IMMUNIZATION

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Outline

- Random Immunization
  - *Random Networks*
  - *Heterogeneous Networks*
- How to Halt an Epidemic
- Vaccination strategies in Scale-Free Networks
  - *Immunizing the Hubs*
  - *Robustness and Immunization*
  - *Selective Immunization for Scale-Free Networks*
  - *Random Immunization*
  - *Selective Immunization*
- Can Pathogens be Eradicated?

Immunization Strategies

- Method specifying how vaccines, treatments, drugs distributed
  - Ideal: distributed to everyone

- Aim to minimize pandemic threat by effective distribution
- Pathogen spreading rate: λ
- Pathogen critical threshold: λ_c
  - If $\lambda < \lambda_c$, the virus naturally dies out
- Epidemic threshold vanishes In Scale-free network models
  - Is this strategy valid?

Random Immunization

- Immunization Objectives:
  - Primary: protect immunized persons from disease
  - Secondary: reduce speed at which pathogen spreads in population
- SIS (Susceptible-Infected Susceptible) Model
  - *β = rate at which an individual becomes infected*
  - *μ = rate at which infected individuals recover*
  - $\lambda = \frac{\beta}{\mu}$

- *g* Nodes immunized to pathogen, *(1-g)* nodes susceptible
- Degree of susceptible nodes changes from <k> to <k>(1-g)
- Spreading rate changes from $\lambda = \beta/\mu$ *to* $\lambda' = \lambda(1-g)$

Random Immunization

- Random Networks
  - λ' could fall below epidemic threshold
  - $g_c = 1 - \frac{\mu}{\beta}\frac{1}{<k>+1}$
  - Note how vaccinations lower the rate of spreading and also make it easier for the disease to become eradicated

Random Immunization

- Heterogenous Networks
  - $g_c = 1 - \frac{\mu}{\beta}\frac{<k>}{<k>^2}$ new immunization rate for λ' to fall below the epidemic threshold
  - In a scale free with $\gamma < 3, < k^2 > \rightarrow \infty$, so $g_c = 1$
    - This implies that virtually every person would have to be immunized
    - 80%-100% in practice (95% for disease such as measles)

Random Immunization

- An example
  - *Digital Virus spreading on email network*
  - *Random, undirected*
  - $\langle k \rangle$=3.26
  - λ=1 (spreading rate)
  - *Solve for* g_c=0.76
  - So 76% of computers would need the anti-virus software

  - Since email network is actually scale-free, with $<k^2>$=1,271, g_c=0.997 for λ=1
  - This means virtually all computers must have the antiviral software
  - Impractical in practice

