UNIVERSITAT POLITÈCNICA DE VALÈNCIA

VRAIN
Valencian Research Institute for Artificial Intelligence

Agent-Based Simulation in Complex Networks

ESSAI 2024. Athens

Miguel Rebollo (@mrebollo)

Session 5. Dynamics

Complex networks display
a surprising degree of robustness:
although key components malfunction,
local failures rarely lead
to the loss of the global information.

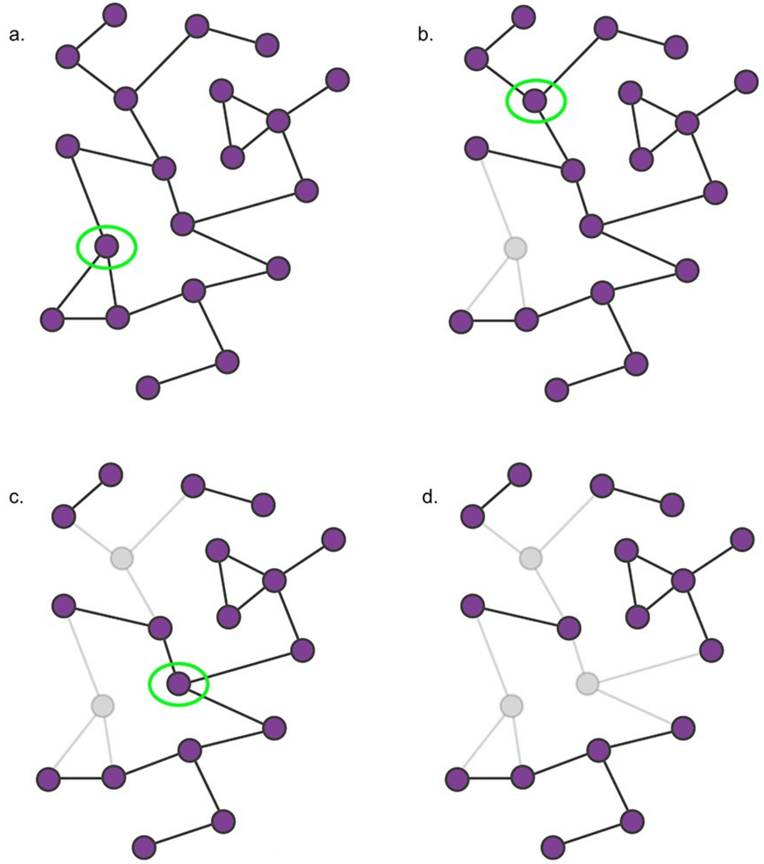
We'll study why this effect appears.

PERCOLATION THEORY

Impact of node removal

Percolation theory

removal of one link has limited impact, but remove several can break a network into components. How many nodes we have to delete?

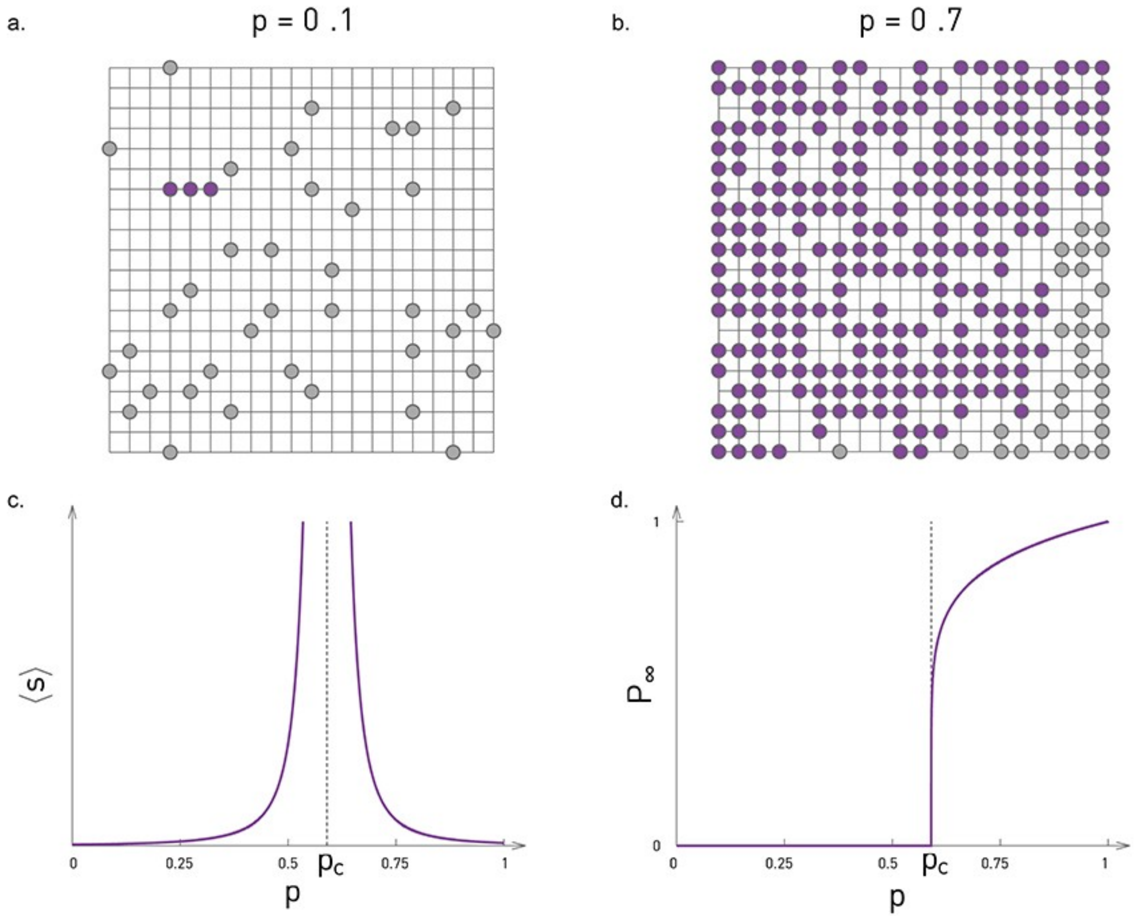


Percolation

Which is the expected size of the largest cluster?

What is the average cluster size?

When it is formed?



