CT561: Systems Modelling & Simulation

Lecture 9: SIR Model Part 1

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https://github.com/JimDuggan/SDMR

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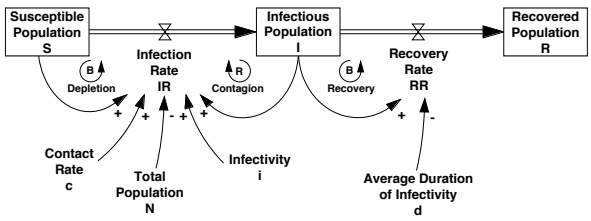
Public Health: Modelling Infectious Disease Outbreaks

- Context
- SIR Model
- Related variables



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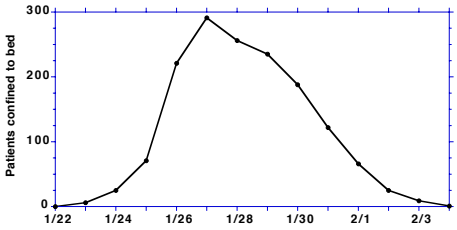
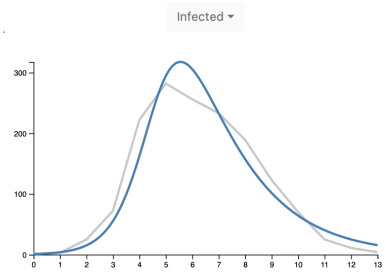
(1) Context – Outbreak Dynamics

Figure 9-3
Dynamics of epidemic disease
Sources: British Medical Journal, 4 March 1978, p. 587;.



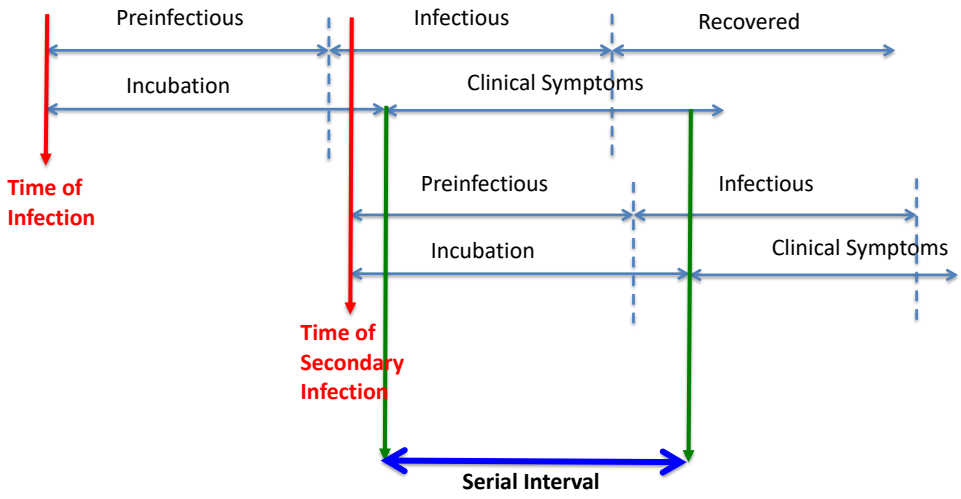


Influenza epidemic at an English boarding school, January 22-February 3, 1978. The data show the number of students Confined to bed for influenza at any time (the stock of symptomatic individuals).

Examples of Infectious Agents – Microparasites (Vynnycky & White)

Type of Agent	Characteristics	Examples
Virus	Small, simple, obligatory parasites of larger cells	Measles, Mumps, Rubella, Ebola, Smallpox, SARS, Influenza
Bacteria	Larger and more complex than viruses- many are able to grow independently but some require a cell host	Bordella pertussis (whooping cough), Mycobacterium tuberculosis (tubercolosis), Salmonella typhi (typhoid fever)
Protozoa	Large single-celled organisms, more complex than bacteria- many are able to grow independently but some require a cell host	Plasmodium falciparum (Malaria)

Typical Life cycle of infection.



