Infectious Disease Epidemiology Transmission Dynamics

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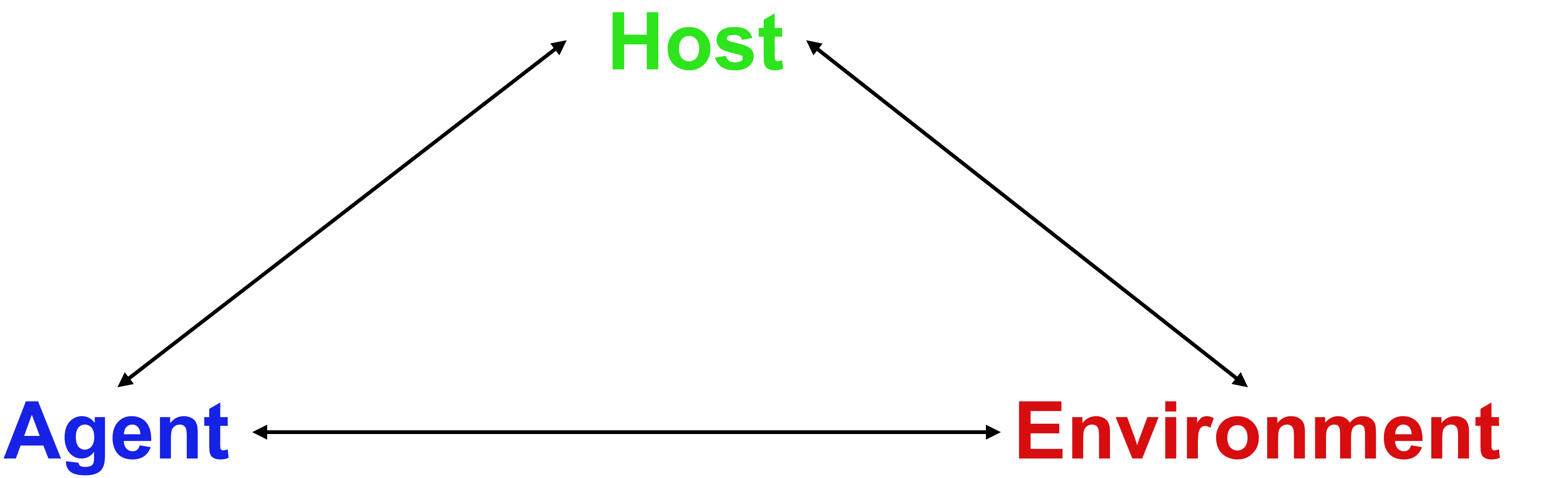
Learning Objectives

- Understand the epidemiologic triangle as a conceptual model
- Understand agent, host, and environmental factors involved in infect. disease transmission
- Learn basic infectious disease terminology and epidemiology
- Understand basic concepts of transmission dynamics

The Epidemic Triangle

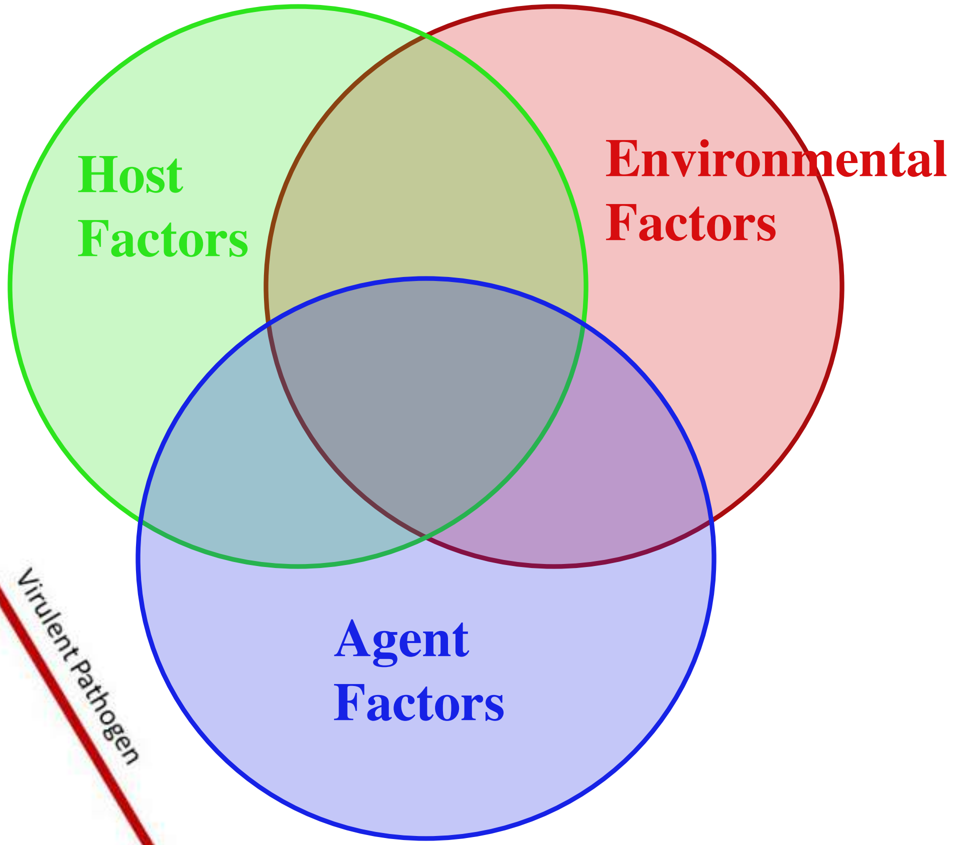
A helpful conceptual model to frame our thoughts about infectious diseases

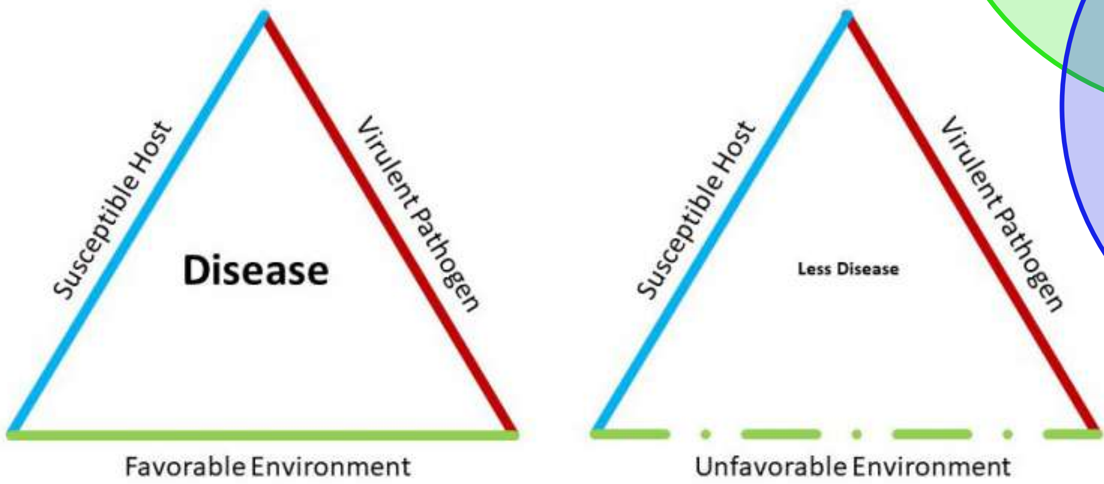


The Epidemiologic Triangle

A Multi-Causal Model

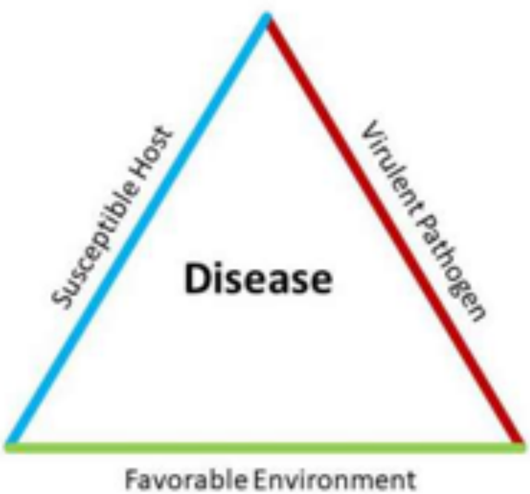
- Agent, Host, and Environment interact
- This interaction is a necessary cause for infection to occur

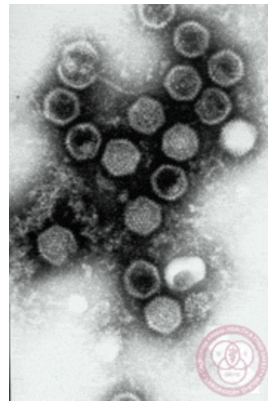


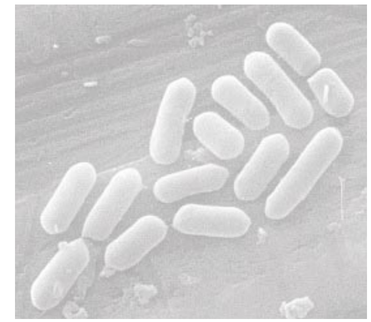


Main Infectious Disease Agents (pathogens)