Percolation

Average cluster size <s>

$$\langle s \rangle \sim |p - p_c|^{-\gamma_p}$$

Order parameter P_∞

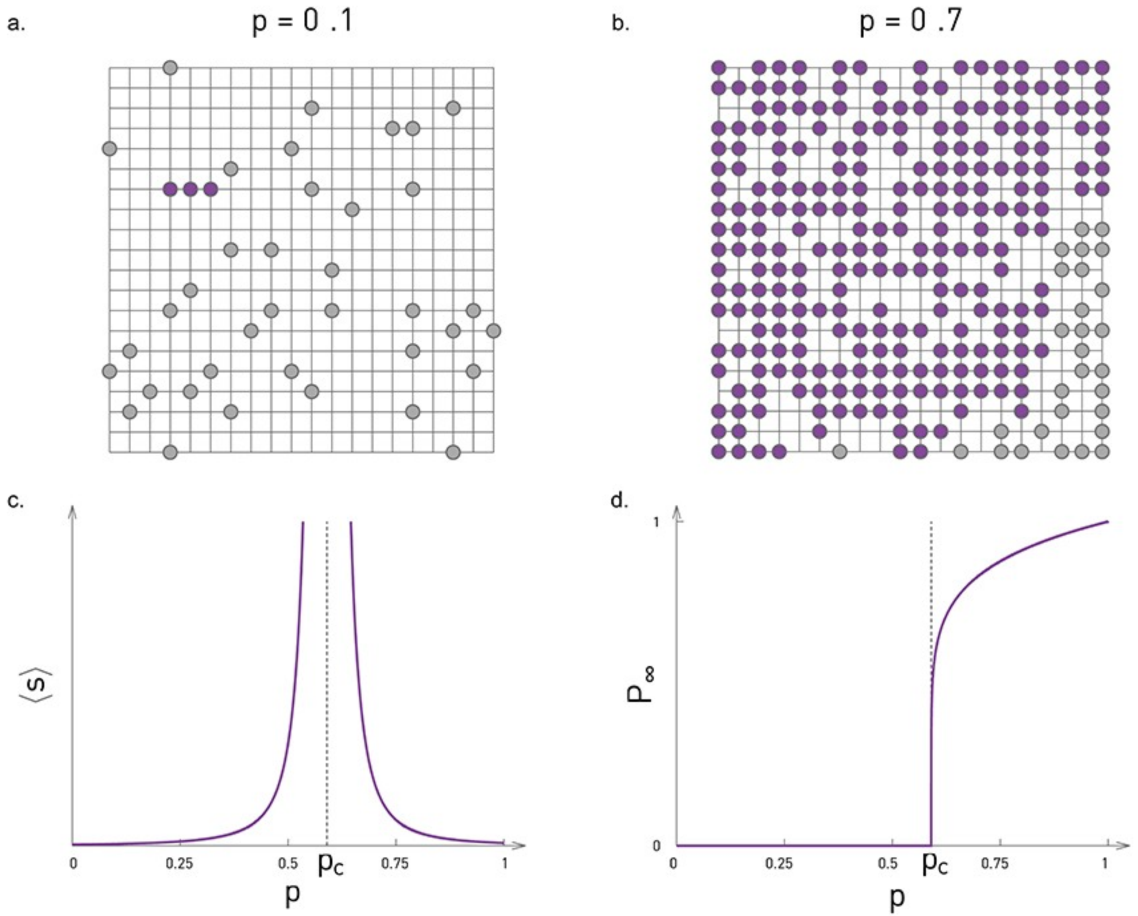
$$P_\infty \sim (p - p_c)^{\beta_p}$$

Correlation length

$$\xi \sim |p - p_c|^{-\nu}$$

γ, β and υ:
critical exponents

p_c = 0.593 universal value



ROBUSTNESS

Robust (from oak -roble-) system that resist errors

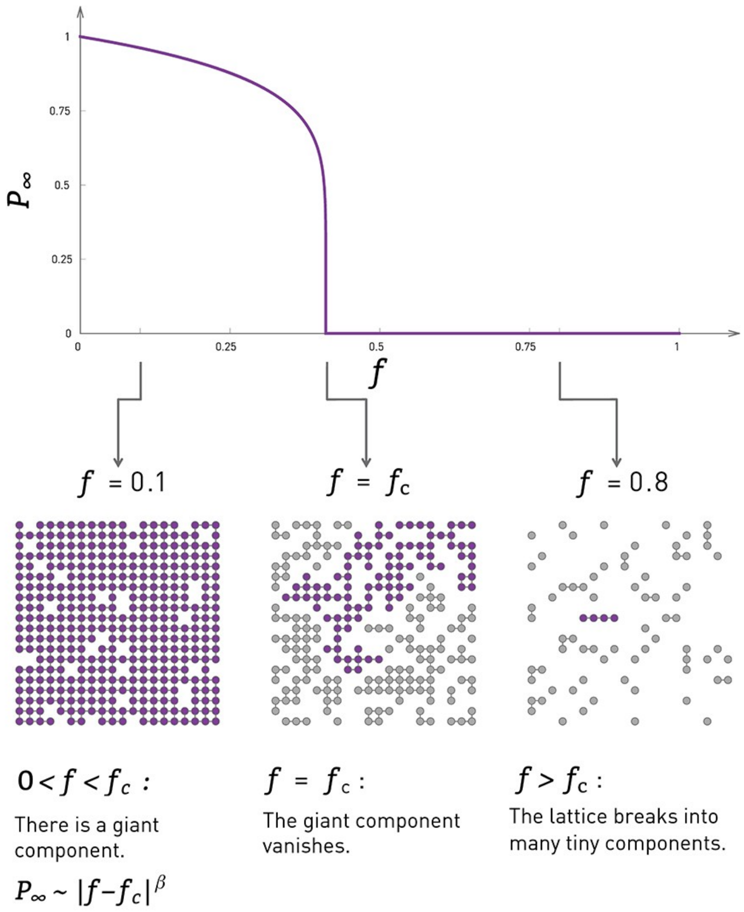
and failures without degrading

Robustness

Inverse percolation: node removal until disconnection

Critical exponents are the same