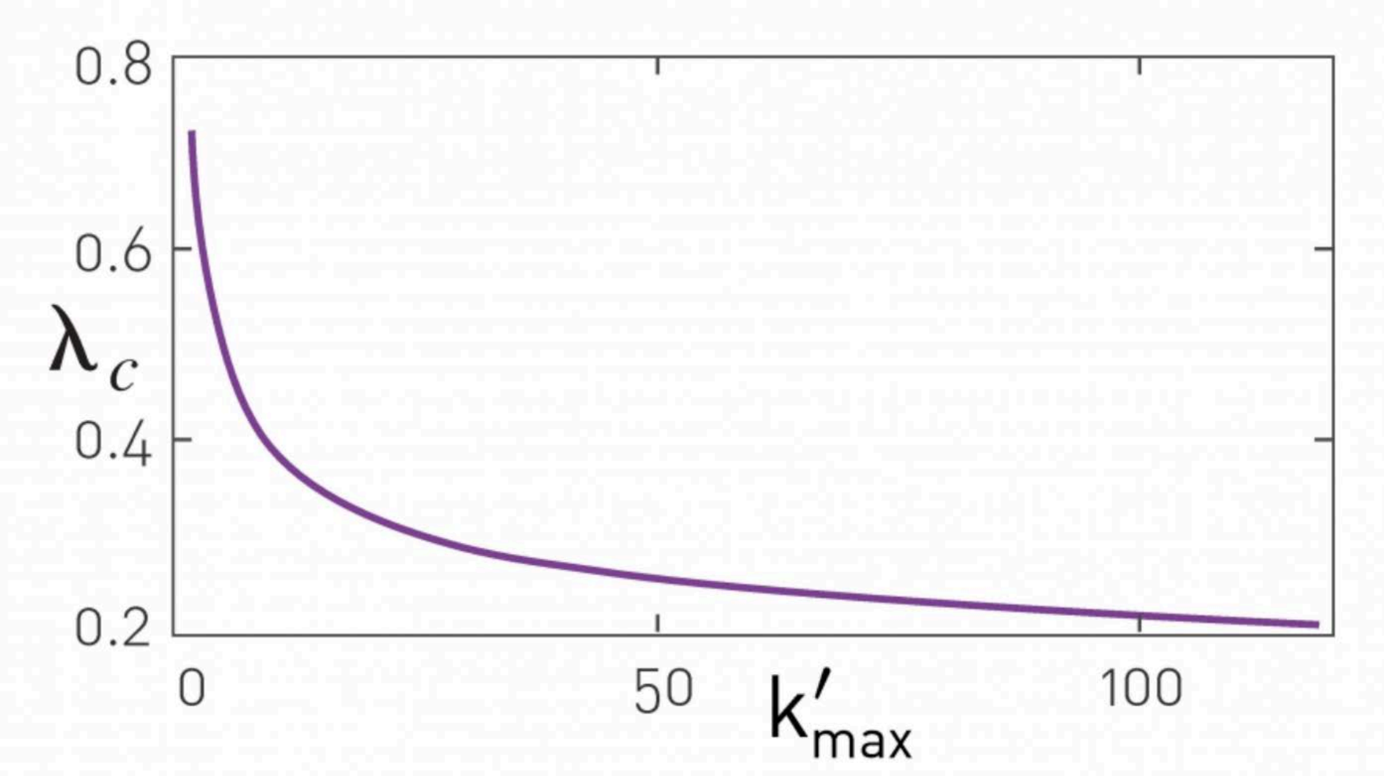
How to Halt an Epidemic

- Interventions to control/delay epidemic outbreak
  - *Transmission-Reducing Interventions*
    - Face masks, gloves, hand washing
  - *Contact-Reducing Interventions*
    - Patient quarantine, school closings, mall/movie theater closings
    - Make network more sparse
  - *Vaccinations*
    - Permanently remove vaccinated nodes from the network

Vaccination Strategies in Scale-Free Networks

Random Immunization is ineffective. How can we minimize the network?

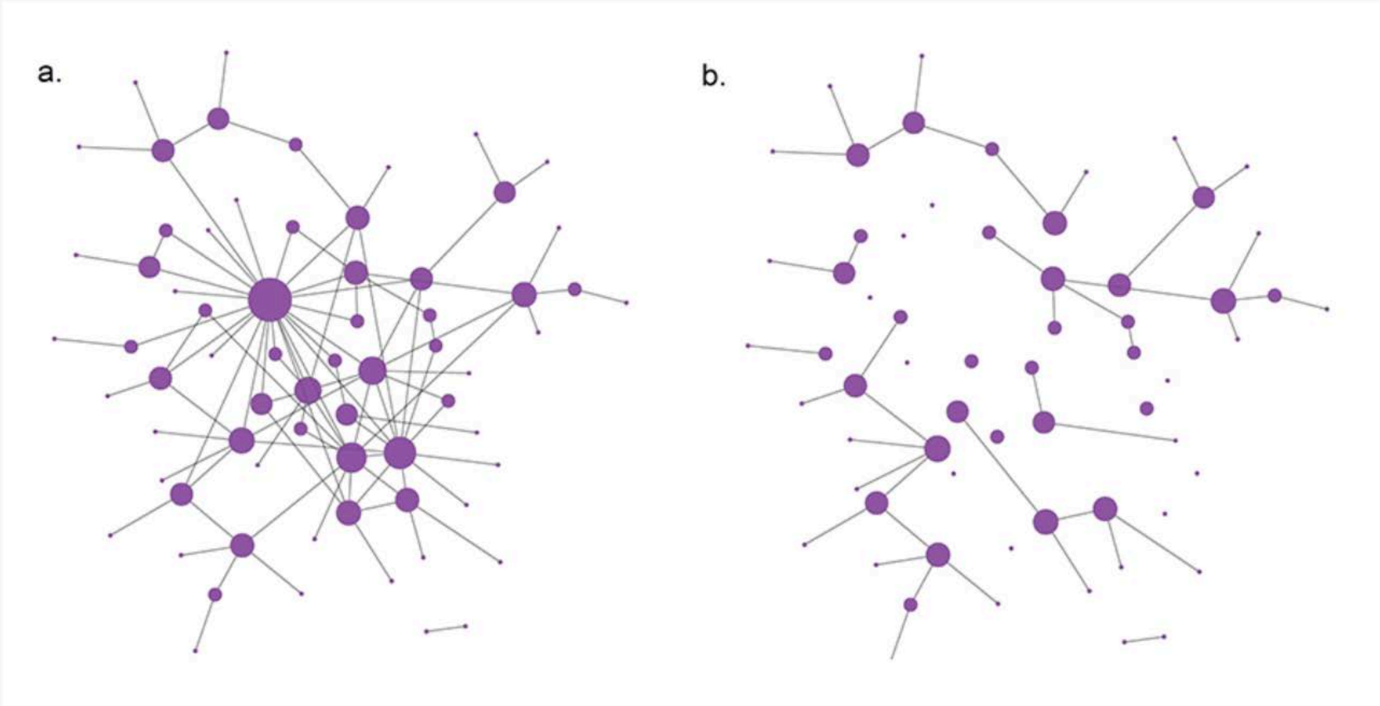
A: Reduce variance $\langle k^2 \rangle$ of underlying contact network (Scale-Free Network)



