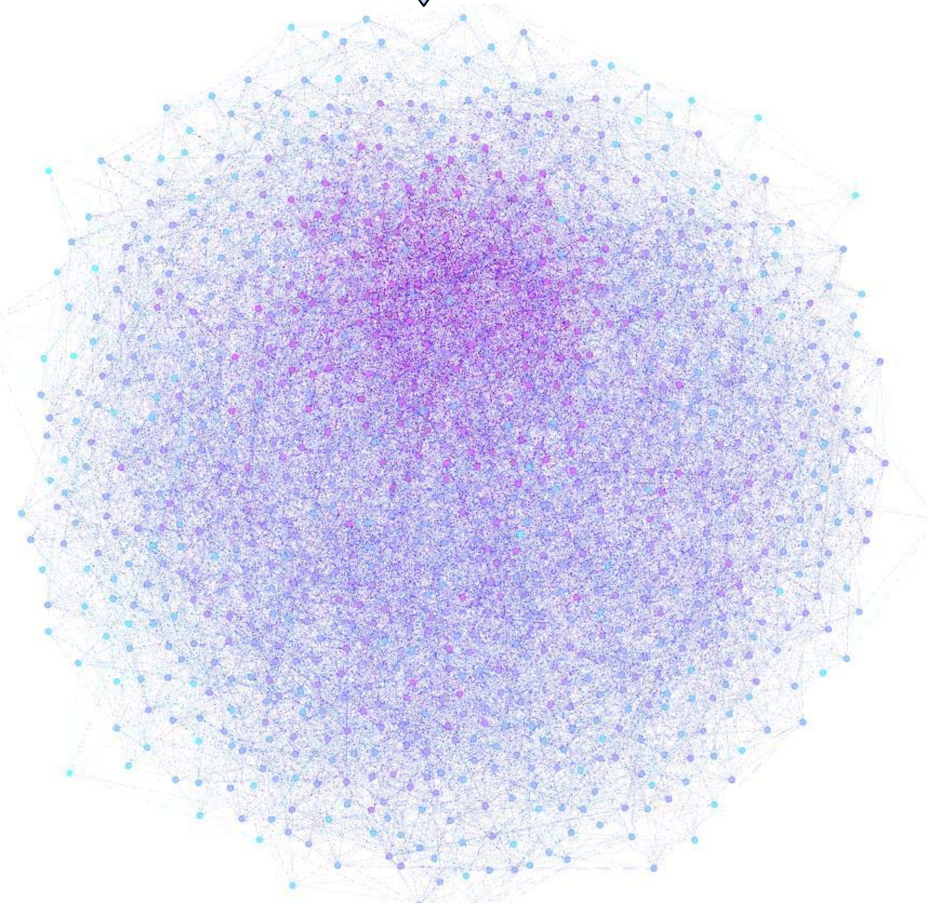
The entire network structure for a community can be exported to the GraphML format

Network colored by age classes



Same network colored by node degree



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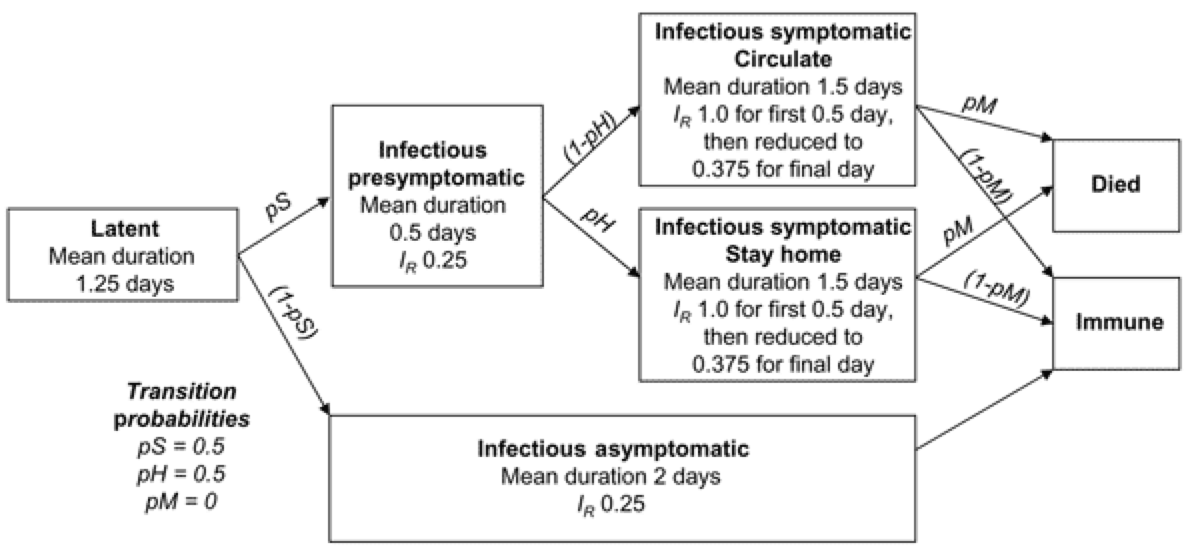
Models of Contagion