- Viruses
- Bacteria
- Protozoans
- Fungi



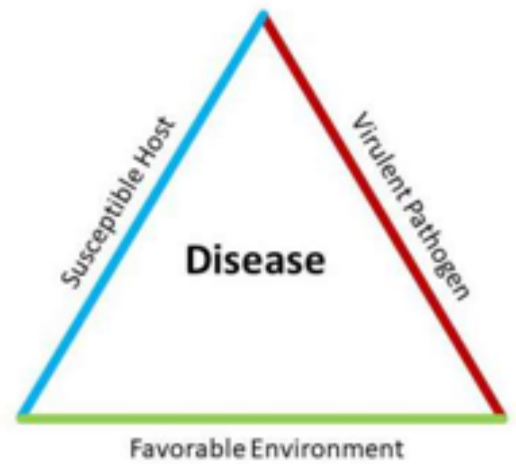

Viral Particles


Bacteria


The Protozoa
Giardia lamblia


The infectious fungus
Blastomyces dermatitidis

Infectious Disease Host Factors

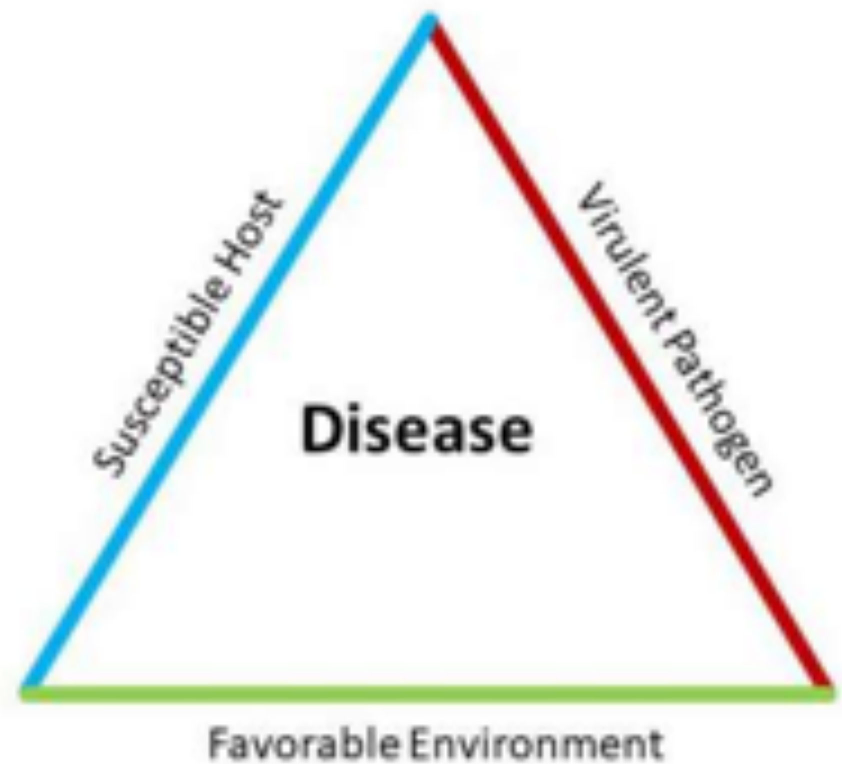


- Overall health
- Immune status
- Age
- Comorbidities and underlying health conditions
- Nutrition
- Genetics

The Environment

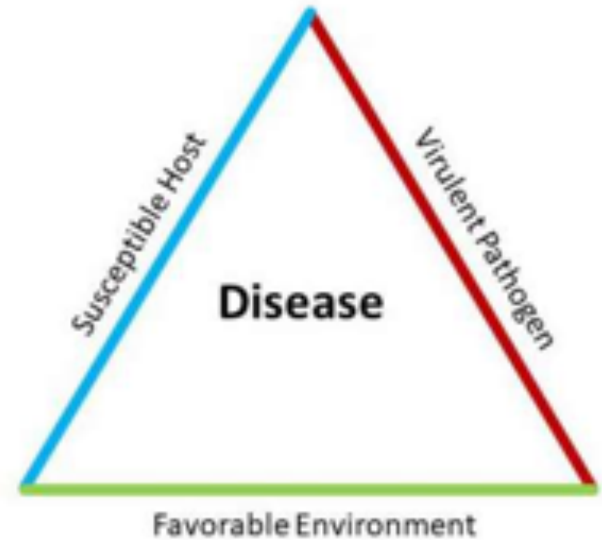
Think big! Environment can refer to:

- Physical environment
- Climactic conditions
- Ecology
- Geography
- Social environment
  - Poverty
  - Demographics
  - Urban Crowding
- Agent environment
  - Changes in microflora can tip the competitive balance and cause once harmless organisms to flourish and cause disease

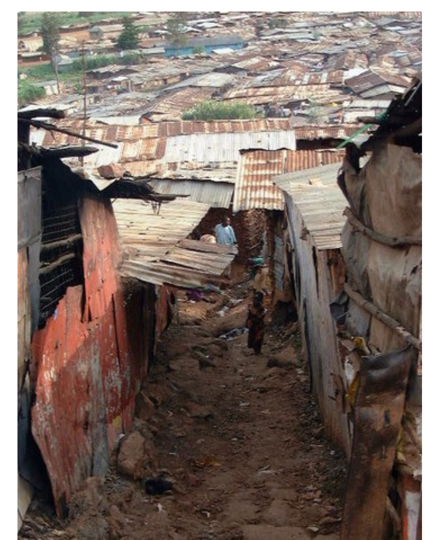


The Environment- examples

Overcrowding, poor sanitation, lack of water for hand-washing



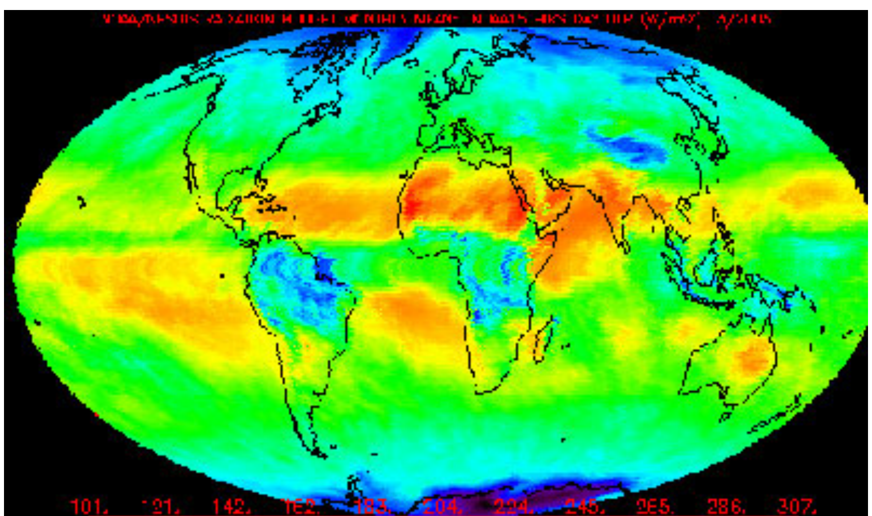
- Can increase the contact between host and agent (pathogen)
- May allow agents (pathogens) to survive well outside of a host
- Increases contact between hosts resulting in greater infection spread potential

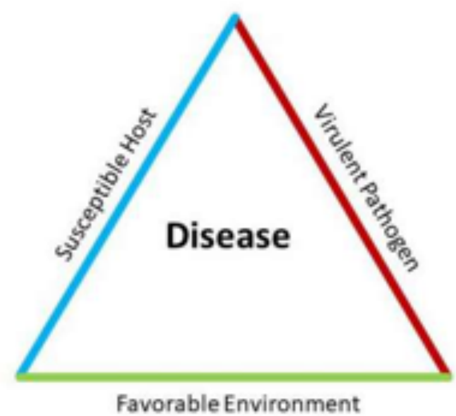


The Environment- examples

Climate and Weather

- Flooding can increase or decrease mosquito numbers
- Changing climate can alter the population of reservoir animals and their proximity to humans
- Global warming allows mosquitoes to survive at higher elevations and previously colder climates





The Triangle in Action: COVID-19

Agent (pathogen)

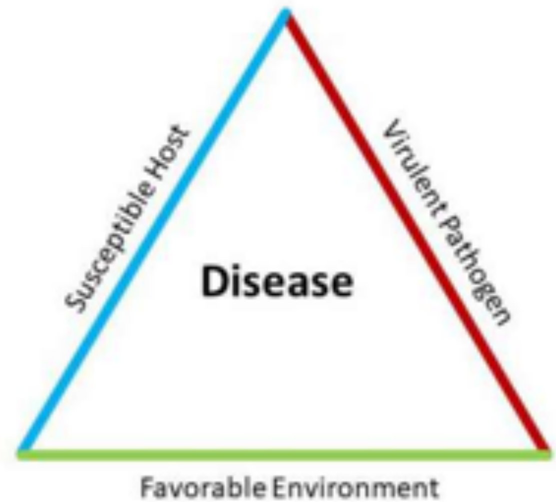
– *COVID-19 or SARS-CoV-2* is a coronavirus

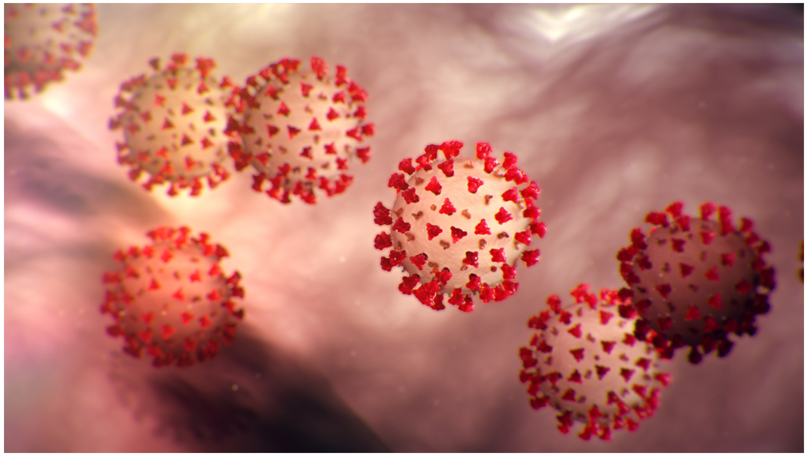
Host

– Infects humans and some animals (bats, cats, others?)
– Spreads person to person, mainly through respiratory droplets
– Highest risk= older persons, immunocompromised, people with preexisting health conditions, other factors?