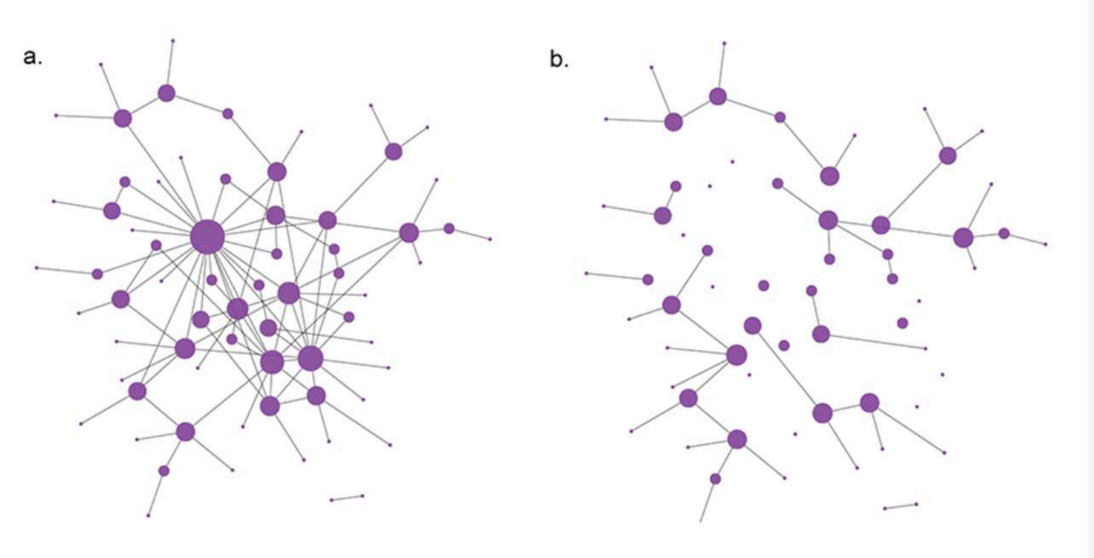
Immunize the Hubs

Immunizing all nodes with degree > k'_{max}

The more hubs that are immunized, the larger λ_c becomes, thus increasing the chance the disease dies out

