Herd immunity in a network

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Herd immunity

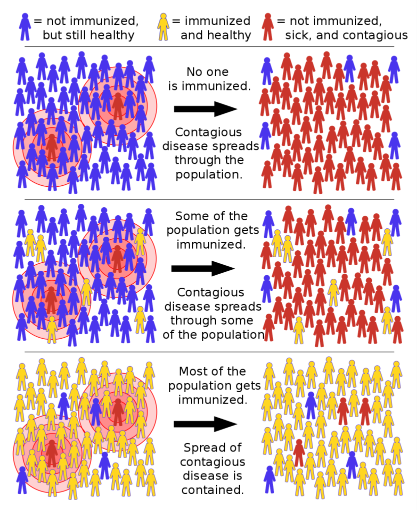


Figure 1: By Tkarcher - Own work, CC BY-SA 4.0,
`https://commons.wikimedia.org/w/index.php?curid=56760604`

Let's frontload some variables!

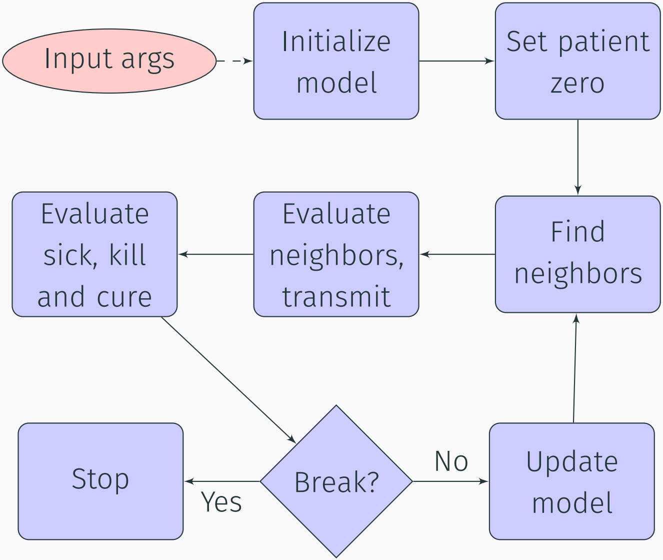
- R_0: 'basic reproduction number'
  - Avg. no. of people infected pr. person
- $\text{HIT} = 1 - 1/R_0$
- N: no. of people initially
- n_{sick}: no. of sick people
- n_{immune}: no. of immune people
- n_{dead}: no. of dead people
- n_{healthy}: no. of healthy people (not immune)
- $R_e = R_0 \cdot n_{\text{healthy}} / \left(N - n_{\text{dead}}\right)$

Diseases

	R_0	Mortality rate	HIT
Ebola	1.5-2.5	0.25-0.90	0.33-0.60
Measles	12-18	0.15	0.92-0.94
Polio	5-7	0.15-0.30	0.80-0.86

Table 1: Data from `https://en.wikipedia.org/wiki/Herd_immunity`

Code

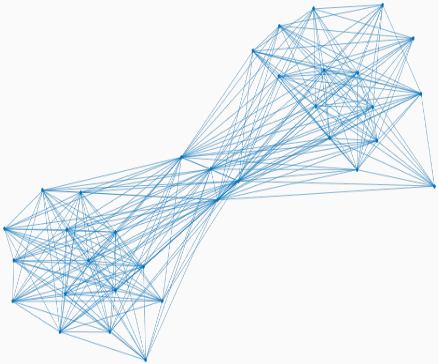

Input args
Initialize model
Set patient zero
Find neighbors
Evaluate neighbors, transmit
Evaluate sick, kill and cure
Break?
Yes
Stop
No
Update model

Networks

- Small world
- Scale free
- Random
- Custom network (two cities with commuters. Random networks for each city)

Custom network

Custom network, simulating two cities with commuters



Movie time: two cities, death

Movie time: two cities, death

Movie time: two cities, immunity

Success criteria

- Real world
  - Disease no longer endemic
- Our model
  - Discussion of alternate criteria
    - Percolation
    - Effective reproductive number
      $R_e = \text{fraction of susceptible individuals} \cdot R_0 \leq 1$
    - $n_{\text{sick}} = 0$ and $n_{\text{healthy}} \neq 0$
    - $n_{\text{healthy}} = 0$
    - **Total sick $<$ arbitrary threshold**

The simulations

- Test 20 values of p_I (0 to 0.95, in steps of 0.05)

