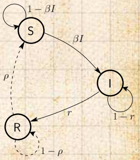
Biological Contagion

Principles of Complex Systems | @pocsvox
CSYS/MATH 300, Fall, 2017

Prof. Peter Dodds | @peterdodds

Dept. of Mathematics & Statistics | Vermont Complex Systems Center
Vermont Advanced Computing Core | University of Vermont



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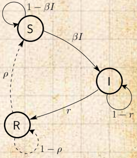

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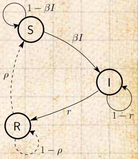
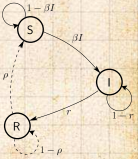


Outline




THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
MINISTRY OF RANDOM WALKS
THE UNEXPECTED TRANSFIGURATION
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
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THE MEASURING
THE DATA POOR
THE POURING DATA
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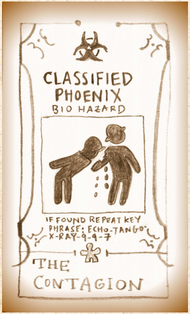
CLASSIFIED
PHOENIX
BIO HAZARD
IF FOUND REPEAT KEY PHRASE: ECHO-TANGO-X-RAY-9-9-7
THE CONTAGION


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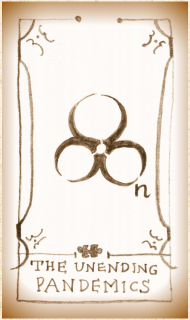
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THE UNENDING PANDEMICS

An awful recording: Wikipedia's list of epidemics from 430 BC on.

List of epidemics

From Wikipedia, the free encyclopedia

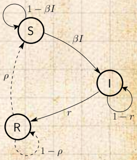
This article is a **list of epidemics** of infectious disease. Widespread and chronic complaints such as heart disease and allergy are not included if they are not thought to be infectious.

This list is incomplete; you can help by expanding it.

Death toll (estimate)	Location	Date	Comment	Disease	Reference
ca. 75,000 - 100,000	Greece	429–426 BC	Known as Plague of Athens, because it was primarily in Athens.	unknown, similar to typhoid	
ca. 30% of population	Europe, Western Asia, Northern Africa	165–180	Known as Antonine Plague, due to the name of the Roman emperor in power at the time.	unknown, symptoms similar to smallpox	
	Europe	250-266 AD	Know as the Plague of Cyprian named after St. Cyprian Bishop of Carthage.	unknown, possibly smallpox	
ca. 40% of population	Europe	541–542	Known as Plague of Justinian, due to the Byzantine emperor in power at the time.	Bubonic plague	[1]
30% to 70% of population	Europe	1346–1350	Known as "Black Death" or Second plague pandemic, first return of the plague to Europe after the Justinianic plague of the 6th century.	plague	[2]
5-15 million (80% of population)	Mexico	1545-1548	Cocoliztli	viral hemorrhagic fever	[3][4][5]
2 - 2.5 million (50% of population)	Mexico	1576	Cocoliztli	viral hemorrhagic fever	[6][7][8]
	Seneca nation	1592–1596		measles	[9]


Plague panel with the triumph of death. 1607–35, Deutsches Historisches Museum Berlin


An artistic portrayal of cholera which was epidemic in the 19th century

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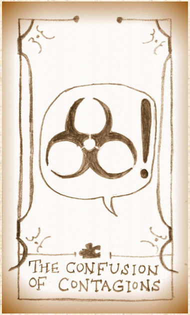
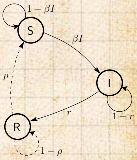

THE CONFUSION OF CONTAGIONS

Contagion

A confusion of contagions:

- Is Harry Potter some kind of virus?
- What about the Da Vinci Code?
- Did Sudoku spread like a disease?
- Language? The alphabet?[9]
- Religion?
- Democracy...?