Fragmentation process is abrupt, not gradual



Efficiency

$$E = \frac{1}{N(N-1)} \sum_{i,j \neq i} \frac{1}{d_{ij}}$$

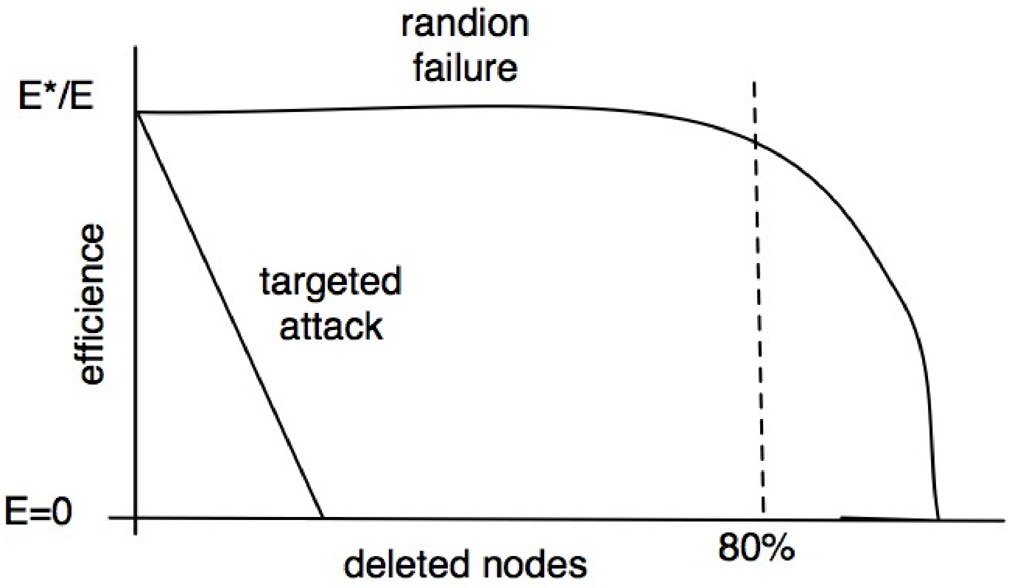
The bigger the distance, the less efficient the network

Networks with short paths are more efficient

Vulnerability

Measures how failures affect to the efficiency (variation of eff when a link/node disappears)

Dependence on the topology



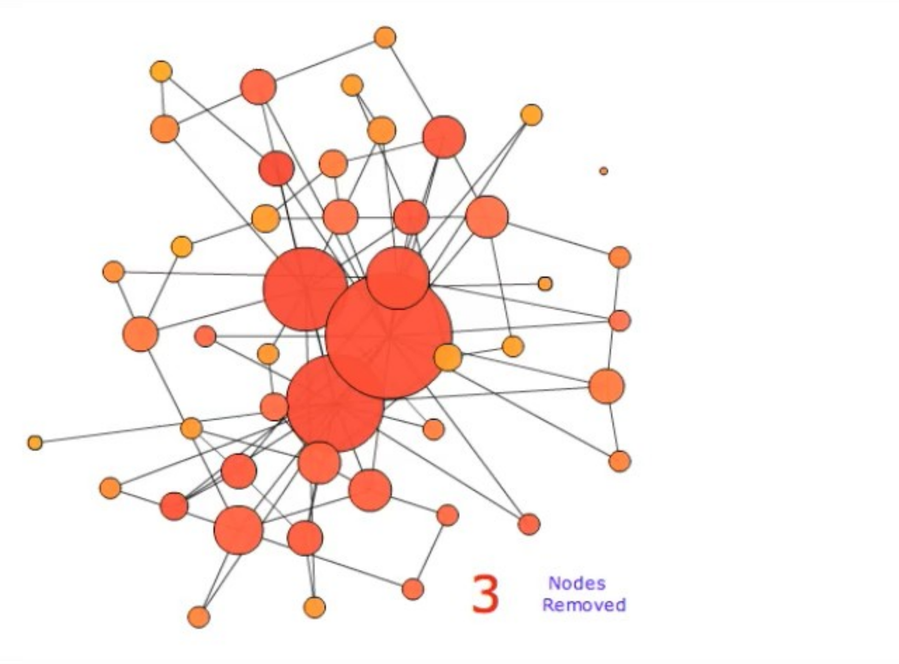
ATTACK TOLERANCE

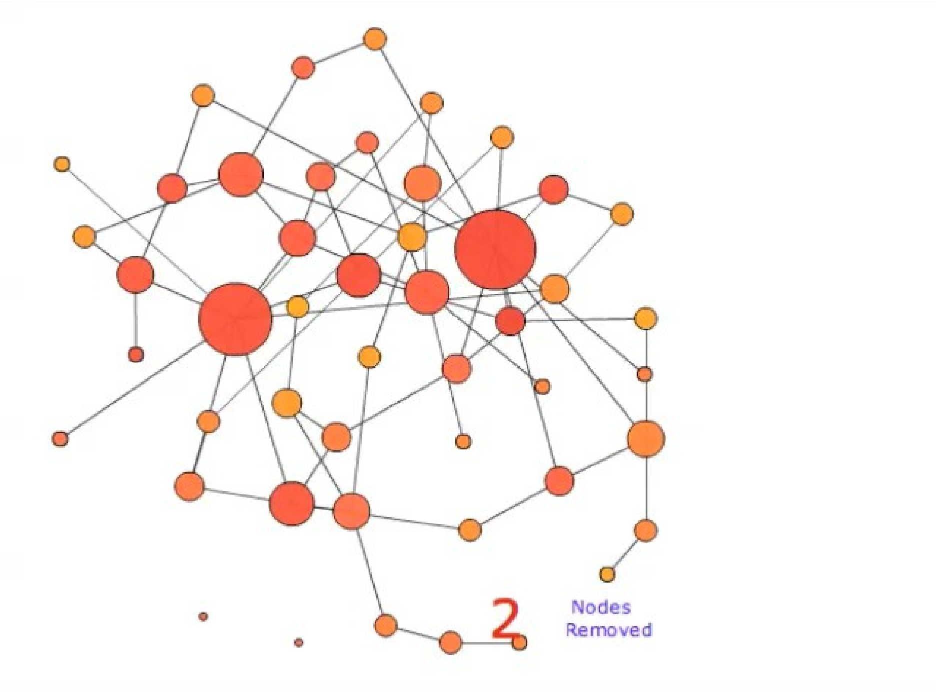
What happens in the network when s sabotage is intended?