Environment

- Worldwide distribution
- Demographic, political and social factors

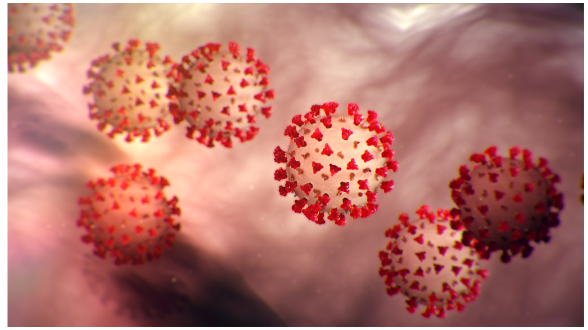


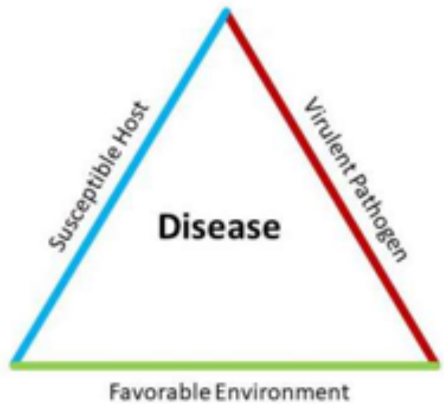


Coronavirus (COVID-19)

From cdc.gov

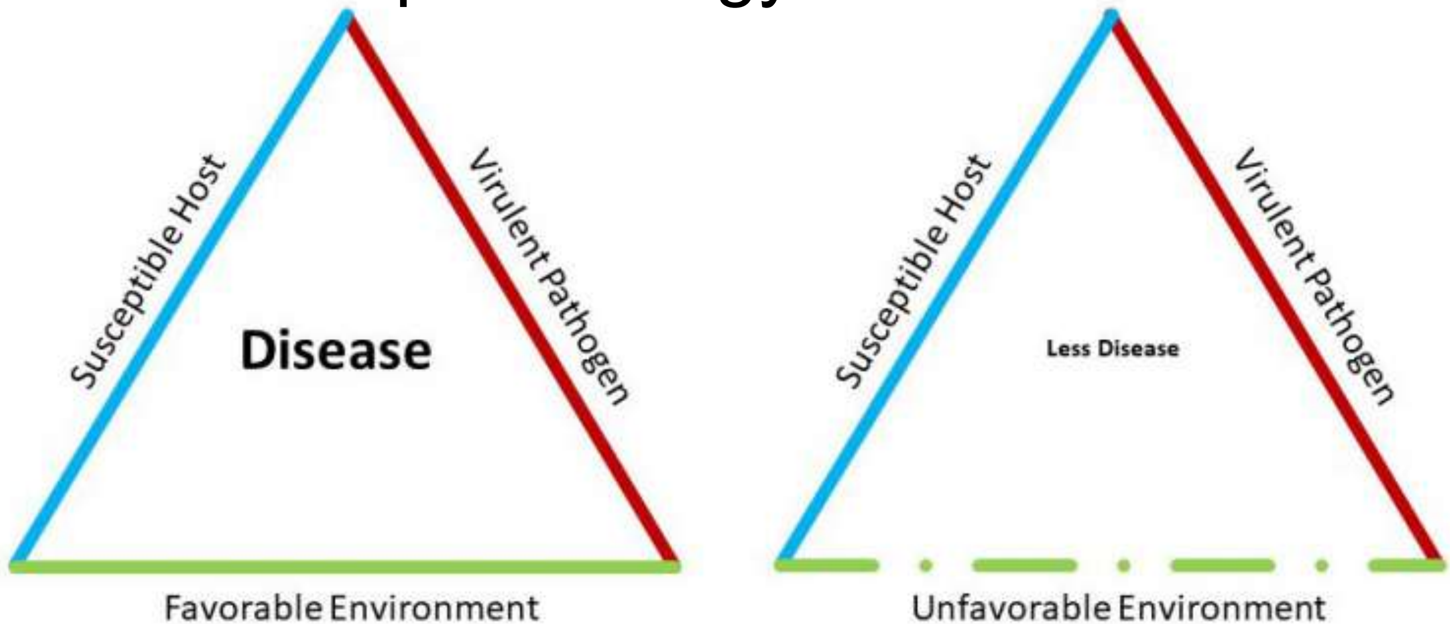
The Triangle in Action: COVID-19





Conclusion: The Epidemiologic Triangle

– A model we use to frame our ideas about infection transmission
– Focus on it as a flexible concept
– Forces a big-picture approach to infectious disease epidemiology

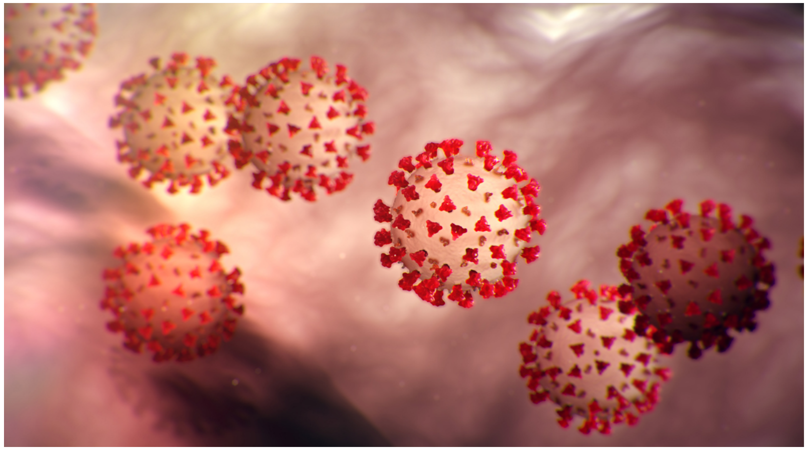


Infectious Disease Basics

- **Infection** - The invasion of a susceptible host by an infectious agent. Usually implies a relationship where the agent's benefit comes at the expense of the host

- **Infectious** - Usually refers to an infected host who is capable of *transmitting infection* to other susceptible hosts

- **Infectious Disease** - A set of physical and clinical symptoms present in an infectious host. These symptoms can result from direct pathology caused by the agent, or by damage incurred by the host's own immune response



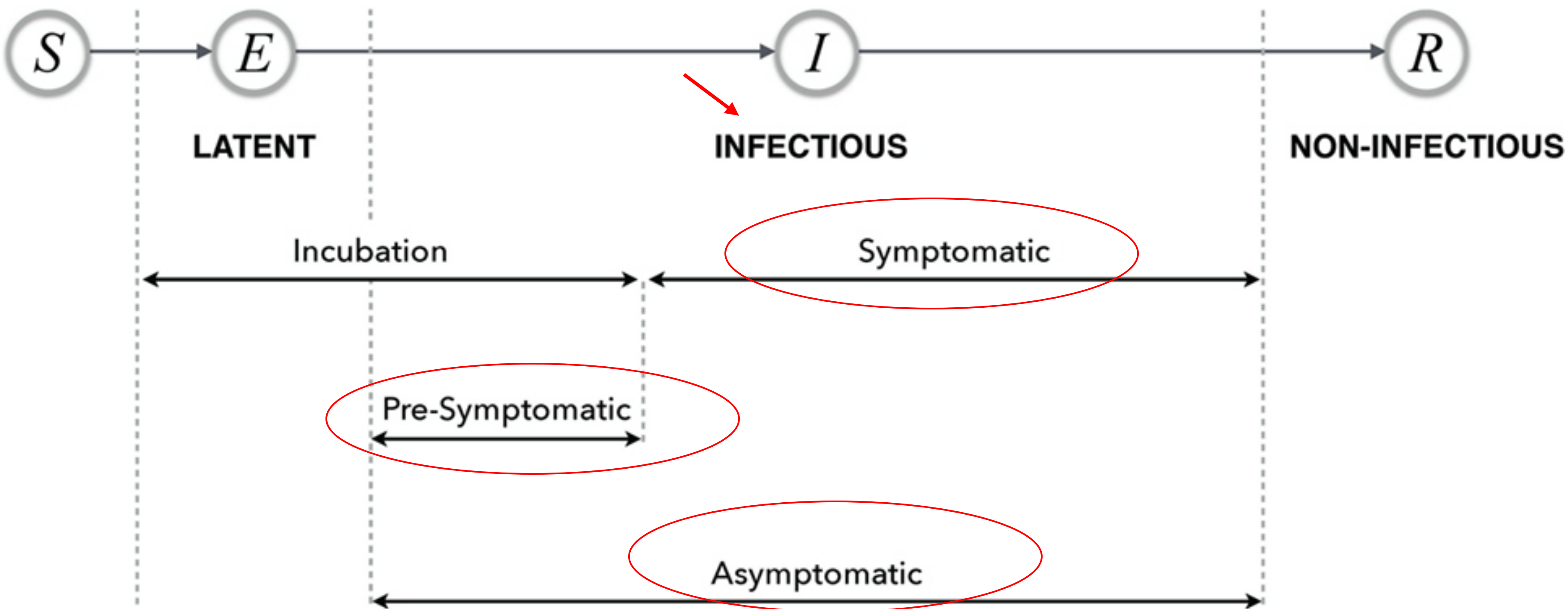
Coronavirus is an infectious agent (pathogen)

Another example: Infected, infectious and diseased= a rabid dog

Duration of <u>infectiousness</u> - The amount of time that an infected host is infectious.