- Loki-Infect 3 allows the user to simulate different or multiple contagions on the same social network.
- Currently we have implemented an influenza model developed by Davey et al. between 2006 and 2009 within the context of Loki-Infect 3.
- We are also currently working with Danilo Scepanovic of MIT to implement an alternative manifestation of influenza that is more biologically realistic.
- Loki-Infect 3 is also being adapted to model the spread of opinions and behaviors along social networks.

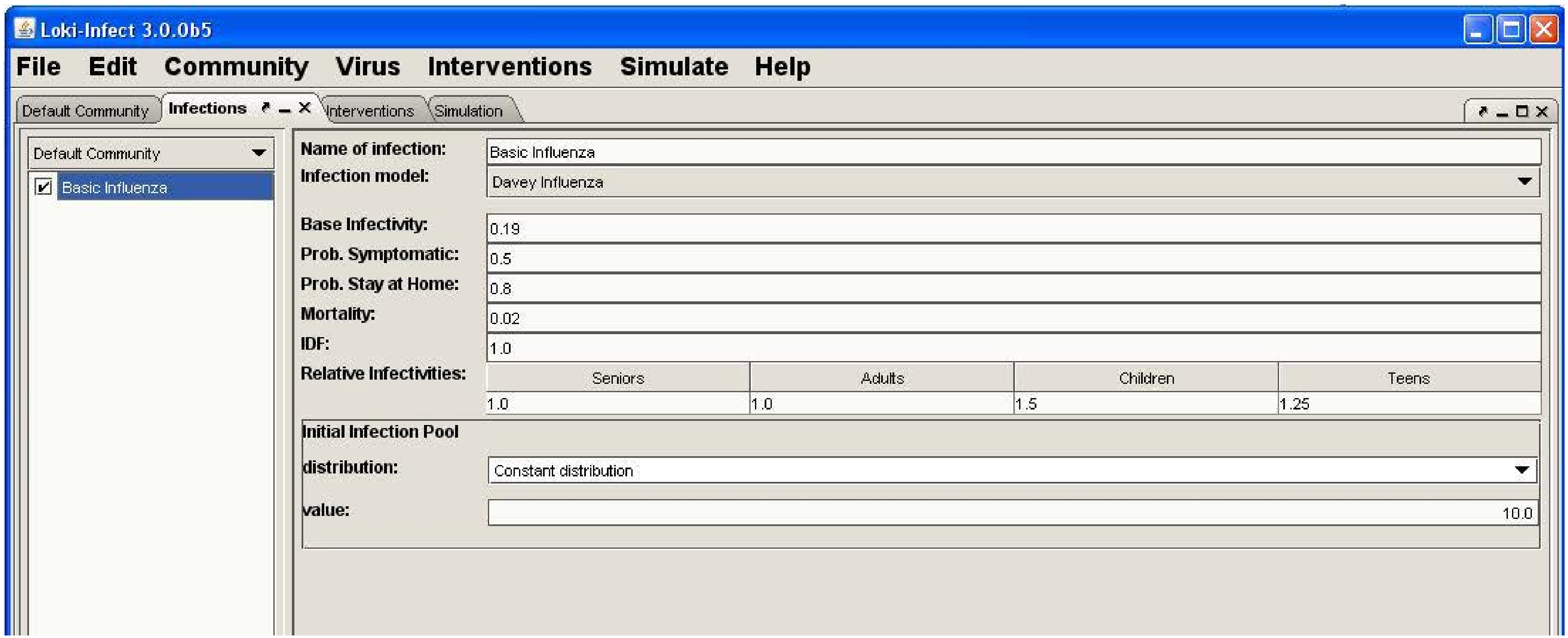
Davey et al. Influenza Manifestation

- In the influenza manifestation by Davey et al., each edge in the social network represents a potential contact between two people with an associated contact **frequency**, **duration**, and **intensity**.
- Individuals progress through a probabilistic state machine, either remaining susceptible, or becoming infectious and later recovering or dying from the infection. The infection spreads through individual contact.