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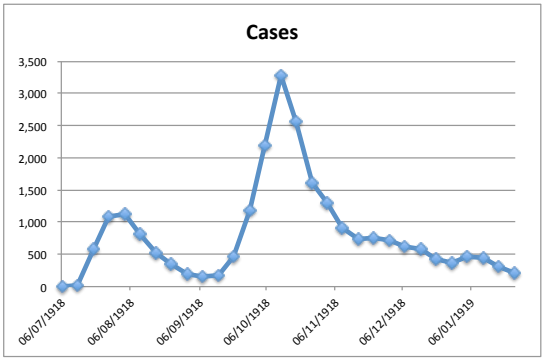
Data from 1918/19

- The second wave of the 1918 pandemic was much deadlier than the first.
- The first wave had resembled typical flu epidemics; those most at risk were the sick and elderly, while younger, healthier people recovered easily.
- But in August, when the second wave began in France, Sierra Leone and the United States, the virus had mutated to a much deadlier form. This has been attributed to the circumstances of the First World War.

Gothenberg Data 1918/19



http://en.wikipedia.org/wiki/1918_flu_pandemic

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Challenge 9.1

https://github.com/owid/covid-19 data/tree/master/public/data

- Explore the data set our world in data (COVID-19)
- Focus on the epidemic curves (behaviour over time)

README.md

Data on COVID-19 (coronavirus) by *Our World in Data*

Our complete COVID-19 dataset is a collection of the COVID-19 data maintained by *Our World in Data*. It is updated daily and includes data on confirmed cases, deaths, hospitalizations, and testing, as well as other variables of potential interest.

Download our complete COVID-19 dataset : CSV | XLSX | JSON

We will continue to publish up-to-date data on confirmed cases, deaths, hospitalizations, and testing, throughout the duration of the COVID-19 pandemic.

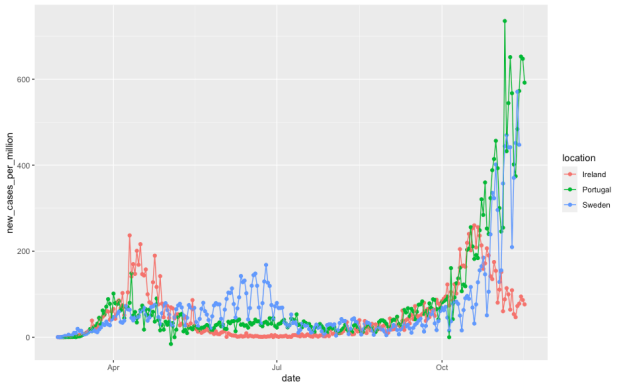
Our data sources

- **Confirmed cases and deaths:** our data comes from the European Centre for Disease Prevention and Control (ECDC). We discuss how and when the ECDC collects and publishes this data here. The cases & deaths dataset is updated daily. *Note: the number of cases or deaths reported by any institution—including the ECDC, the WHO, Johns Hopkins and others—on a given day does not necessarily represent the actual number on that date. This is because of the long reporting chain that exists between a new case/death and its inclusion in statistics.* ***This also means that negative values in cases and deaths can sometimes appear when a country sends a correction to the ECDC, because it had previously overestimated the number of cases/deaths. Alternatively, large changes can sometimes (although rarely) be made to a country's entire time series if the ECDC decides (and has access to the necessary data) to correct values retrospectively.***