Deliberate Attacks

Random

Scale-free



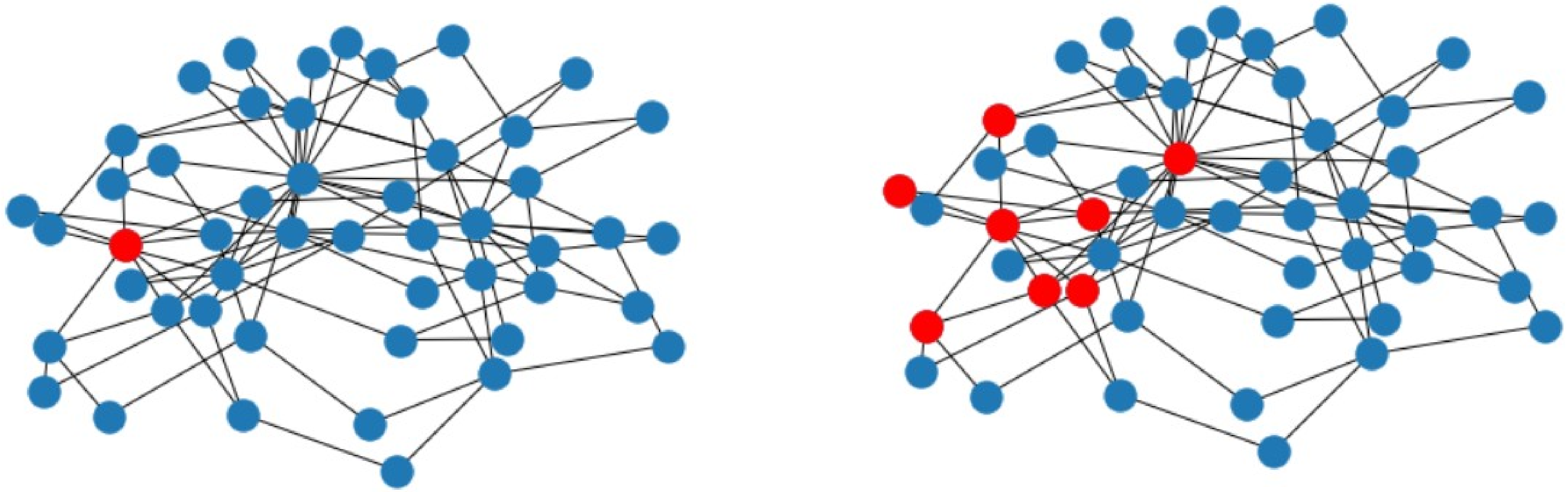


Hubs play a significant role in failure tolerance

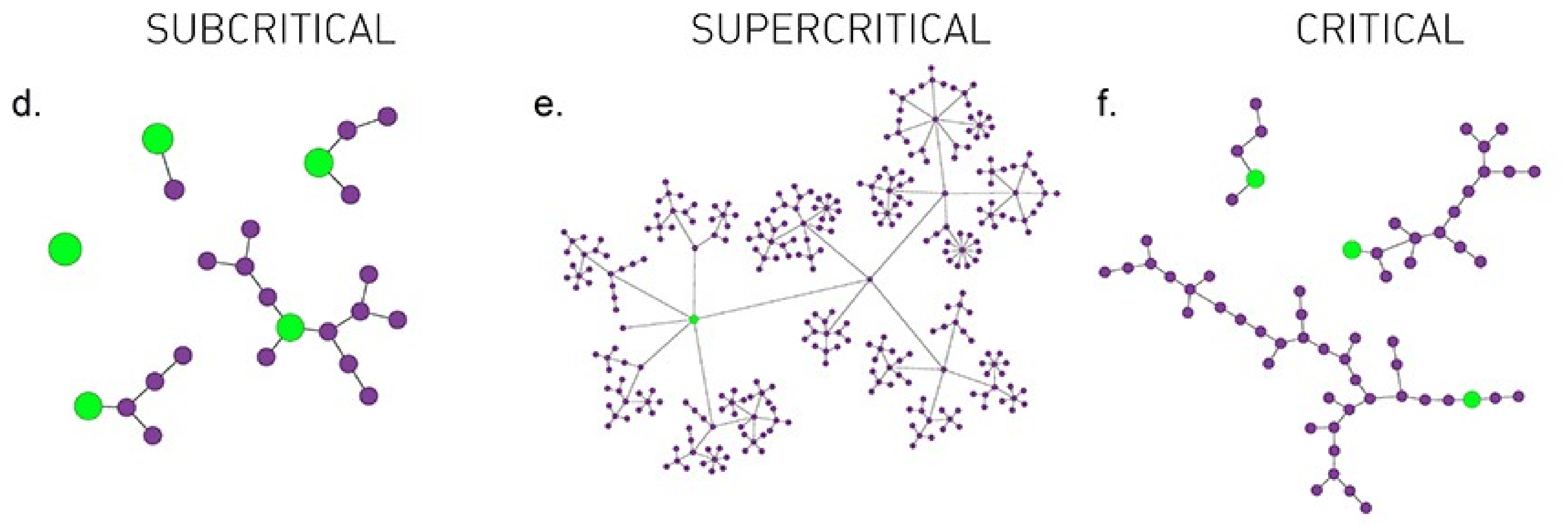
CASCADE FAILURES

Because failures do not arrive isolated

Cascades



Three regimen



Subcritical <k> < 1 Supercritical <k> > 1 Critical <k> = 1

DIFFUSION

Diseases, computer viruses, innovation or memes,

all they share the same transmission scheme