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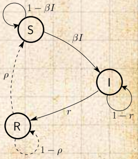

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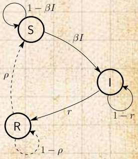

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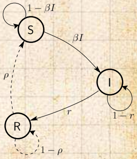

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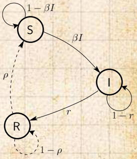

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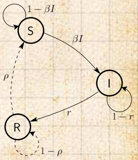

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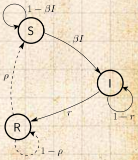

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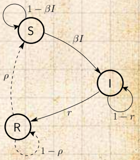
Naturomorphisms

- "The feeling was contagious."
- "The news spread like wildfire."
- "Freedom is the most contagious virus known to man."
  —Hubert H. Humphrey, Johnson's vice president
- "Nothing is so contagious as enthusiasm."
  —Samuel Taylor Coleridge

Optimism according to Ambrose Bierce

The doctrine that everything is beautiful, including what is ugly, everything good, especially the bad, and everything right that is wrong. ...



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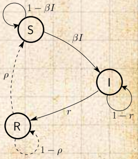

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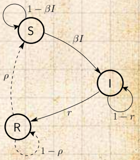

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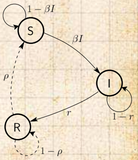

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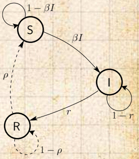

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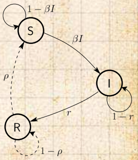

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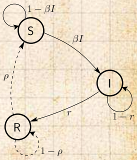
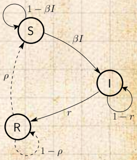


Social contagion

Eric Hoffer, 1902–1983

There is a grandeur in the uniformity of the mass.

Hoffer was an interesting fellow...



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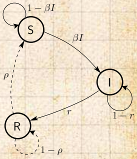

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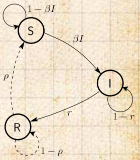

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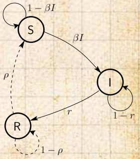

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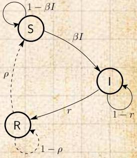

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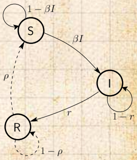

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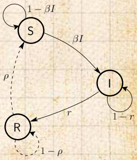

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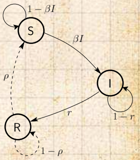
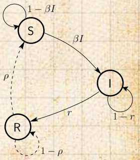


The spread of fanaticism

Hoffer's most famous work: "The True Believer: Thoughts On The Nature Of Mass Movements" (1951)[11]

Aphorisms-aplenty:

- "We can be absolutely certain only about things we do not understand."
- "Mass movements can rise and spread without belief in a God, but never without belief in a devil."
- "Where freedom is real, equality is the passion of the masses. Where equality is real, freedom is the passion of a small minority."



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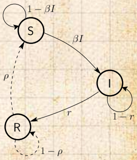

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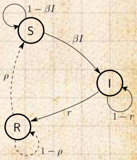

The spread of fanaticism

Hoffer's most famous work: "The True Believer: Thoughts On The Nature Of Mass Movements" (1951) [11]

Aphorisms-aplenty:

- "We can be absolutely certain only about things we do not understand."
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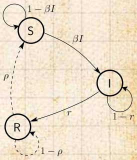

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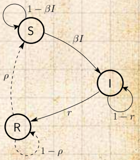
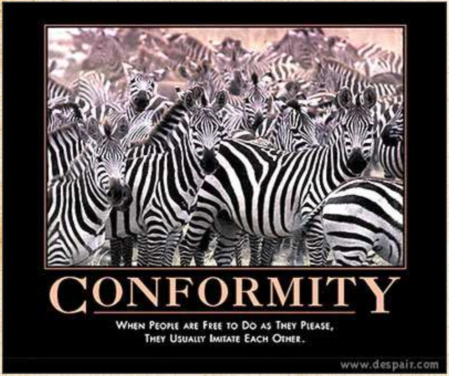