A	B	C	D	E	F	G	H	I	J	K	L	M
iso_code	continent	location	date	total_cases	new_cases	cases_smoo	total_death	new_death	deaths_smo	cases_per_r	ases_per_r	moothed_
ABW	North America	Aruba	2020-03-13	2	2			0		18.733	18.733	
ABW	North America	Aruba	2020-03-19			0.286			0			2.676
ABW	North America	Aruba	2020-03-20	4	2	0.286		0	0	37.465	18.733	2.676
ABW	North America	Aruba	2020-03-21			0.286			0			2.676
ABW	North America	Aruba	2020-03-22			0.286			0			2.676
ABW	North America	Aruba	2020-03-23			0.286			0			2.676
ABW	North America	Aruba	2020-03-24	12	8	1.429		0	0	112.395	74.93	13.38
ABW	North America	Aruba	2020-03-25	17	5	2.143		0	0	159.227	46.831	20.071
ABW	North America	Aruba	2020-03-26	19	2	2.429		0	0	177.959	18.733	22.747

(2) Susceptible-Infected-Recovered Model

- The total population of a region/community is divided into three categories:
  - Those susceptible to the disease (S)
  - Those who are infectious (I)
  - Those who have recovered (R)
- Births, deaths & migration ignored
- Population homogenous (no sub-groups)
- Once infected people recover after a time lag



Stocks and Flows

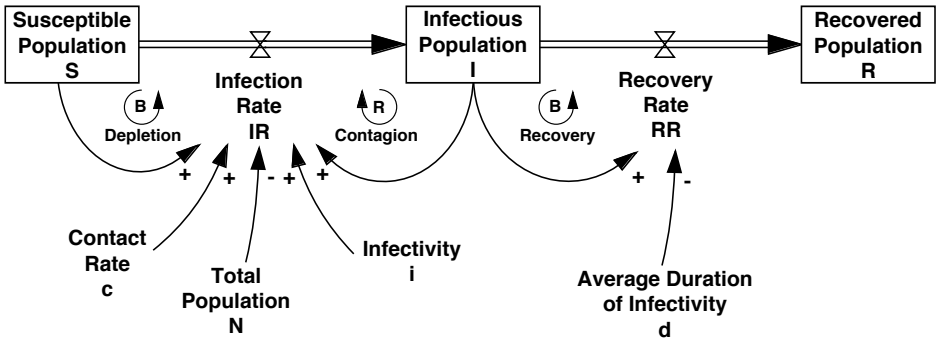


Figure 9-5 People remain infectious (and sick) for a limited time, then recover and develop immunity.

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Stock Equations

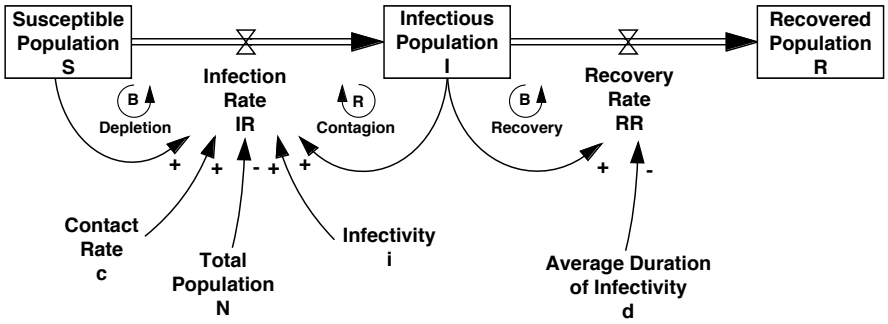

Figure 9-5 People remain infectious (and sick) for a limited time, then recover and develop immunity.

S = INTEG(-IR, 9999)

I = INTEG(IR-RR, 1)

R = INTEG(RR,0)

RR = I / d

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Formulate the Infection Rate

- **Contact Rate** (people/person/time period)
- **Number of Infected**

Product is the Number of encounters for Infectious People per time period

- **Number of Susceptible**
- **Total Population**

Ratio is the chance of meeting a Susceptible Person

- **Infectivity**

Probability that an encounter with a **Susceptible Person** will lead to an infection