Closing credits. Planet of the Apes

EPIDEMIC MODELING

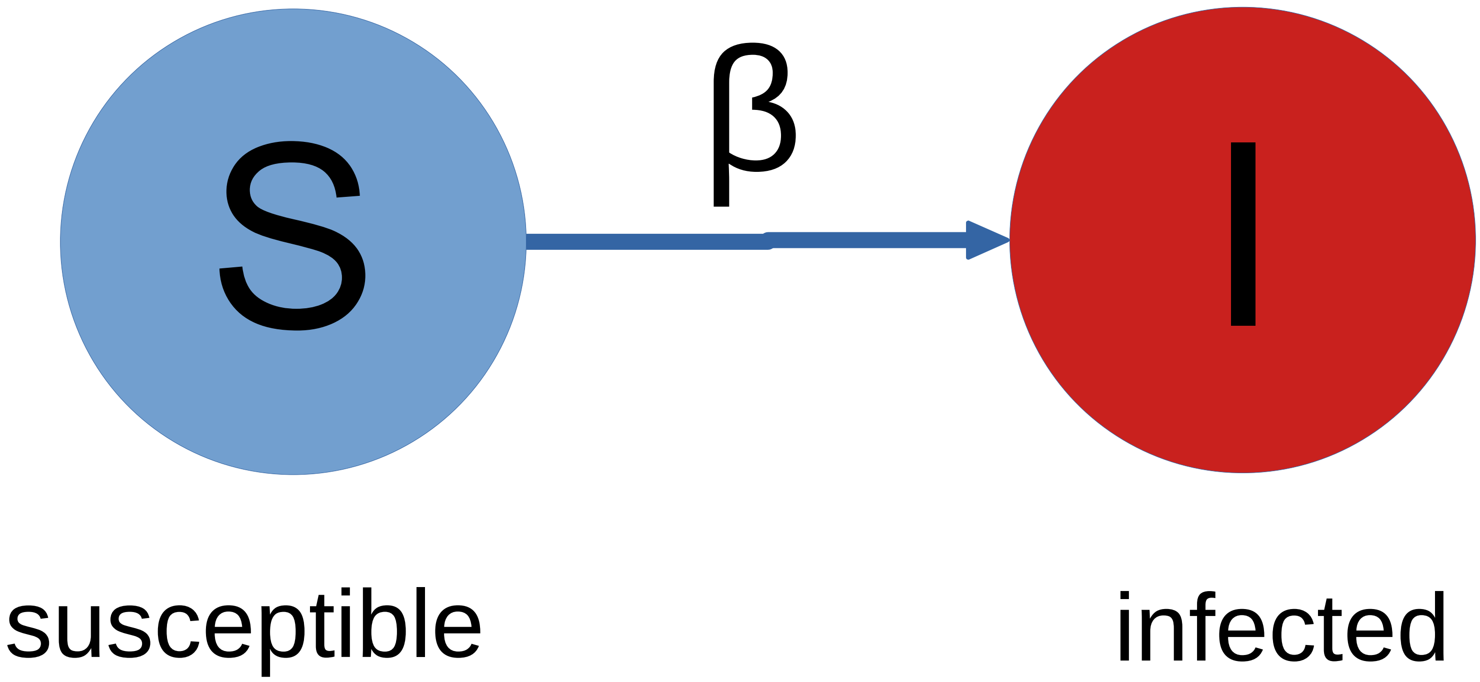
Mathematical models the simulates how a disease evolves

Based on two concetps

compartmentalization: classification of individuals in groups attending to their state (SI / SIS / SIR)

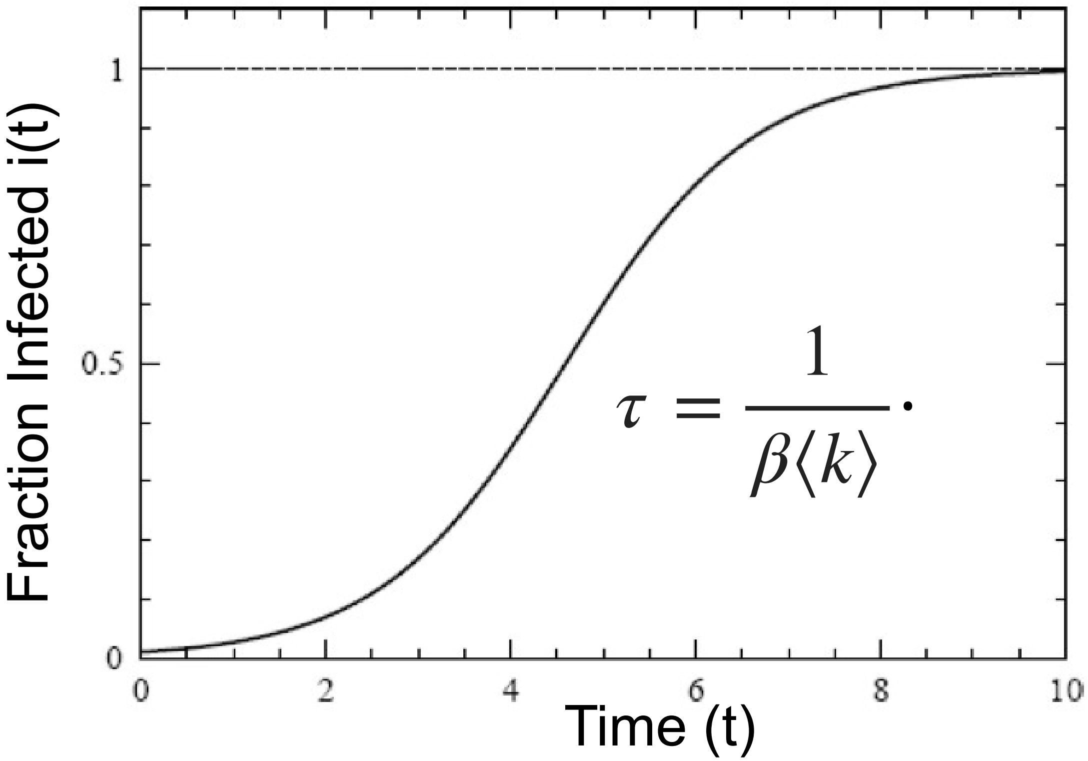
homogenous mixing: all individuals have same prob. to get infected (no contact network)