Can overlap completely or partially with the duration of *infection.*

- S is the fraction of susceptible individuals (those able to contract the disease),
- E is the fraction of exposed individuals (those who have been infected but are not yet infectious),
- I is the fraction of infective individuals (those capable of transmitting the disease),
- R is the fraction of recovered individuals (those who have become immune).



Transmission Dynamics

- The basic reproductive number (Ro)
- Transmission probabilities
- Population mixing
- Modeling disease transmission

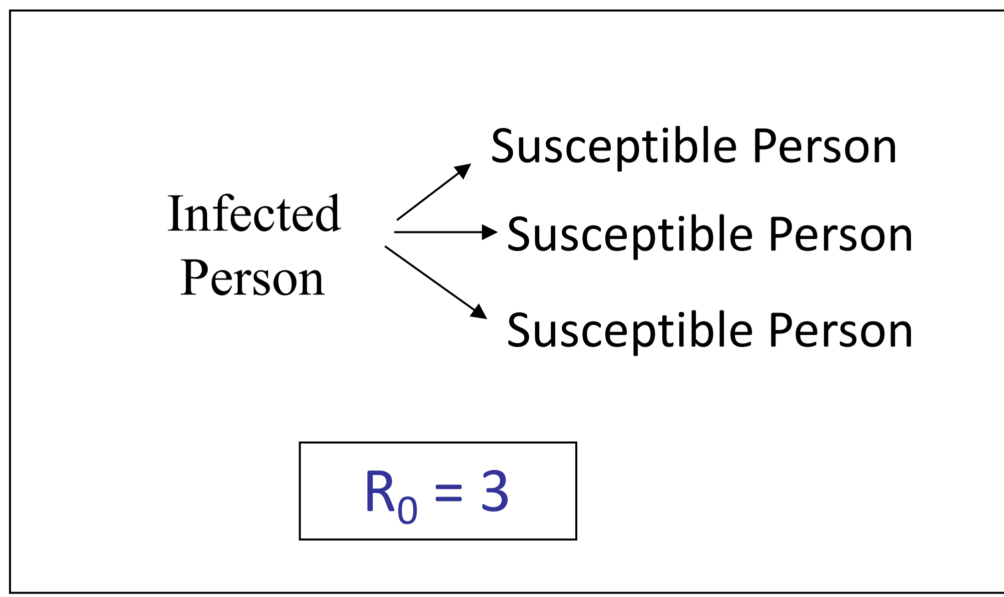
Main Goal:

that you understand why and, to a certain extent, how we model infectious disease transmission

Basic Reproductive Number (R_0)

- Average number of secondary infections caused by introducing a single infected person (infectious individual) into an entirely susceptible population
- A value that shows how an infectious disease will spread in a population

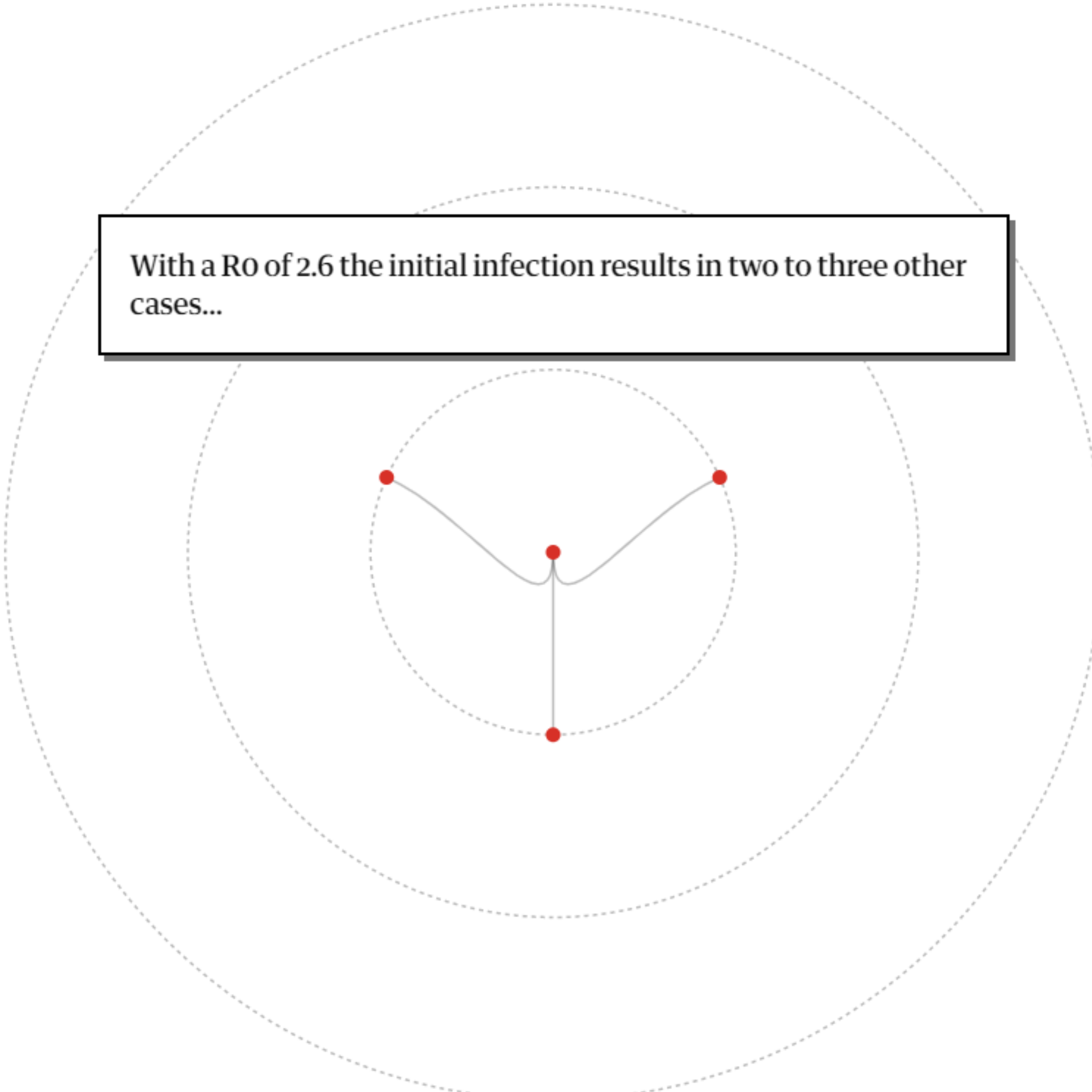
I = Infected individual
S = Susceptible individual (not-immune)
→ = Transmission