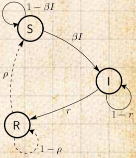
Imitation



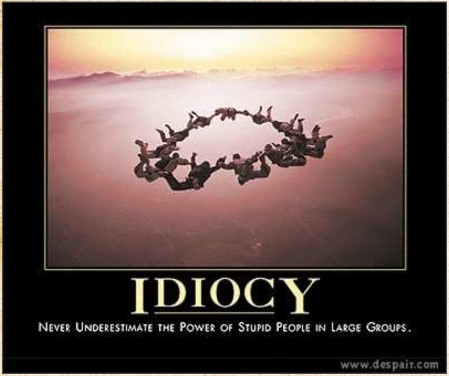
despair.com

"When people are free to do as they please, they usually imitate each other."

—Eric Hoffer
"The Passionate State of Mind" [12]



The collective...



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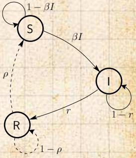
"Never Underestimate the Power of Stupid People in Large Groups."

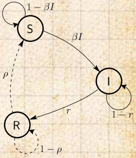


Examples of non-disease spreading:

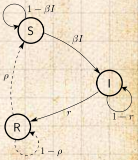
Interesting infections:

- Spreading of certain buildings in the US:

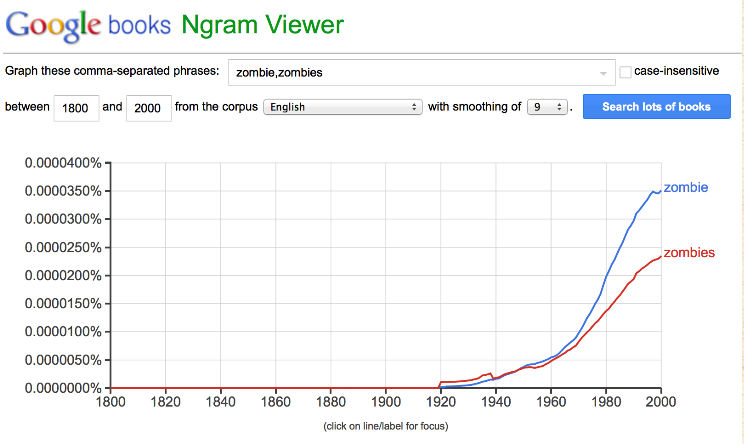
- 2008 Viral get-out-the-vote video.

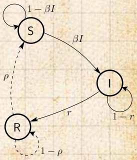


Marbleization of the US:

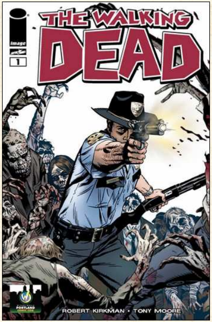


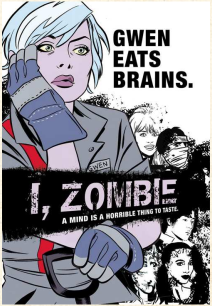
The most terrifying contagious outbreak?






THE
WALKING DEAD


THE WALKING DEAD
1
ROBERT KIRKMAN • TONY MOORE


GWEN
EATS
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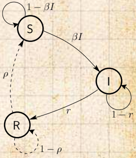
GWEN
I, ZOMBIE
A MIND IS A HORRIBLE THING TO TASTE.


iZOMBiE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S
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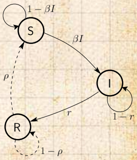
Contagion



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- (2) A disease itself: the plague, a blight, the dreaded lurgi, ...
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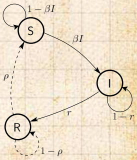

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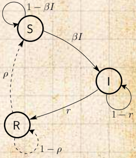

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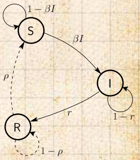

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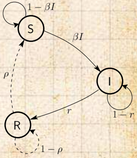