Davey et al. Influenza Manifestation

- This influenza model has a small, yet descriptive, parameter set, which can be configured though the GUI and used to represent a number of influenza manifestations



Infections

Different models for spreading an infection can be selected, and details for that model displayed and editable

Name of infection:	Basic Influenza			
Infection model:	Davey Influenza			
Base Infectivity:	0.19			
Prob. Symptomatic:	0.5			
Prob. Stay at Home:	0.8			
Mortality:	0.02			
IDF:	1.0			
Relative Infectivities:	Seniors	Adults	Children	Teens
	1.0	1.0	1.5	1.25

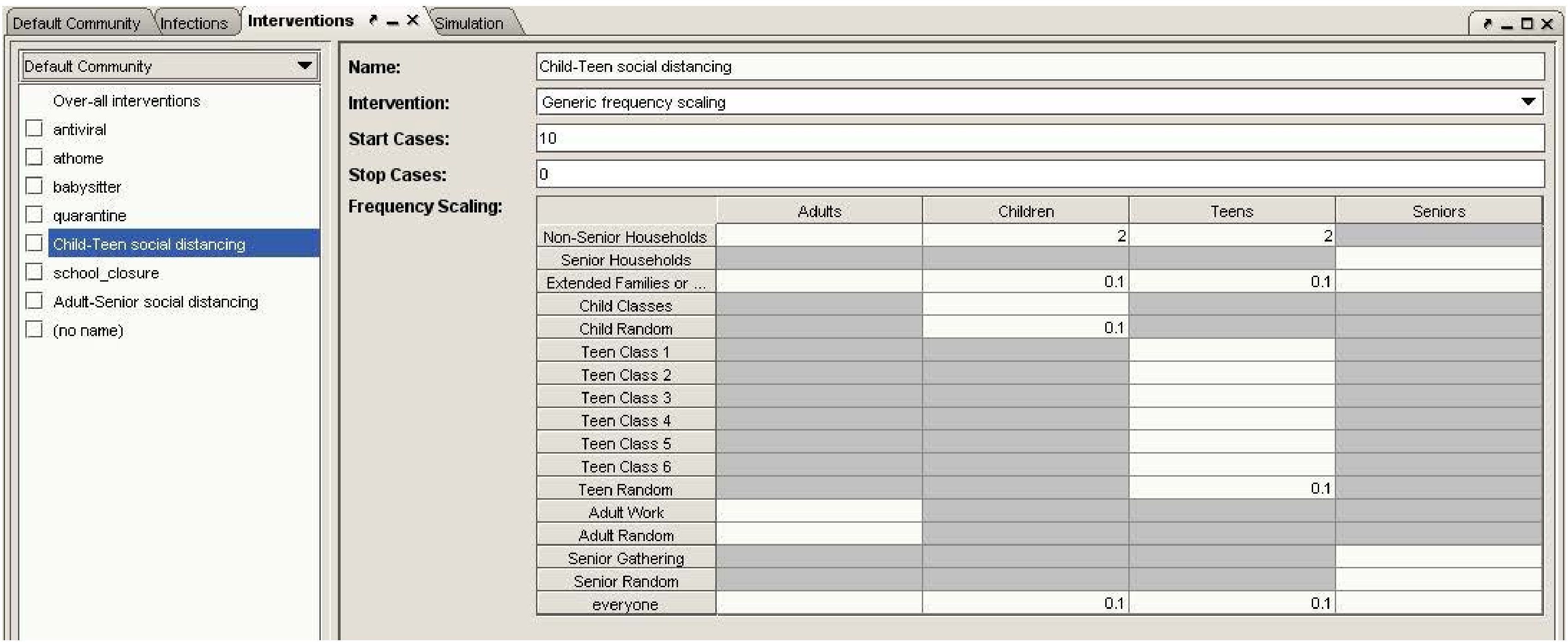
Initial Infection Pool

distribution:	Constant distribution
value:	10.0

A simulation can begin with a distributions of people chosen from the population to be initially infected