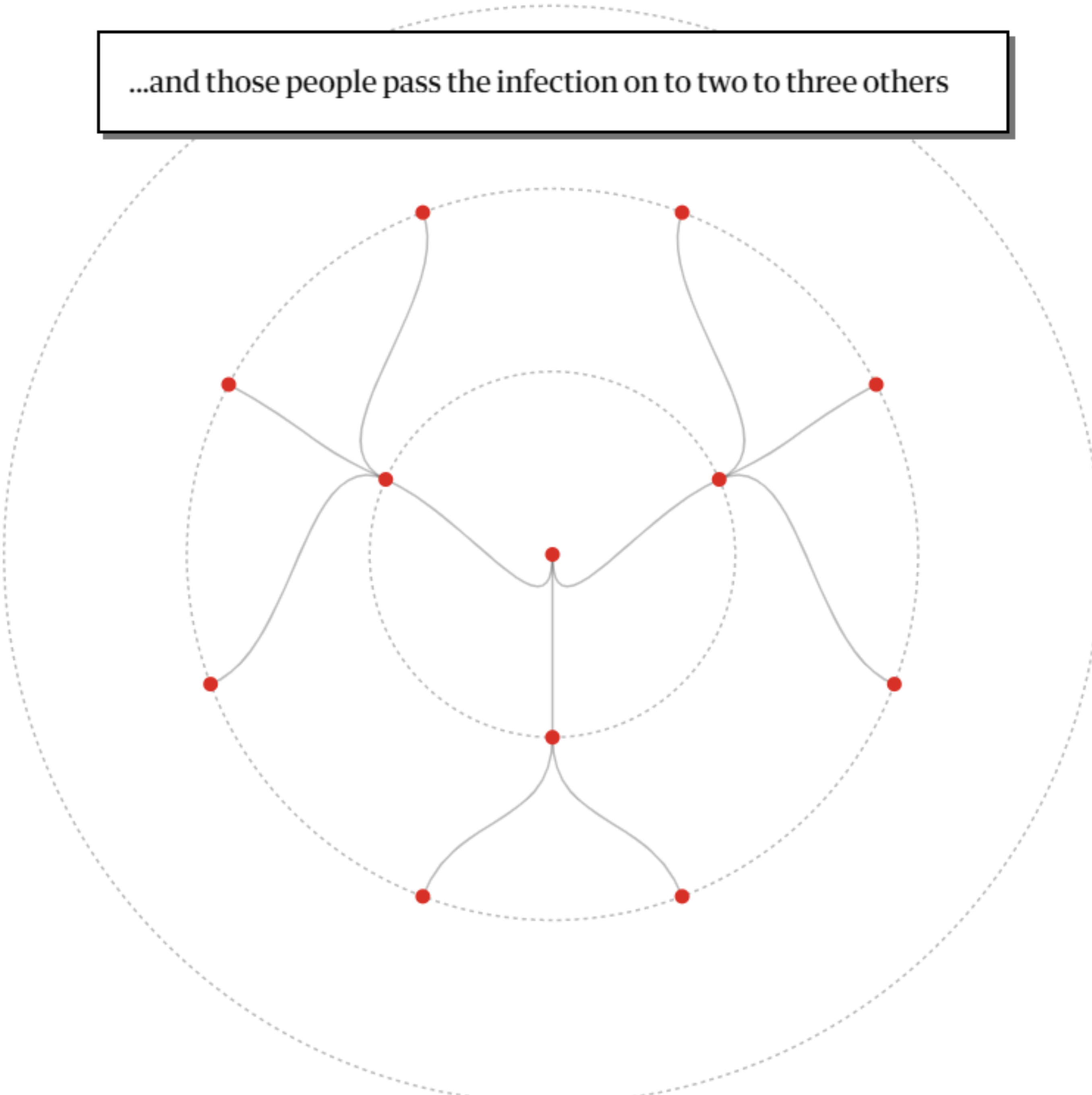
Ro represents an **epidemic threshold**

- Ro > 1 epidemic
- Ro < 1 extinction
- Ro = 1 endemic (stable disease prevalence)

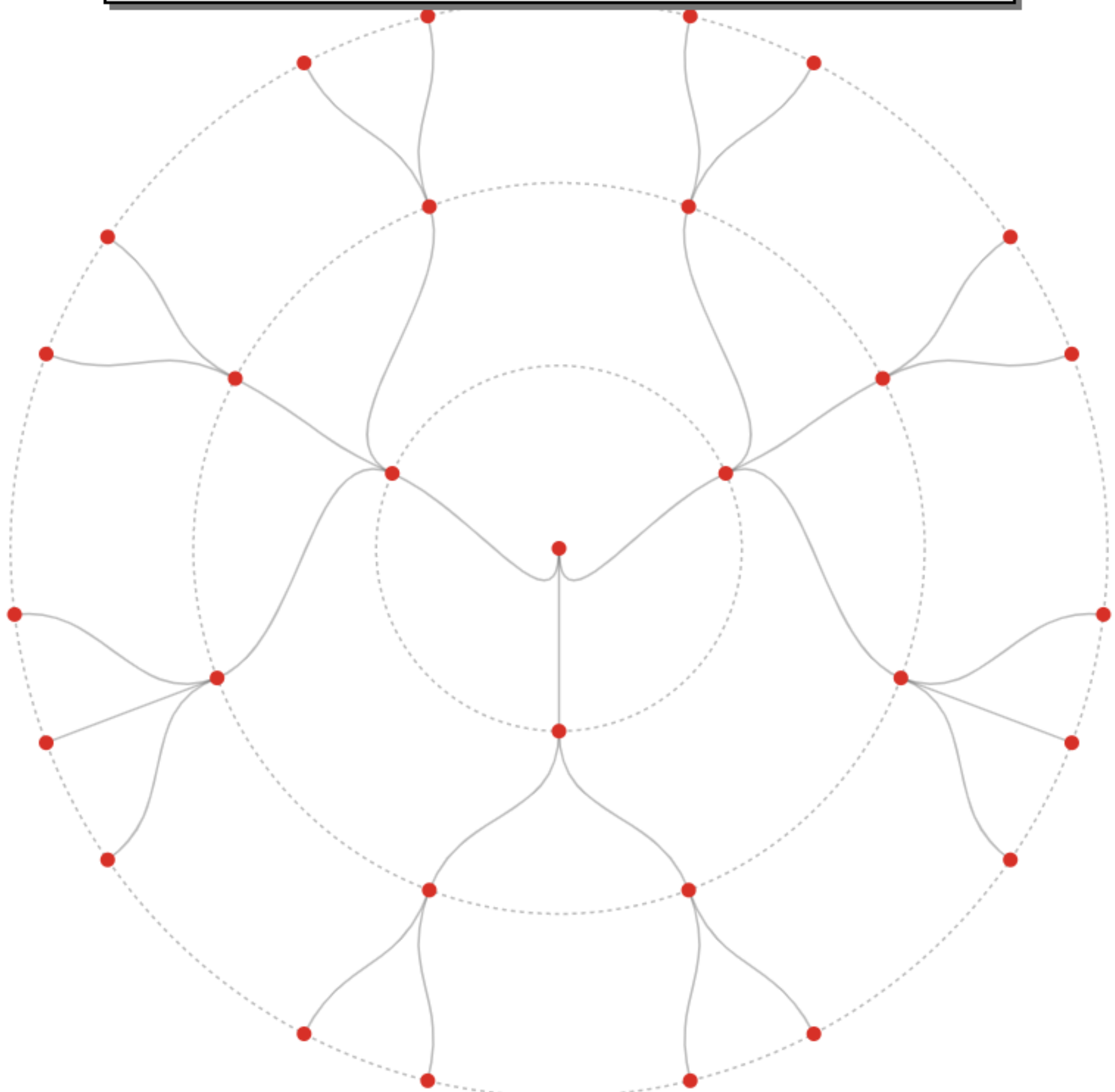
With a R0 of 2.6 the initial infection results in two to three other cases...



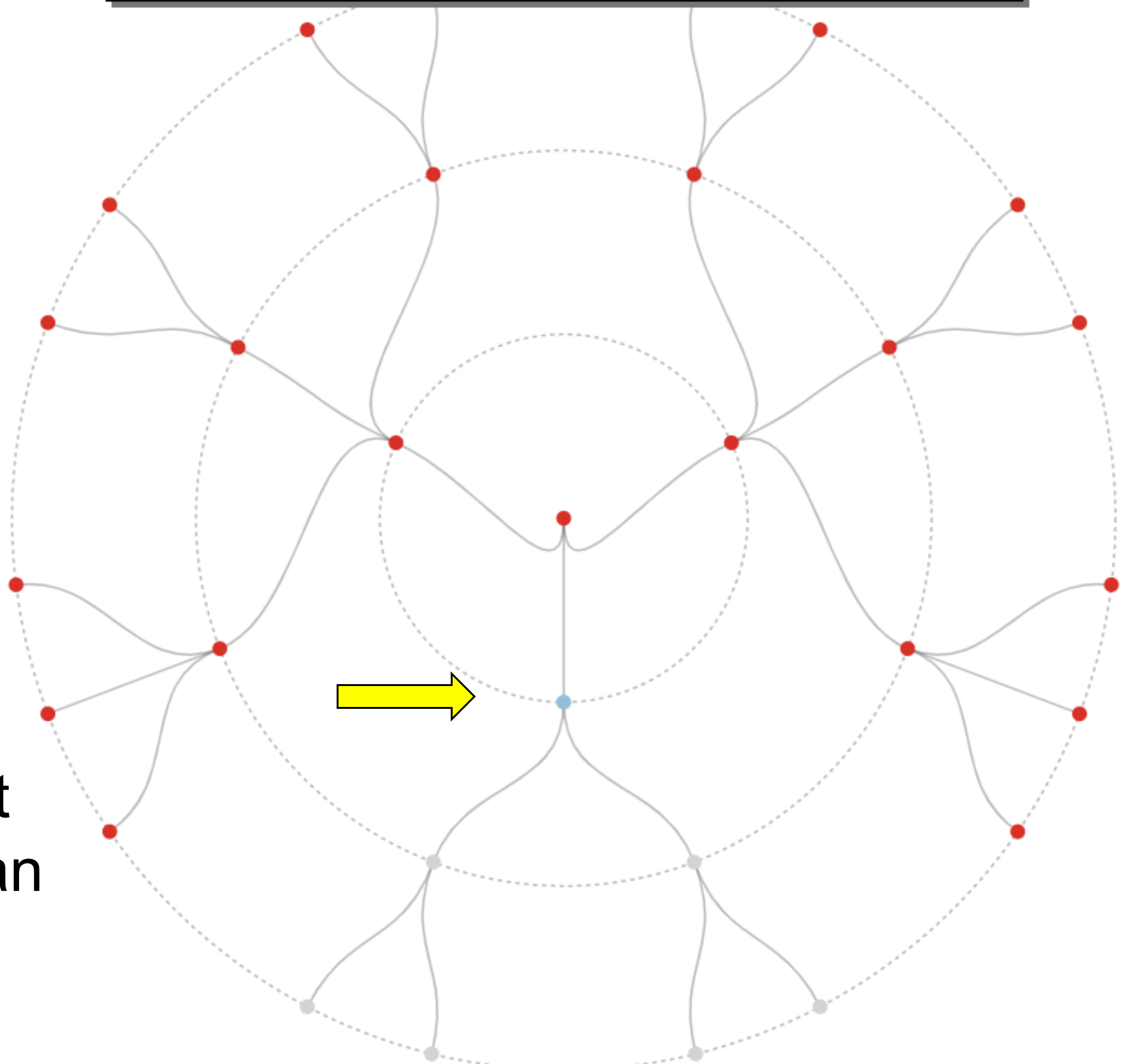
...and those people pass the infection on to two to three others



...And so on. In the case of the Covid-19 virus each new phase takes on average between five and six days.