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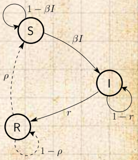

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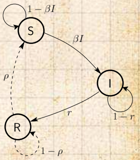

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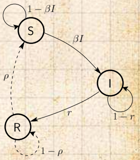

Two main classes of contagion

1. Infectious diseases

2. Social contagion

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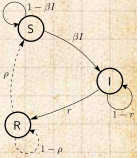

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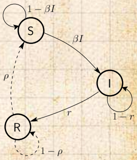

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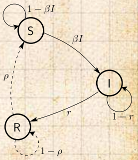

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2. Social contagion:
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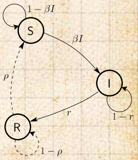
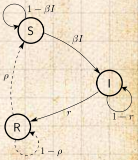
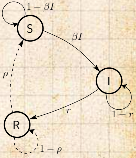


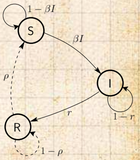
Archival footage from the Black Plague



Community—S2E6: Epidemiology



Outline




THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
MINISTRY OF RANDOM WALKS
THE UNEXPECTED TRANSFIGURATION
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING ROBUST YET FRAGILE
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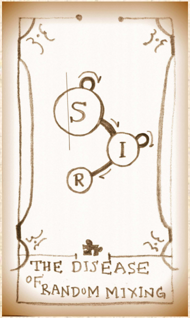
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE MANY TALES OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE KNOWLEDGE OF DEAD MONKS
THE DOORS THAT SHOULD NOT BE OPENED
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE ARK OF THE RANDOM NETWORK
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE UNENDING PANDEMICS
THE RATIO OF GAIN
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE MECHANICS OF FAME
THE STORIES CONTAGIOUS
THE PATHS OF UNIVERSALITY
THE DEPENDENT PATHS
THE TROUSERS OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
THE JOHN DORY
THE STORYTELLERS
THE ADJACENT NARRATIVES
THE END


S
I
R
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The standard SIR model [17]

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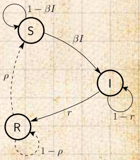
- Discrete and continuous time versions



Mathematical Epidemiology

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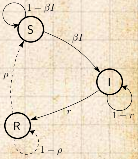

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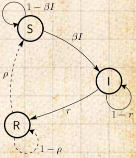

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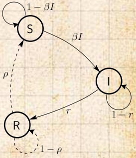

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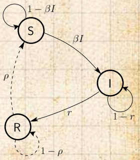

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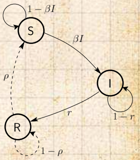

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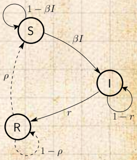

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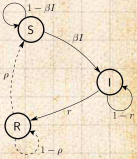

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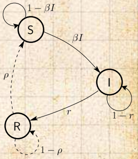

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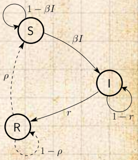

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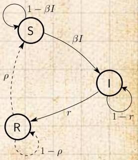
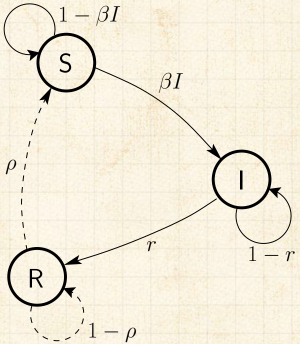
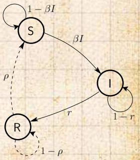


Mathematical Epidemiology

Discrete time automata example:





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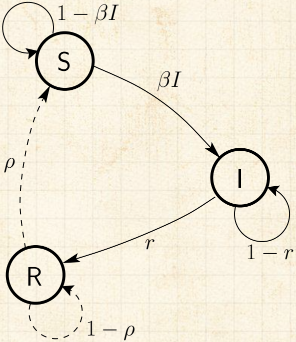
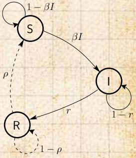
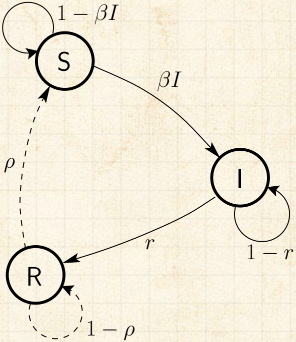


Transition Probabilities:



Mathematical Epidemiology

Discrete time automata example:



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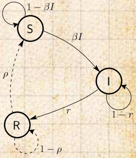
β for being infected given contact with infected



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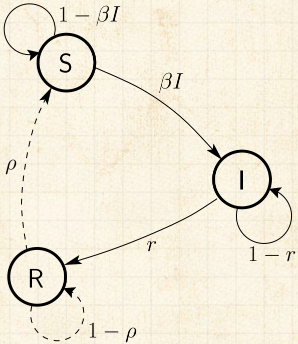

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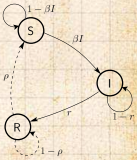

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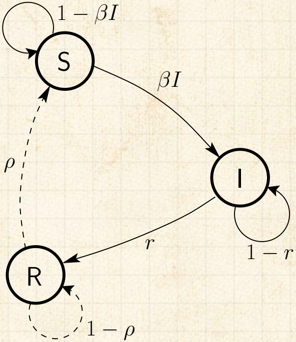
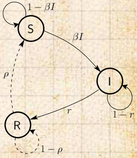


Transition Probabilities:

β for being infected given contact with infected
r for recovery
ρ for loss of immunity



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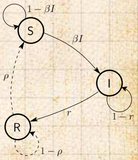
Original models attributed to

- 1920's: Reed and Frost
- 1920's/1930's: Kermack and McKendrick [18, 15, 14]
- Coupled differential equations with a mass-action principle



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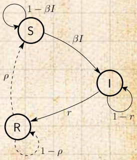

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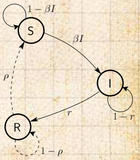

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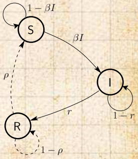
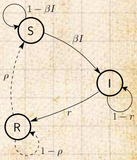


Independent Interaction models



Differential equations for continuous model

$$\frac{\mathrm{d}}{\mathrm{d}t} S = -\beta I S + \rho R$$

$$\frac{\mathrm{d}}{\mathrm{d}t} I = \beta I S - r I$$

$$\frac{\mathrm{d}}{\mathrm{d}t} R = r I - \rho R$$

β, r, and ρ are now rates.

Reproduction Number R_0

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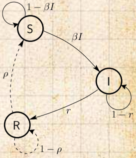
- R_0 = expected number of infected individuals resulting from a single initial infective
- Epidemic threshold: If $R_0 > 1$, 'epidemic' occurs.
- Exponential take off: R_0^n where n is the number of generations.
- Fantastically awful notation convention: R_0 and the R in SIR.



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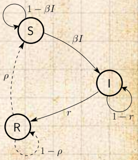

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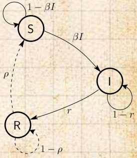

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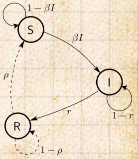

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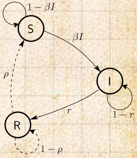

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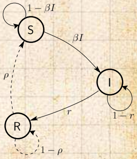

Discrete version:

- Set up: One Infective in a randomly mixing population of Susceptibles
- At time $t = 0$, single infective random bumps into a Susceptible
- Probability of transmission = β
- At time $t = 1$, single Infective remains infected with probability $1 - r$
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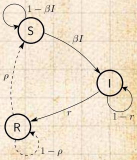

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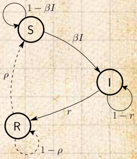