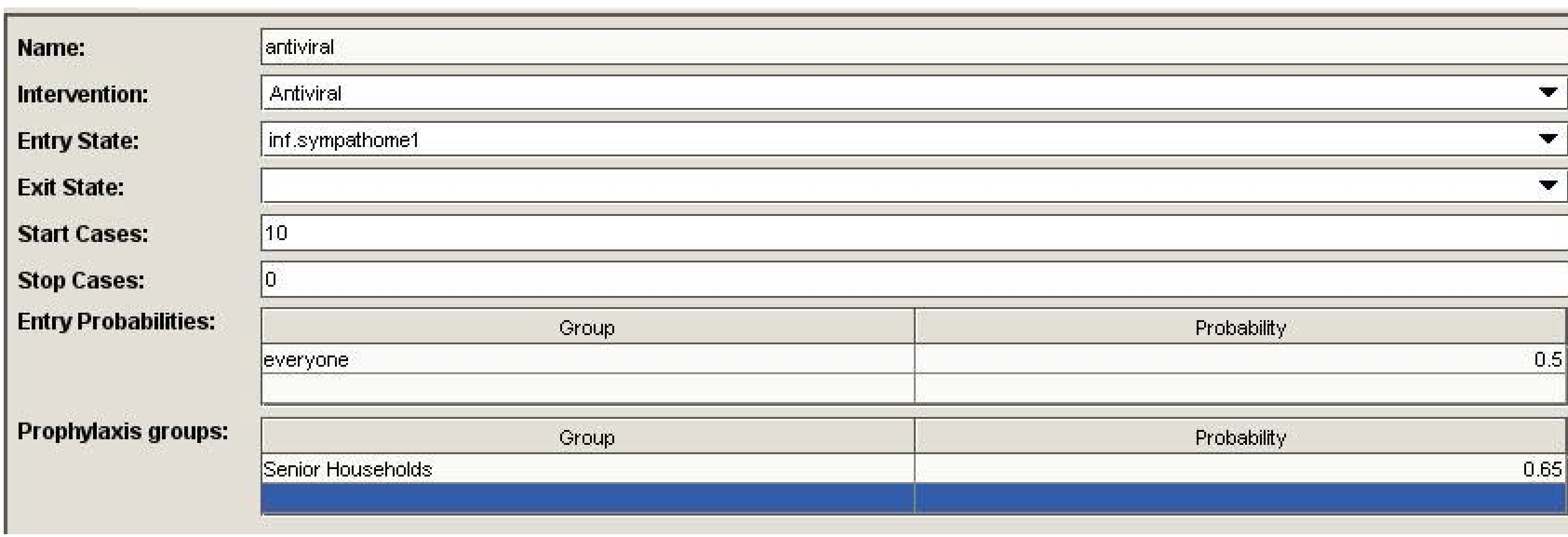
Interventions

- There are two primary categories of interventions: **case-based** and **network-based**.
- Network-based interventions, such as school closures and social distancing, take effect immediately for all relevant nodes.



Interventions

- Case-based interventions include actions such as antiviral treatment and prophylaxis, which reduce a node's infectivity and susceptibility for the duration of antiviral administration.
- Case-based interventions apply only to new cases that emerge.