SI model

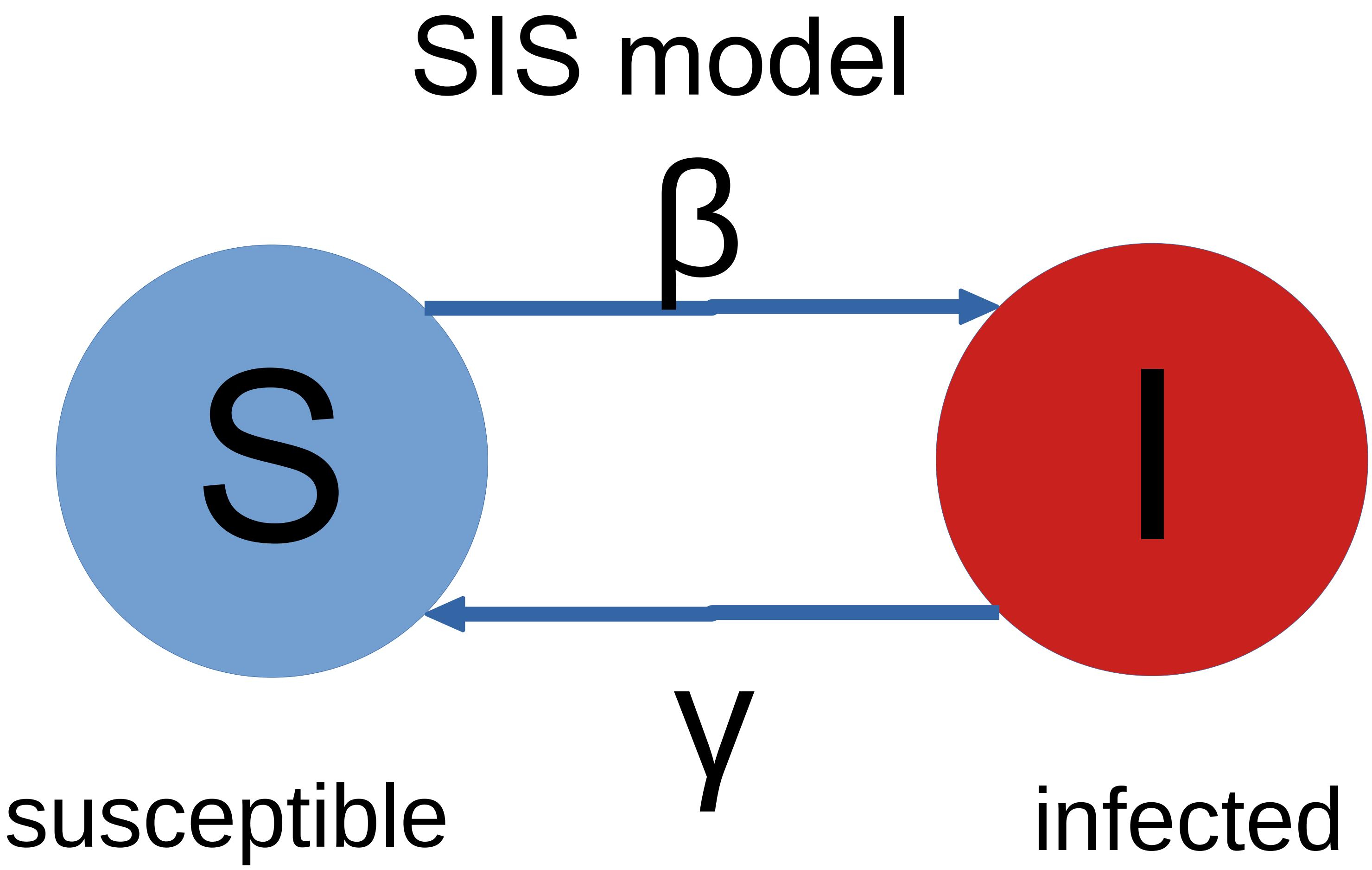


SI model

Infection increases until all population infected



$$\tau = \frac{1}{\beta\langle k\rangle}.$$


SIS model
β
S
I
γ
susceptible
infected

SIS model

Two regimen

Endemic state (γ < β)

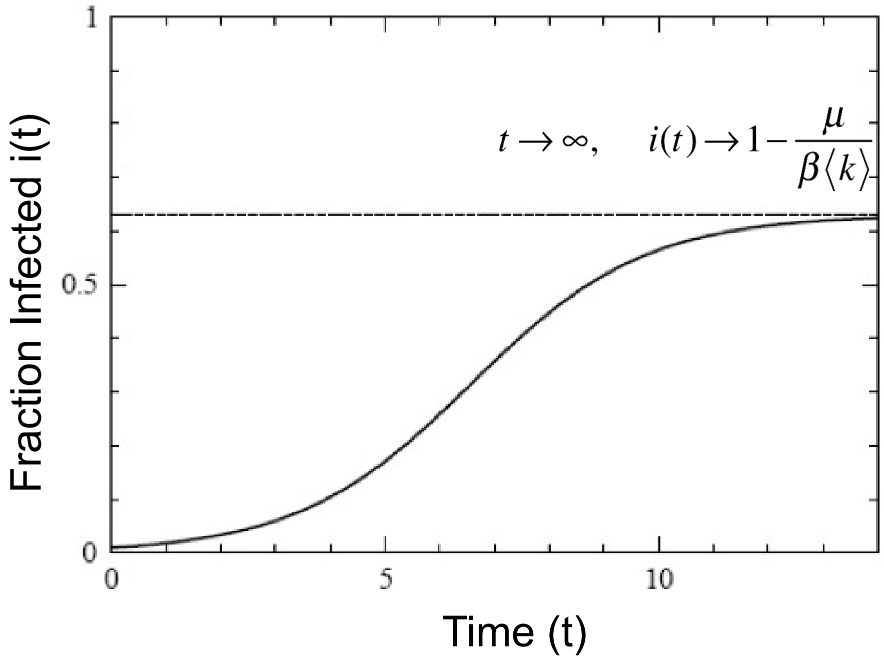
Disease free (γ > β)