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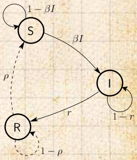

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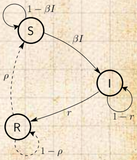

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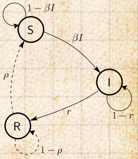
$$R_0 = \beta + (1-r)\beta + (1-r)^2\beta + (1-r)^3\beta + \ldots$$



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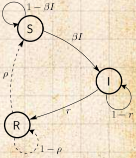

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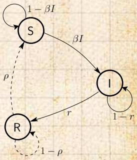

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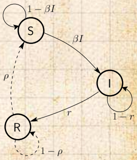
$$= \beta \frac{1}{1-(1-r)} = \beta / r$$



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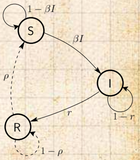
For $S(0) \simeq 1$ initial susceptibles
($1 - S(0) = R(0)$ = fraction initially immune):

$$R_0 = S(0)\beta/r$$



Independent Interaction models

For the continuous version

- Second equation:

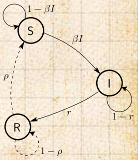
$$\frac{\mathrm{d}}{\mathrm{d}t} I = \beta S I - r I$$

- Number of infectives grows initially if

$$\beta S(0) - r > 0$$

where $S(0) \simeq 1$.

- Same story as for discrete model.



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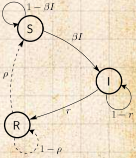

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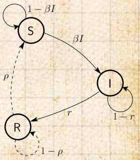

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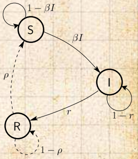

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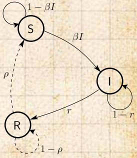

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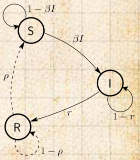

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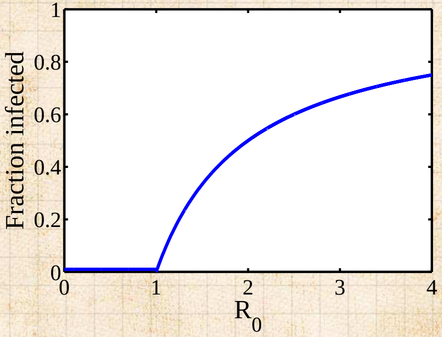

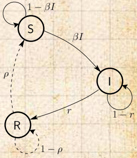

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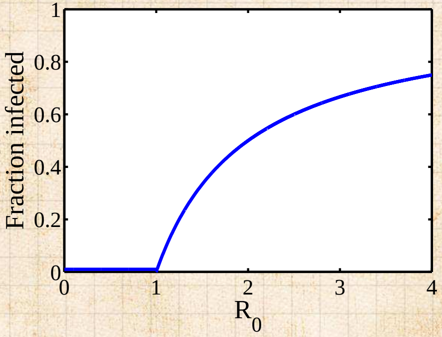

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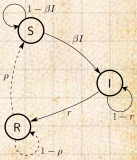

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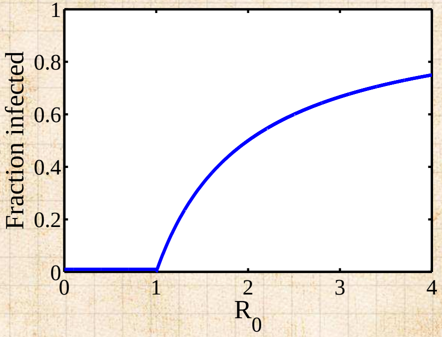
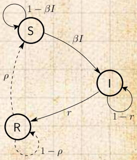


- Continuous phase transition.
- Fine idea from a simple model.