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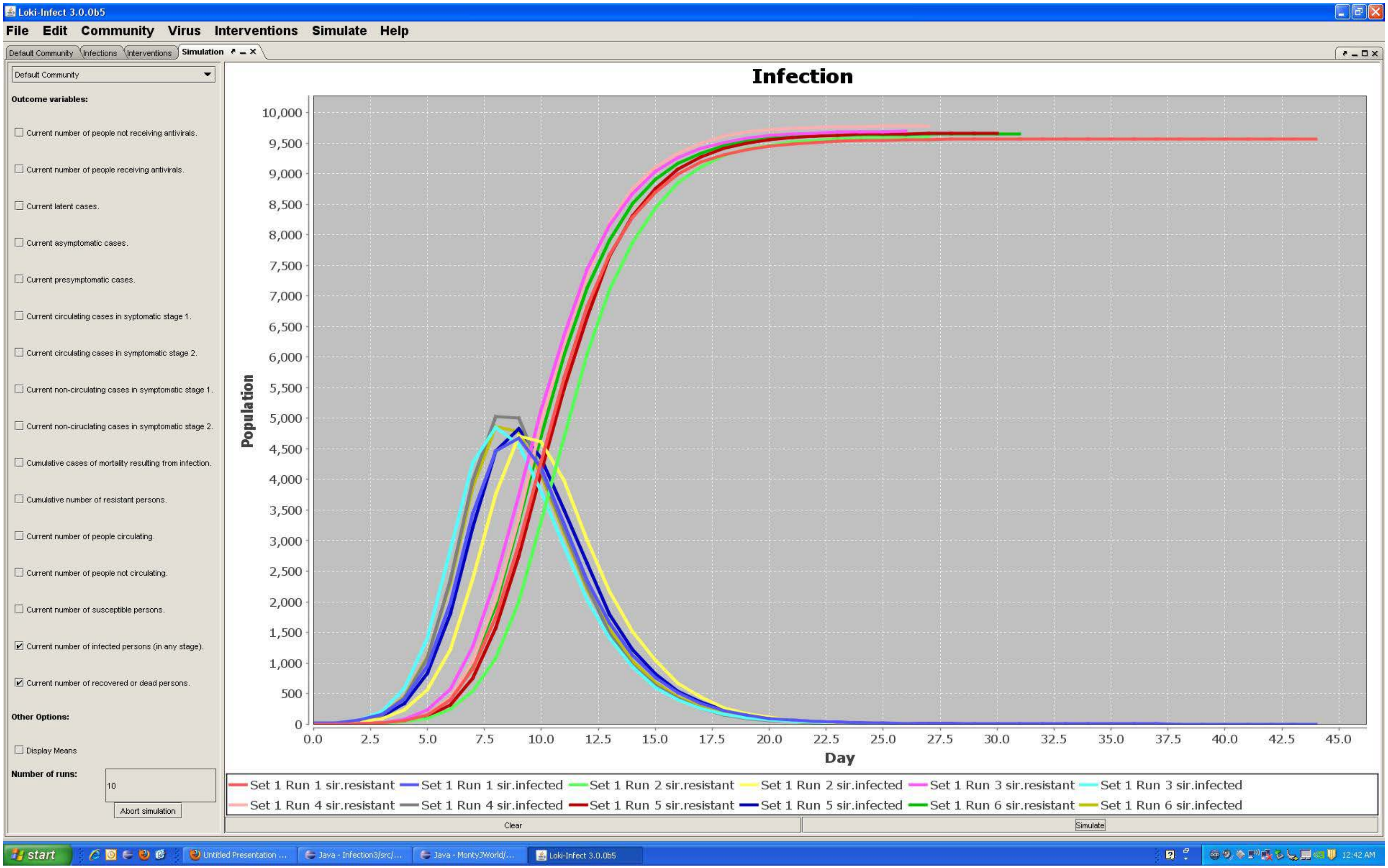
In the simulate window, you can perform multiple runs, and filter the data you wish to view