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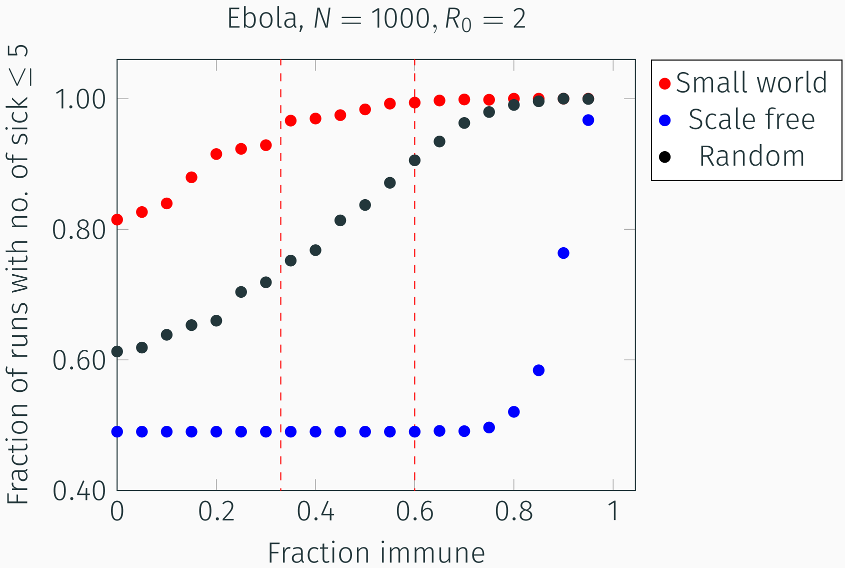
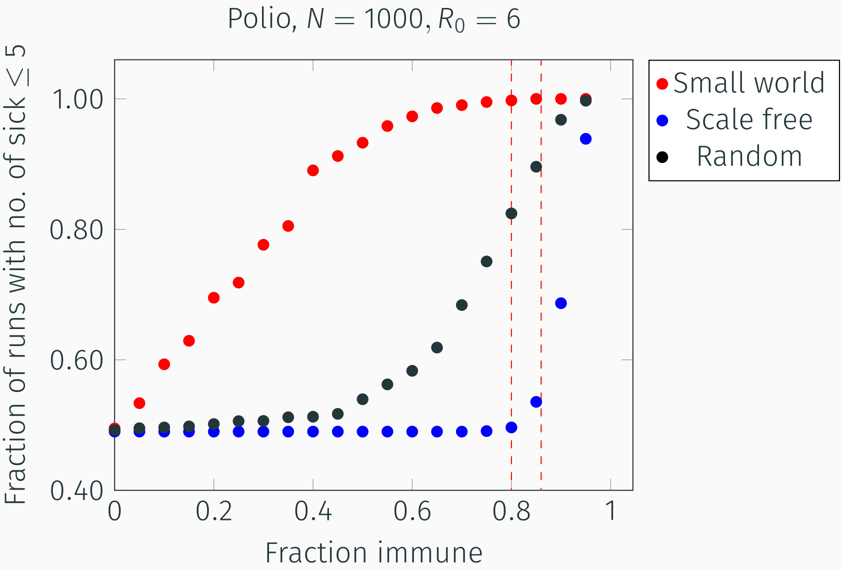
- Test 20 values of p_I (0 to 0.95, in steps of 0.05)
- For each p_I test 50 different networks, and test each network 50 times (random distribution of patient zero and immune nodes)
- Save relevant output

Results



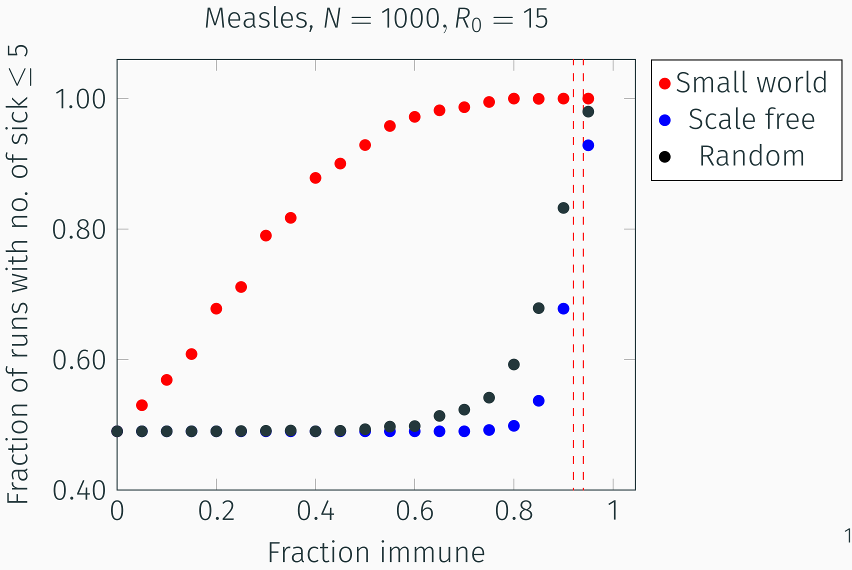
Ebola, $N = 1000$, $R_0 = 2$
Fraction of runs with no. of sick ≤ 5
1.00
0.80
0.60
0.40
0
0.2
0.4
0.6
0.8
1
Fraction immune
Small world
Scale free
Random

Results



Polio, $N = 1000$, $R_0 = 6$
Fraction of runs with no. of sick ≤ 5
1.00
0.80
0.60
0.40
0
0.2
0.4
0.6
0.8
1
Fraction immune
Small world
Scale free
Random

Results



Measles, $N = 1000$, $R_0 = 15$
Fraction of runs with no. of sick ≤ 5
1.00
0.80
0.60
0.40
0
0.2
0.4
0.6
0.8
1
Fraction immune
Small world
Scale free
Random

Conclusion

Simulating the spread of disease is easy. Defining herd immunity is hard.