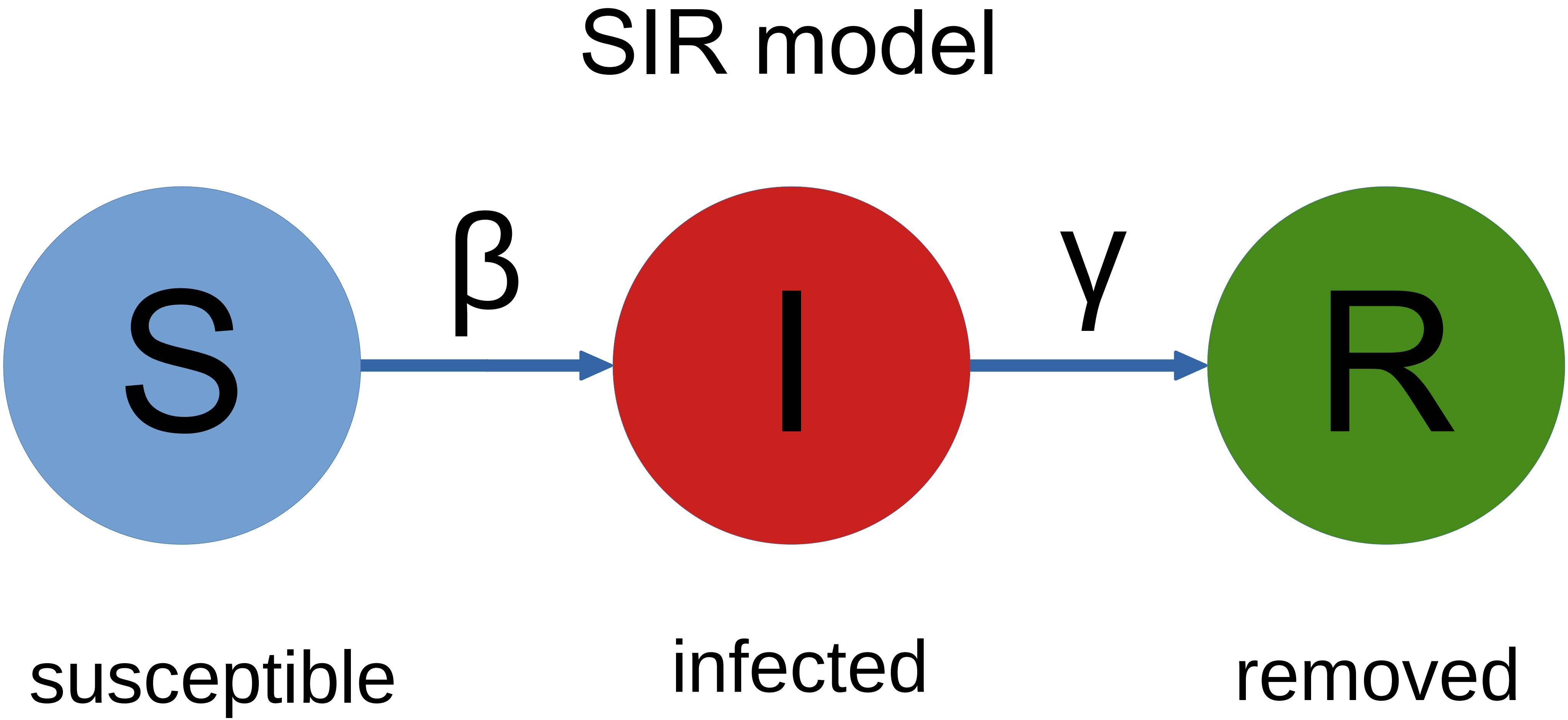
$$\tau = \frac{1}{\gamma (R_0 - 1)}$$

Characteristic time

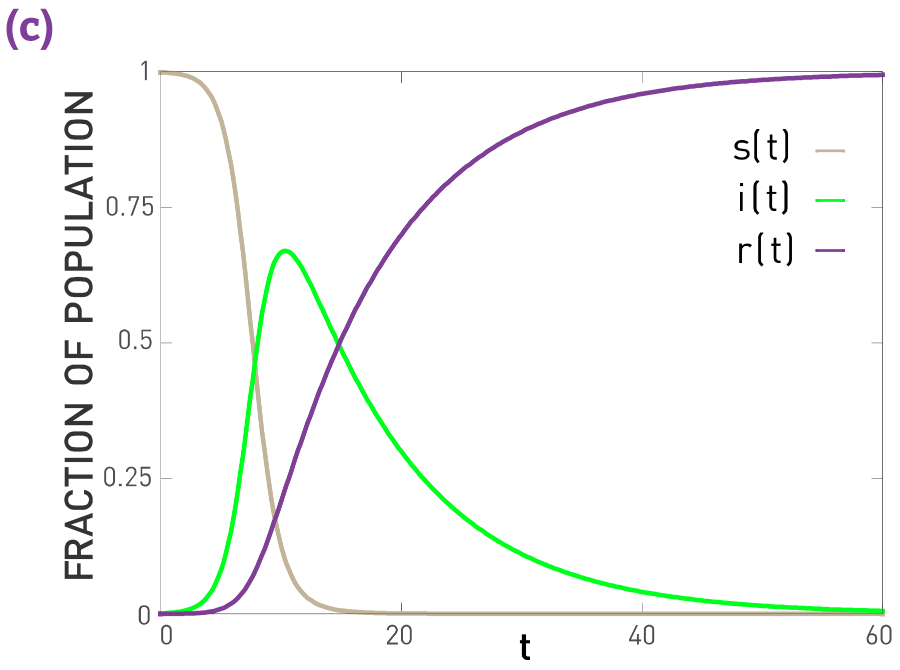
$$R_0 = \frac{\beta \langle k \rangle}{\gamma}$$

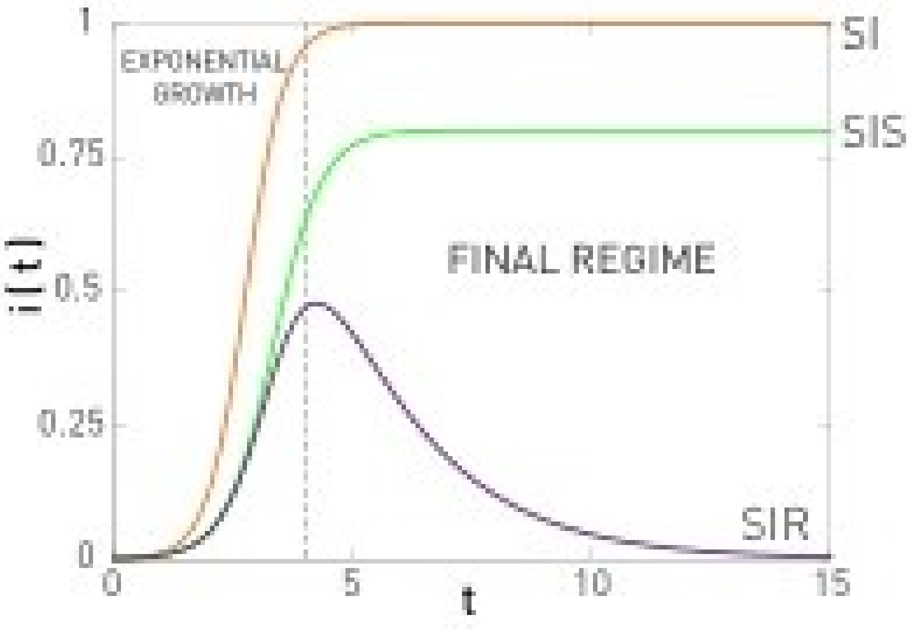
Reproductive number
< 1 extinction
> 1 propagation




SIR model
S
β
I
γ
R
susceptible
infected
removed

SIR model


(c)
FRACTION OF POPULATION
1
0.75
0.5
0.25
0
0
20
40
60
t
s(t)
i(t)
r(t)