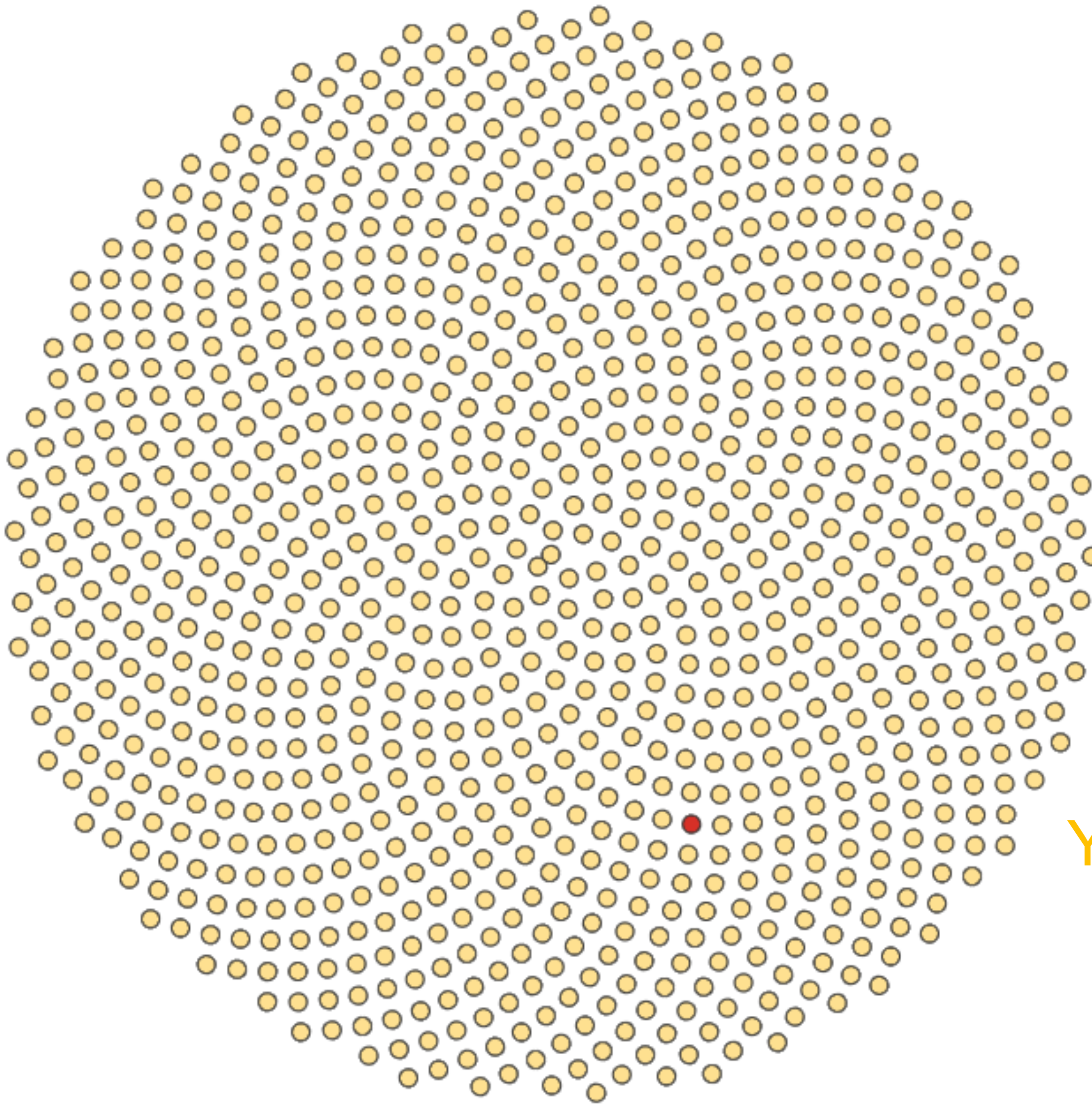
Here we can see how the spread is drastically reduced by isolating just one individual.



The blue dot represents an infectious person who was isolated from others

Total infected: 23 instead of 30

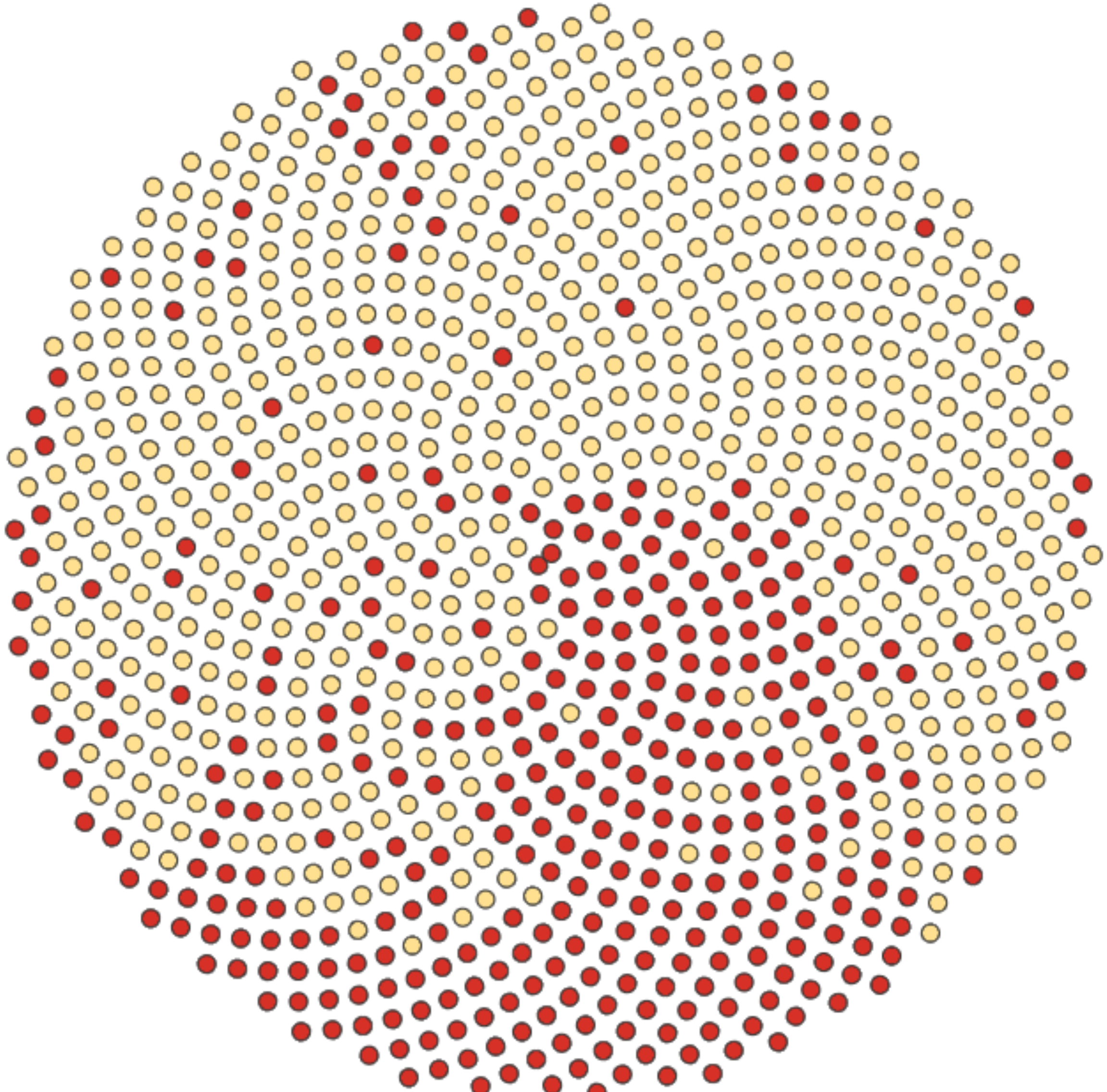
Here, we start with a single person carrying an infection in a hypothetical population of 1,000 uninfected people.