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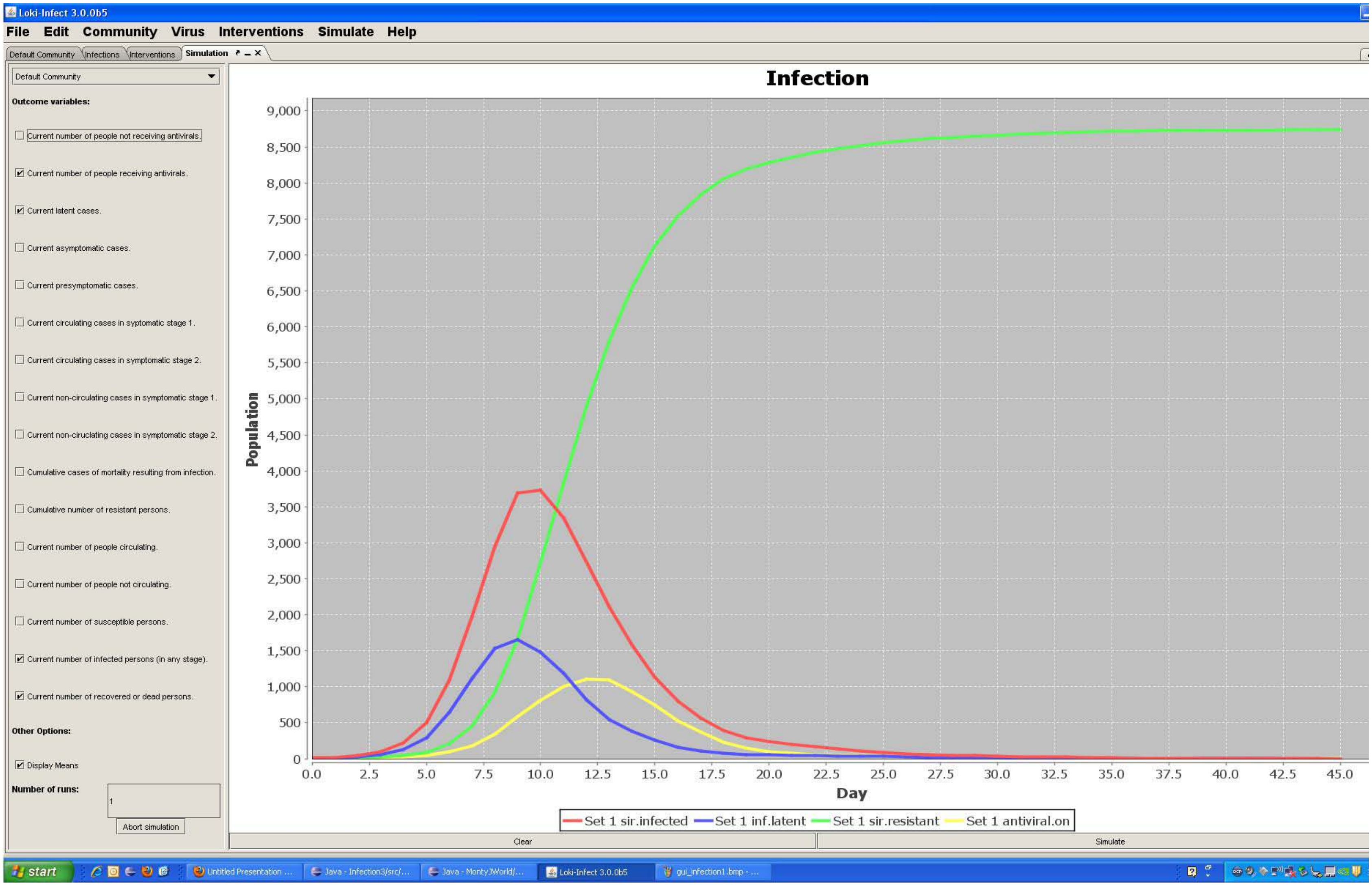
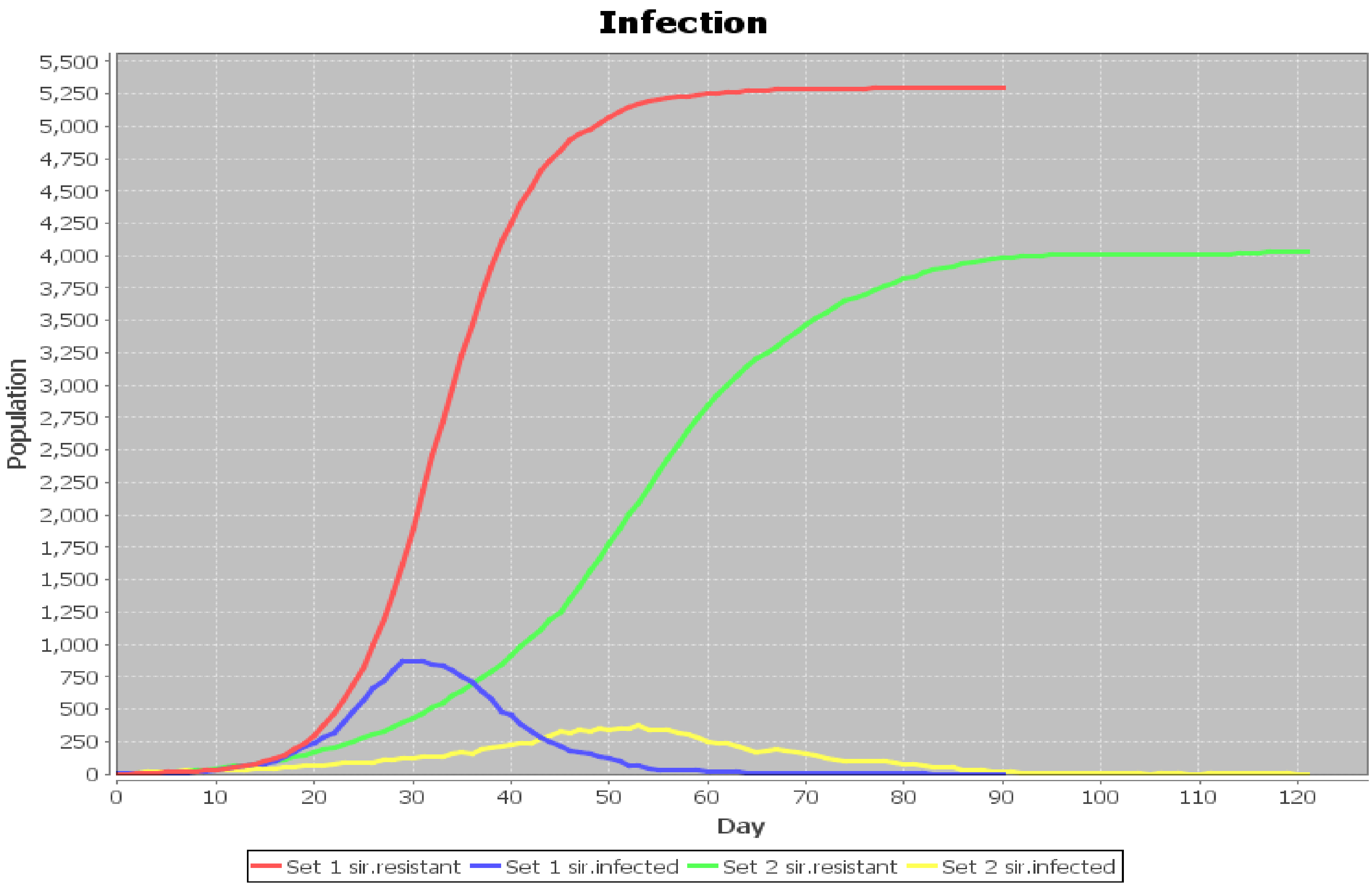
Data can be averaged, and dumped to file



Example: The Effect of School Closures on Disease Propagation



Extensions

- Investigation of the spread of correlated diseases and opinions.
- Investigation of the spread of multiple competitive and non-competitive strains of influenza, including strains that are resistant to neuraminidase inhibitors.
- Used for cost-effectiveness evaluation of mitigation strategies.
- Implementation of a mechanism to retrieve census data based upon GIS coordinates and construct characteristic communities.

Demos

Come see me for demos or if you're interested in beta testing

Distribution and Release

- We intend to publicly release Loki-Infect 3 along with its source code under a free license in the summer of 2011.

Questions?

Additional slides

Representation of a Community

- To construct a layer in the community, we begin by randomly sampling the user-provided distributions to produce new distributions.
- We then use these distributions as constraints in a linear least squares problem, which we solve using a weighted non-negative least squares algorithm.
- We then use a hill-climbing approach to produce a solution that satisfies all necessary constraints (e.g., we must guarantee that the sum of all members in all groups is consistent with the demographics of the population).
- Repeatedly applying this approach to all layers produces a new random community that necessarily satisfies all hard constraints and roughly approximates all soft constraints.