EXPONENTIAL GROWTH
FINAL REGIME
SI
SIS
SIR
i(t)
1
0.75
0.5
0.25
0
0
5
10
15
t

EPIDEMIC IN NETWORKS

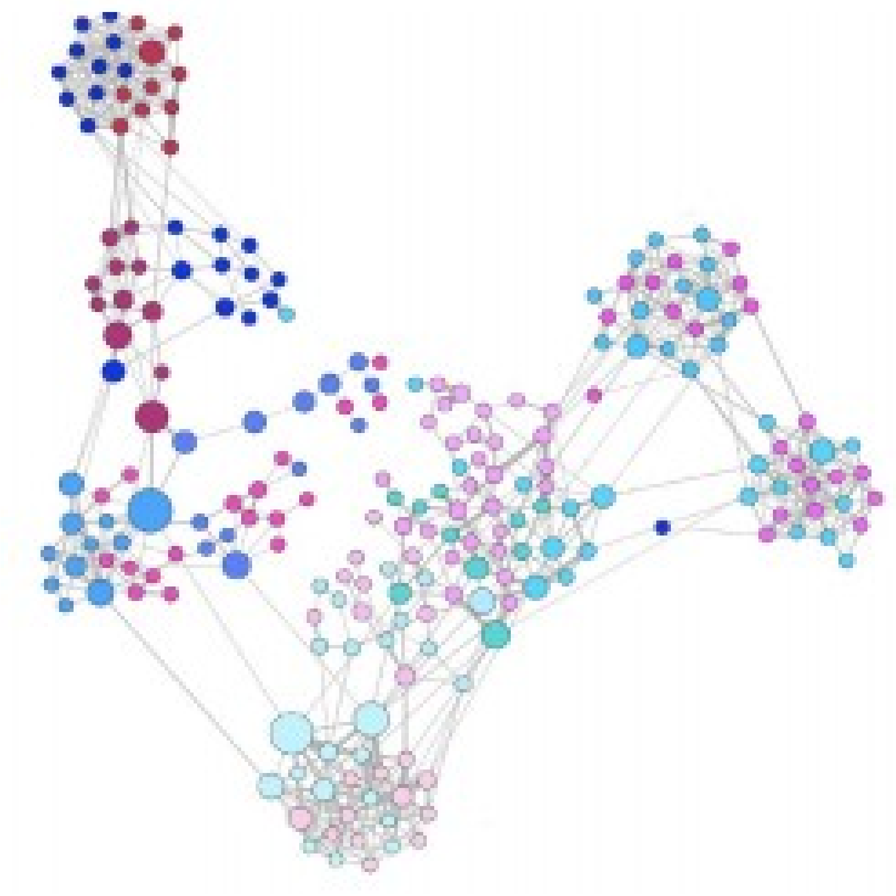
Contacts in a network limits the paths a virus takes in a population

Contact networks

Contacts constrained by the network

Real degree instead of average

Differences on random and scale-free topologies



IMMUNIZATION

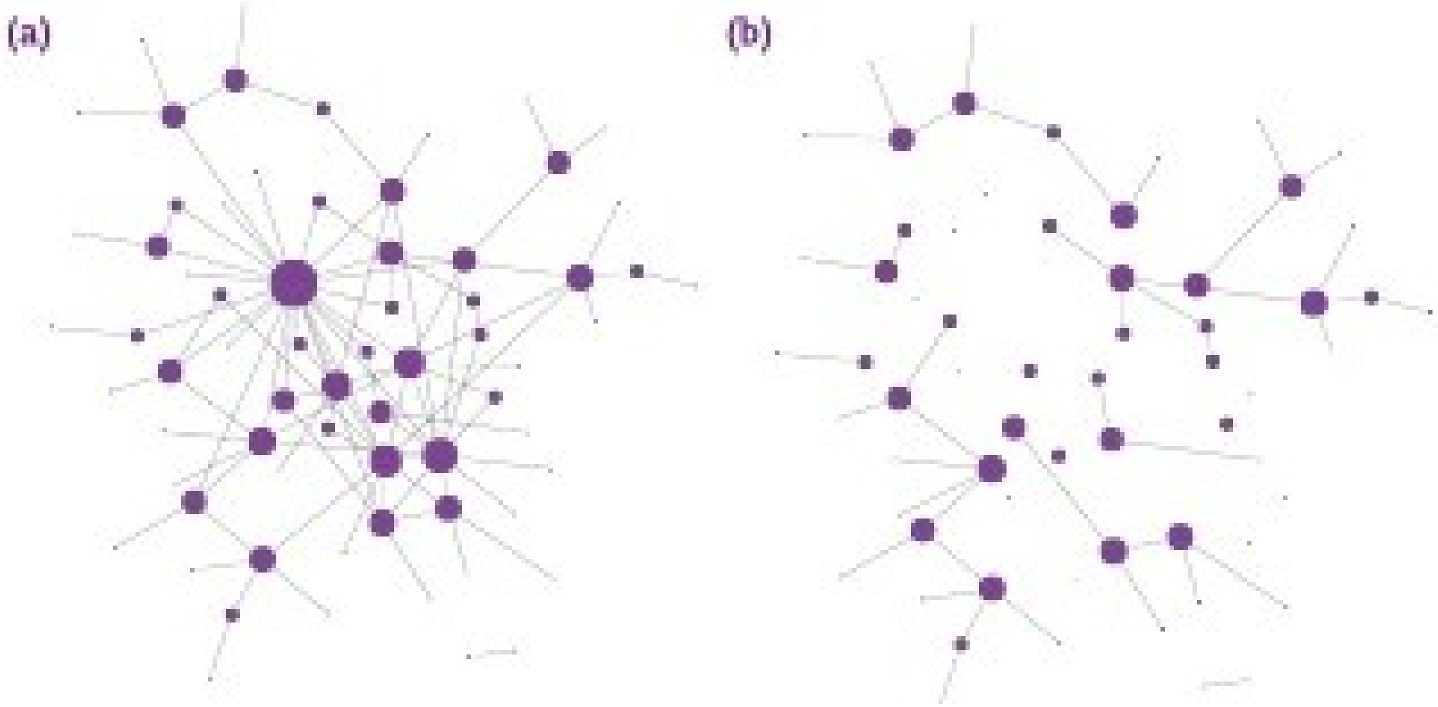
Can we protect? Immunization strategies. Herd immunization

How to control a pandemic?

- Interventions to reduce transmission (masks, gloves,…)
- Contact-reducing interventions (quarentine)
- Vaccination: remove nodes from network

Who should be first vaccinated?

Robustness and immunization



Strategies

- Random immunization
  - Random selection
- Selective immunization
  - Random selection (G0)
  - Neighbors of G0 (G1)
  - illusion of majority deg(G1) > deg(G0)
    → G1 vacinned