IR = Contact Rate * Infectious * (Susceptible/N) * Infectivity

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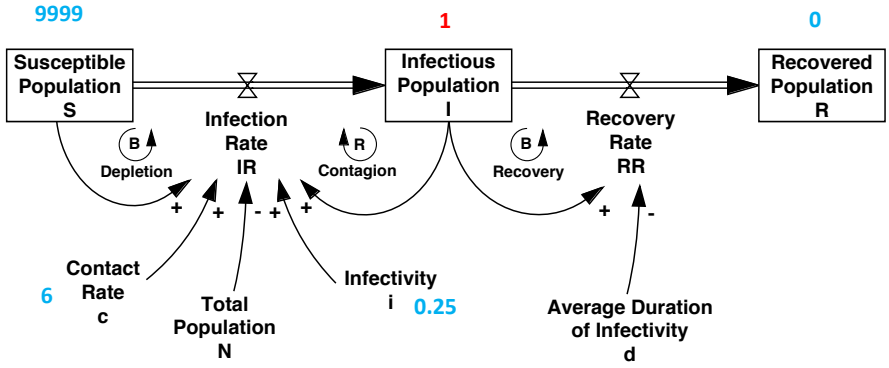
Example



Number of Infectious Contacts = 1 * 6 = 6 (#Encounters for infectious people)
Chance of Meeting Susceptible = 9999/10000 = 0.999
Probability of Transmission = 0.25

IR = 6 * 0.9999 * 0.25 = 1.4985

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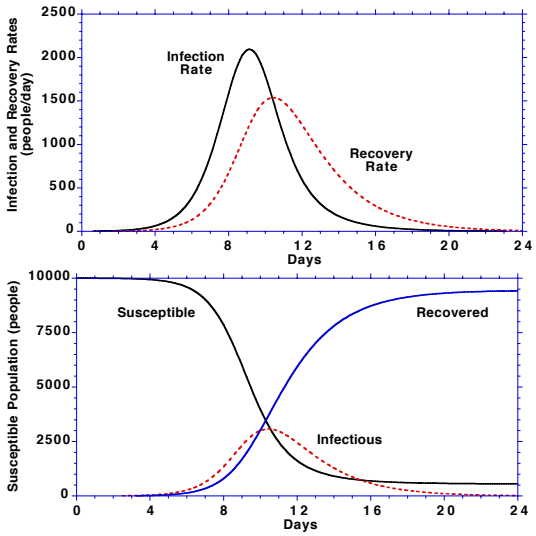
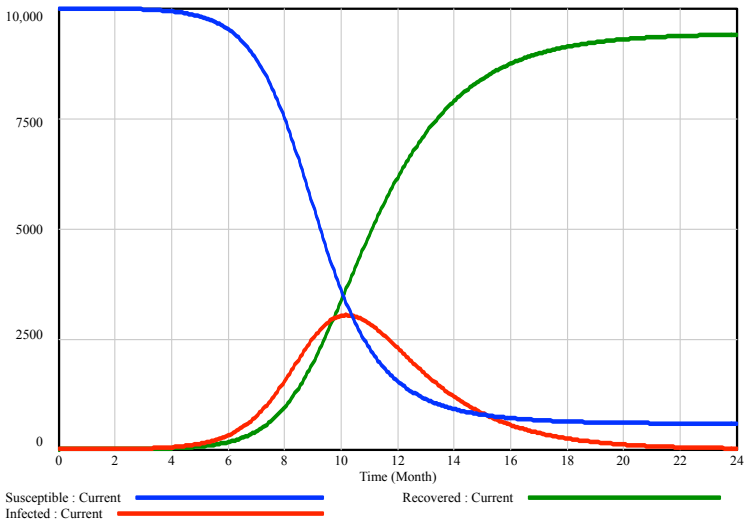


Figure 9-6 Simulation of an epidemic in the SIR model. The total population is 10,000. The contact rate is 6 per person per day, infectivity is 0.25, and average duration of infectivity is 2 days. The initial infective population is 1, and all others are initially susceptible.