Red dot = one infected (infectious) person

Yellow dots = currently uninfected people

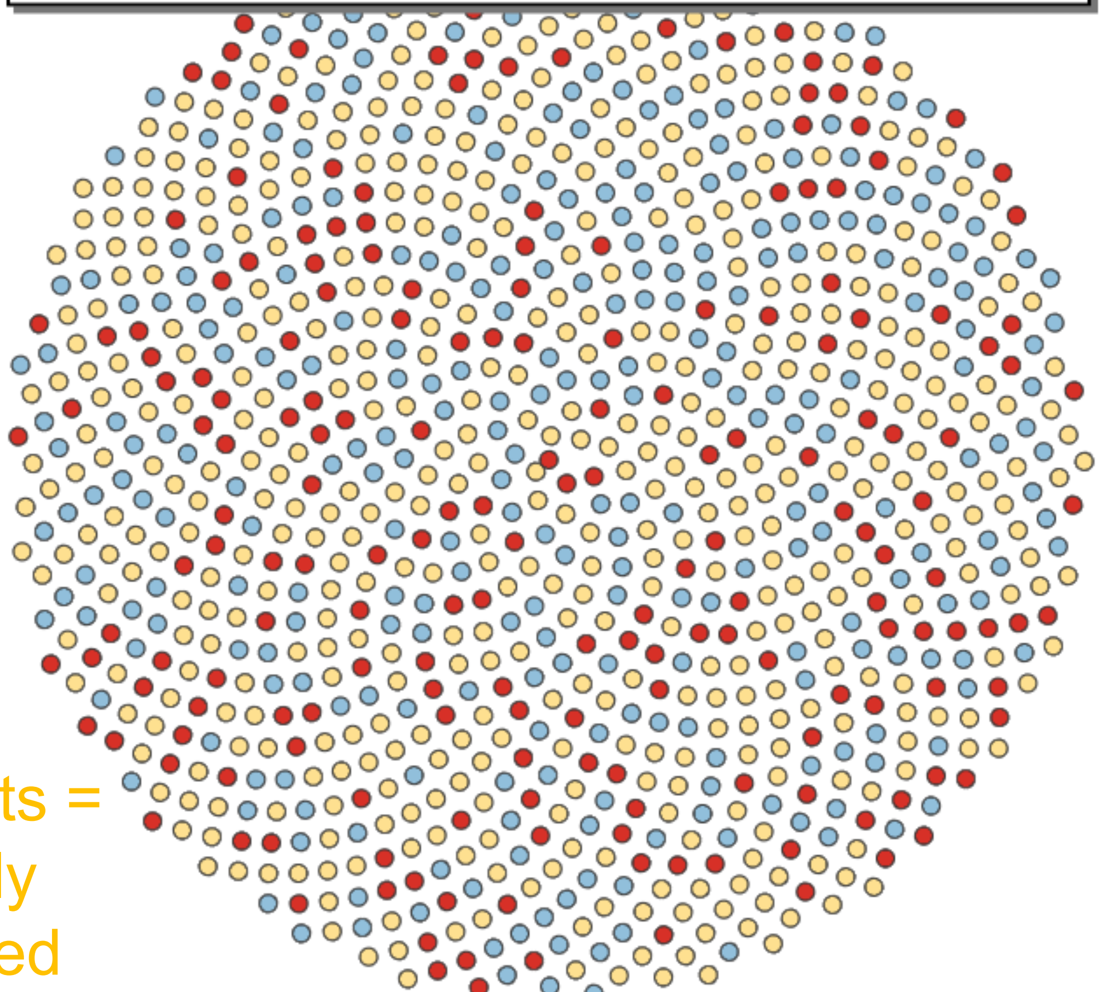
With any R value greater than 1, and a population that is entirely susceptible, the infection will spread throughout.



Ro > 1

Red dots = infected and then infectious people (increasing over time)

But if some people are not susceptible to infection - because of immunity through vaccination, because they have previously been infected or because of other biological reasons - or if transmission is curbed due to part of the population being isolated, then the effective R value becomes lower, and the spread is incomplete, and slowed.

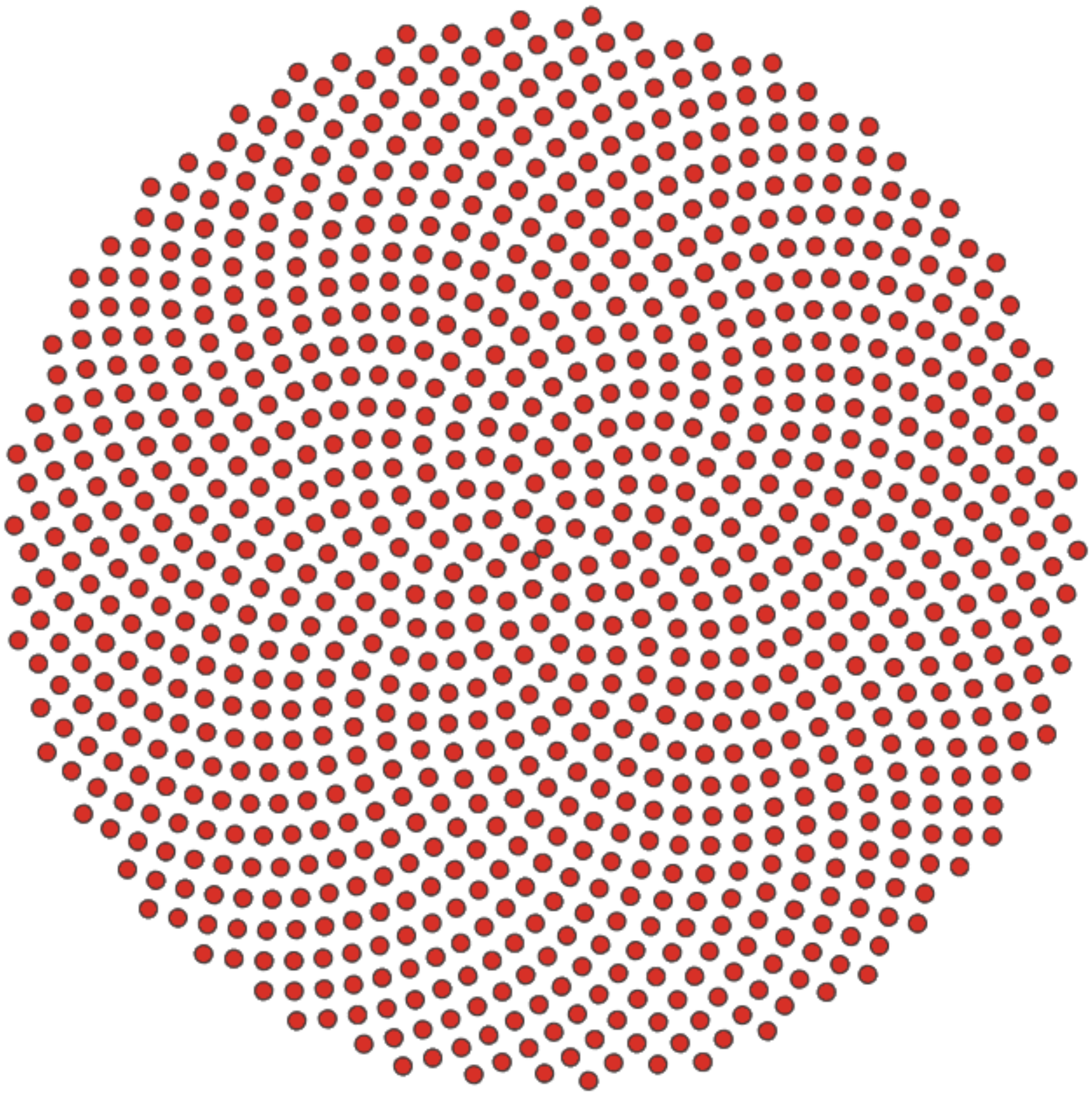


Red dots = infected and infectious people (transmitting to the yellow people)

Blue dots = isolated people (not transmitting to others)

Yellow dots = currently uninfected people

With any R value greater than 1, and a population that is entirely susceptible, the infection will spread throughout.



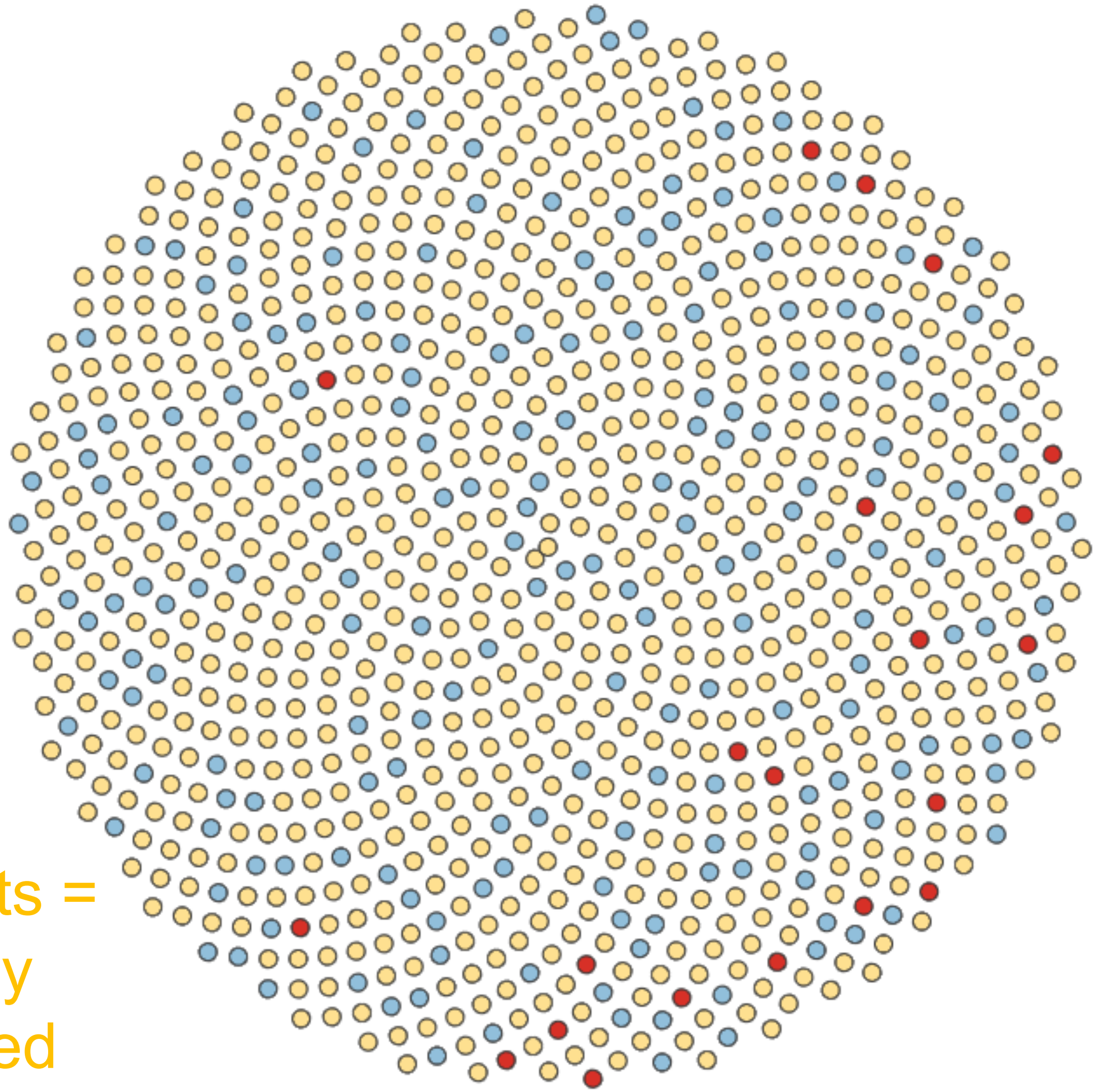
Ro > 1

Red dots = infected people

<u>What we want to prevent (exponential spread)!</u>

If the effective R is reduced below one, the spread can be halted. Reducing the R generally will also allow healthcare systems to better cope with the influx of patients.