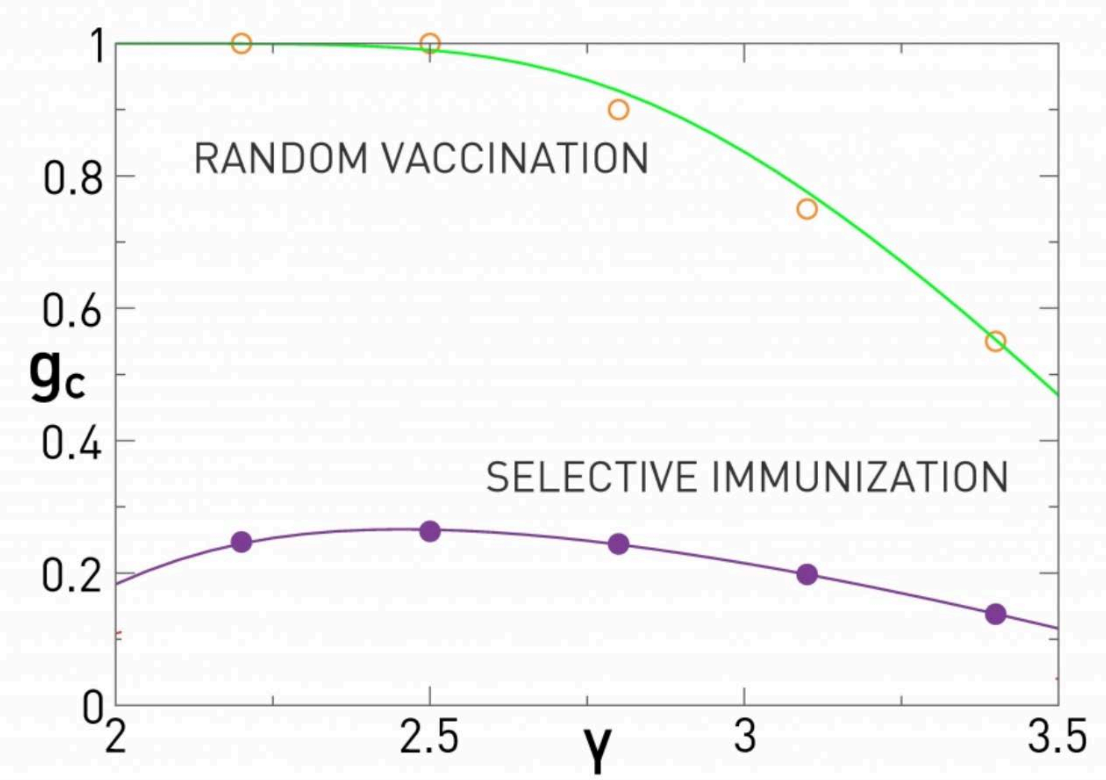


Robustness & Immunization



- Scale-free networks are robust to random node/link failures, but removing hubs/nodes with highest connectivity, they fall apart
- This problem similar to attack problem on scale-free networks
- See network (a)
  - *5 largest hubs removed (b)*
  - *Network is shattered*
- Issue
  - *Hub identification difficult due to minimal network map knowledge*
  - *Friendship Paradox:*
    - Average neighbors of a node have higher degree than node itself
    - Algorithm:
      - *take fraction of infected people*
      - *Immunize a single random individual the infected individual had contact with*

Selective Immunization of Scale-free Networks



- g_c on the left as a function of the degree exponent γ.
- Random Immunization
  - *For heterogeneous networks (small γ) $g_c \cong 1$, but in high γ networks, immunizing a smaller portion eradicates the disease*
- Selective Immunization
  - *Using the biased strategy, g_c is < 30%*
  - *Immunize random neighbor of 30% of the nodes, to eradicate disease*
  - *MUCH more efficient*

Can Pathogens be Eradicated?

- Eradication: the compete elimination of a pathogen from a population
- Smallpox started w/ mass vaccination strategy, but was unsuccessful in high population areas
- Eventually developed network based vaccination (treat anyone in contact with infected individual), and smallpox became first disease to become officially eradicated
- Process:
    - *Select disease with only human carriers*
    - *Vaccination exists*
    - *Mixed success*
        - Smallpox, rinderpest successful
        - Hookworm, malaria, yellow fever unsuccessful
- Right: Rahima Banu, last smallpox patient (1976)

Conclusion

- Immunization increases the difficulty for a disease to spread
- Random networks/Scale-free networks with high γ require near total immunization
- Effective vaccination and immunization strategy prevents disease outbreak
  - *Eradication occurs when effective strategy combined with effective vaccine works well*

References

- Barabási, Albert-László, and Márton Pásfai. *Network Science*. Cambridge University Press, 2016.