Vensim Output



Epidemic dynamics for different contact rates

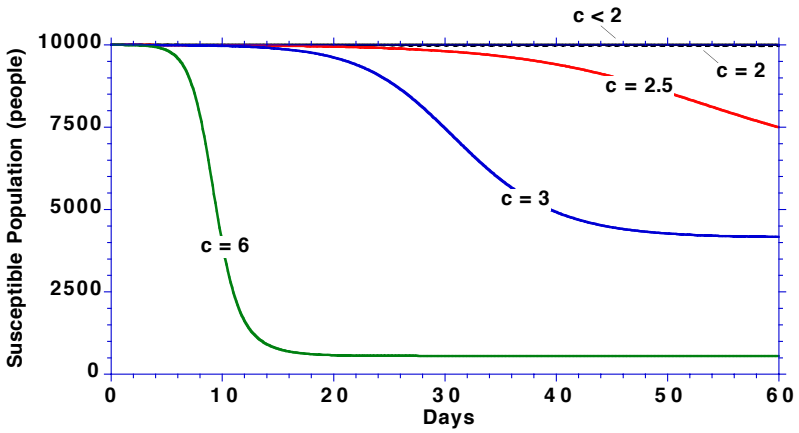


Figure 9-7 The contact rate is noted on each curve; all other parameters are as in Figure 9-6.

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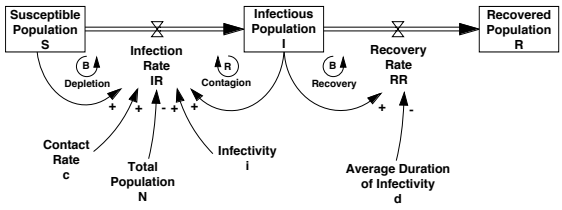
Summary:
Key feature of SIR model

- It captures a fundamental feature of infectious diseases
- The disease spreads through contact between susceptible and infectious
- Nonlinear equation



IR = Contact Rate * Infectious * (Susceptible/N) * Infectivity

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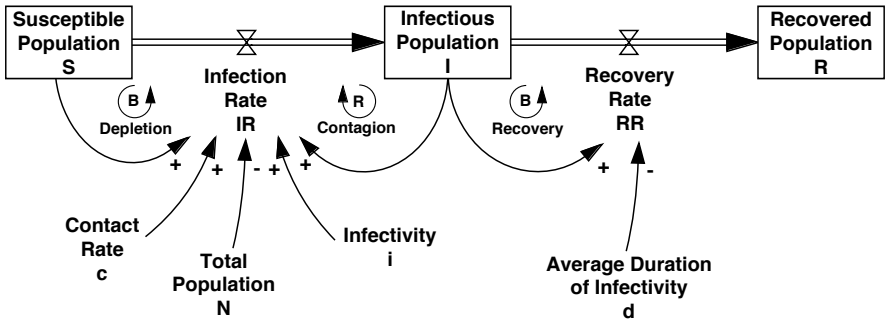
Challenge 9.2



- Explore the SIR Model
- What three model conditions will halt disease spread?

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(3) Related variables

- Effective contacts
- Reproduction Number

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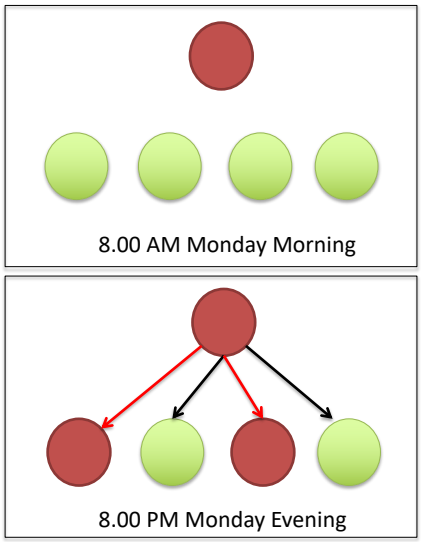
Effective Contacts (C_e) = c * i