Ro < 1



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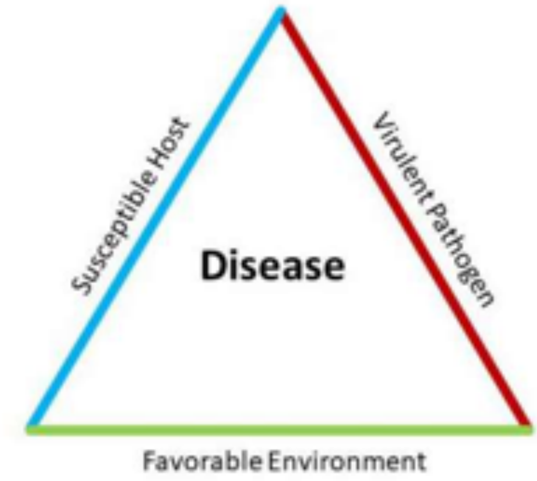
Ro is determined by:



- Pathogen biology
- Host factors (e.g. genetics, nutrition, age, comorbidities, overall health)
- Host behaviors (e.g. going out vs. staying in, using a mask, maintaining social distancing, cultural practices)
- Population structure (e.g. demography, contact patterns, geographic dispersion)

How would an asymptomatic disease affect Ro?

- Would a large number of people with asymptomatic disease affect the transmission probability?
- Asymptomatic disease may lead to a greater transmission probability
- Asymptomatic infection may be associated with a persons' behavior (e.g. the person may not stay at home and may be out and about), leading to higher transmission rates

How would virulence affect Ro?

- Would severe illness or death from the disease change the transmission probability?
- Depends on the disease: increased virulence may lead to a greater transmission probability or a lower transmission probability
- High levels of virulence are often associated with high viral loads or increased secretions that can transmit virus, and this may affect the transmission rate
- High levels of virulence may also be associated with changes in the persons’ behavior (e.g. the person may stay at home or be hospitalized if they are very ill), leading to lower transmission rates

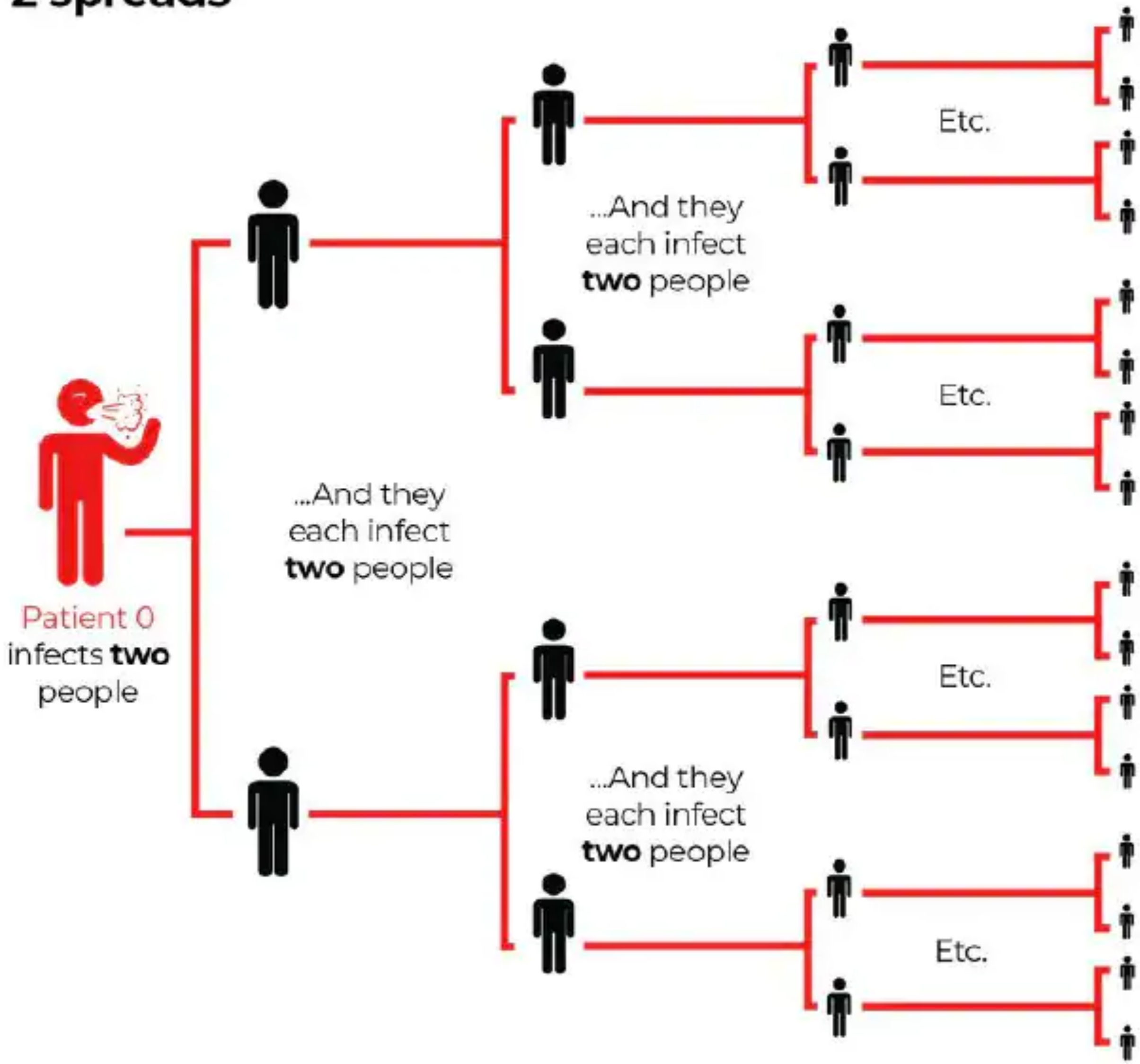
Effective reproduction number (Called R_e or Rt or R)

Average number of secondary infections that arise from a typical primary case during the entire course of his/her infectious period.

Ro vs. Rt

- Ro is the reproductive rate when everyone is susceptible
- Rt or R or Re is the **effective reproductive number** - it describes the reproductive rate as susceptibles are removed from the population (i.e. via recovering from infection with immunity or from vaccination)
- Rt = Ro(S/N) where S is the number of susceptibles and N is the population size
  - Notice that at the beginning of the epidemic, when everyone is susceptible, Rt=Ro
  - As the epidemic proceeds and susceptibles are removed from the population, Rt decreases
  - This is why epidemics die out
- When Rt drops below 1, the epidemic eventually halts

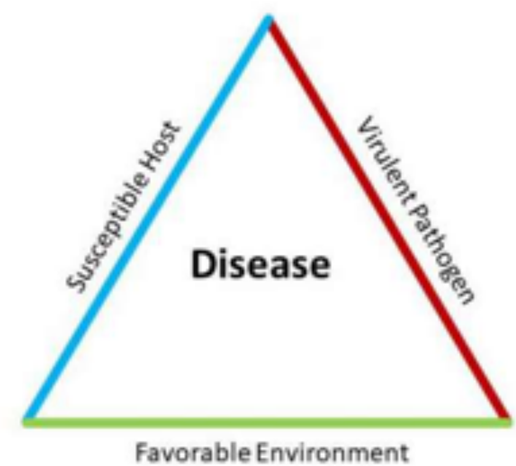
How a virus with a reproduction number (R0) of 2 spreads



Wrapping Up

Infectious Disease Epidemiology
& Transmission Dynamics

- Host (pathogen), environmental, and agent factors that facilitate transmission



- Described by:
  - Basic Reproductive number, or threshold
  - Transmission Probability
  - Infectious Periods
  - Population Mixing

- Mathematical Modeling
  - A tool that we use to understand transmission dynamics

Worked Example of Ro Calculation

- Transmission probability = 0.4
- Average # effective contacts per infectious person = 3
- Recovery rate (γ) = 0.25
- R_0 = ?

$R_0 = \beta * c / \gamma = 0.4 * 3 / 0.25 = 4.8$

Note: duration = $1/\gamma = 1/0.25 = 4$

$R_0 = \beta * c * d = 0.4 * 3 * 4 = 4.8$

Worked Example of Rt Calculation

- R_t = Ro * (S/N)
- so Rt = (β*c*d) * (S/N)
- S = # susceptible people in population =1900
- N = total population size = 2000
- Ro= 2
- Rt = ?

R_t = 2 * (1900/2000) = 1.9 (disease will spread)

95% of population susceptible and

Ro=2

Reference

- The illustrative graphics showing Ro come from: https://www.theguardian.com/world/datablog/ng-interactive/2020/apr/22/see-how-coronavirus-can-spread-through-a-population-and-how-countries-flatten-the-curve