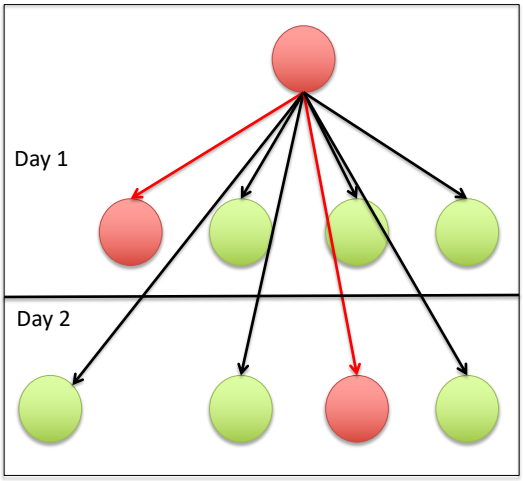
- Defined as one which is sufficient to lead to infection, were it to occur between a **susceptible** and **infectious** individuals
- For example, if C_e = 2
  - An infectious person will infect two susceptible people in one day
  - They could meet 4 people, and pass on the virus with probability (0.50)



Reproduction Number – R_0

- Formally defined as the average number of secondary infectious resulting from a typical infectious person being introduced to a totally susceptible population

$$R_0 = c_e D$$



$D = 2 \quad c_e = 1 \quad R_0 = 2$

Approximate data for common potentially vaccine-preventable diseases

Infection	Serial Interval (Range)	R_o	Herd Immunity
Diphtheria	2-30 Days	6-7	85
Influenza	2-4 Days	2-4	50-75
Malaria	20 Days	5-100	80-99
Measles	7-16 Days	12-18	83-94
Pertussis	5-35 Days	12-17	92-94

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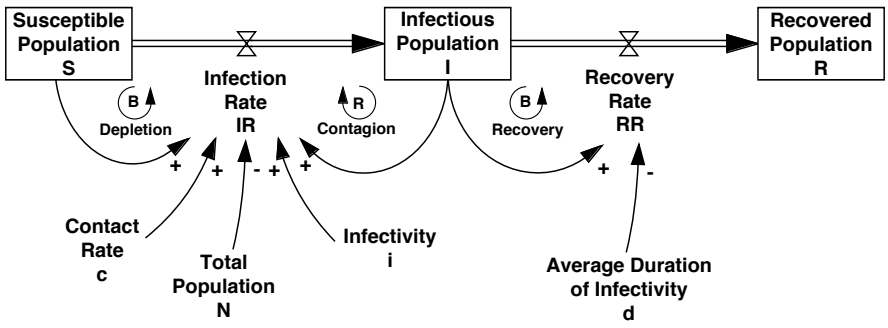
Challenge 9.3



- Add R0 to the SIR Model

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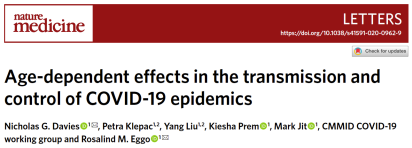
Challenge 9.4 COVID-19 Model

- Build a population model of COVID-19
- Assume an SEIR basic structure
- Assume two streams:
  - Clinical Fraction (Pre-Clinical and Clinical)
  - Sub-clinical Fraction
- Assume subclinical are 50% as infectious as clinical
- Use Population ~ 5M
- 10 People infected at start
- Estimate R0



Parameter	Description	Value
Latent Time	Time Spent in Exposed Stock	3 Days
Pre-Infectious Clinical Time	Time Spent Pre-Infectious (and spreading)	2.1 Days
Infectious Time (Clinical)	Time spent infectious (and spreading)	2.9 Days
Infectious Time (Sub Clinical)	Time spent infectious	5 Days
Clinical Fraction	Proportion of infected who show symptoms	0.60
Contacts	Contacts/Person/Day	10
Infectivity	Probability of transmission	0.10