Independent Interaction models

Many variants of the SIR model:

- SIS: susceptible-infective-susceptible
- SIRS: susceptible-infective-recovered-susceptible
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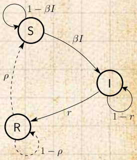
- more categories such as ‘exposed’ (SEIRS)
- recruitment (migration, birth)



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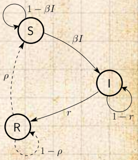

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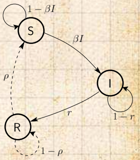

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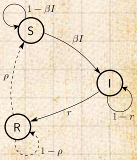

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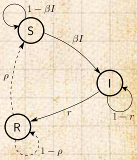

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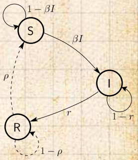
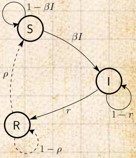
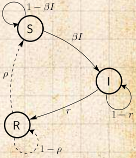


Watch someone else pretend to save the world:

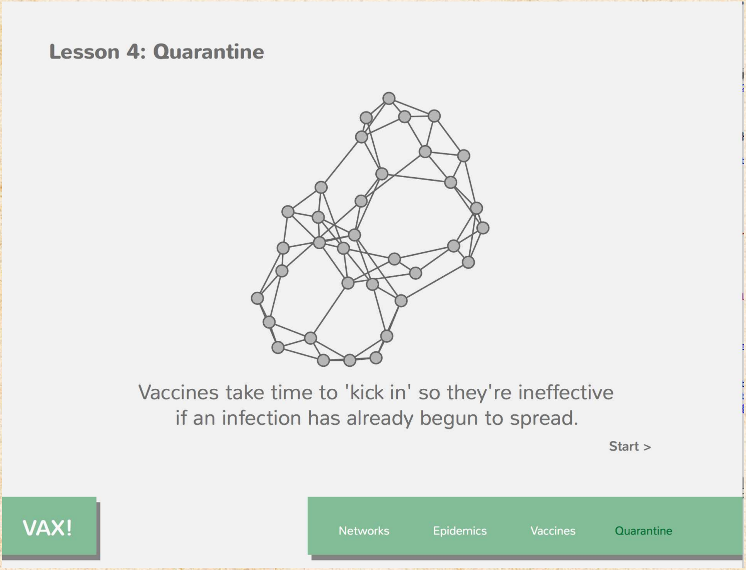


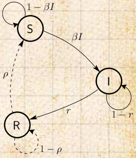
Save the world yourself:

- And you can be the virus.
- Also contagious?: Cooperative games ...

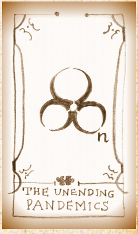


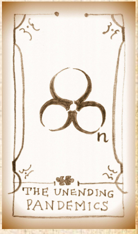
Neural reboot—Save another pretend world with Vax:





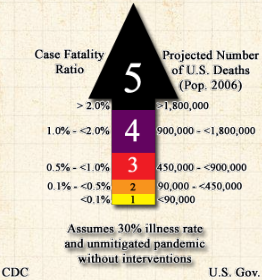
Outline





Pandemic severity index (PSI)

- Classification during/post pandemic:



- Category based.
- 1–5 scale.
- Modeled on the Saffir-Simpson hurricane scale.

For novel diseases:

1. Can we predict the size of an epidemic?
2. How important is the reproduction number R_0?

R_0 approximately same for all of the following:

- 1918-19 “Spanish Flu” $\sim$ 75,000,000 world-wide, 500,000 deaths in US.
- 1957-58 “Asian Flu” $\sim$ 2,000,000 world-wide, 70,000 deaths in US.
- 1968-69 “Hong Kong Flu” $\sim$ 1,000,000 world-wide, 34,000 deaths in US.
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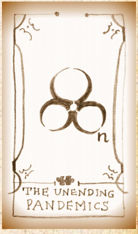

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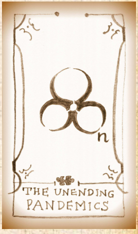

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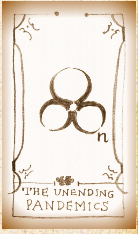

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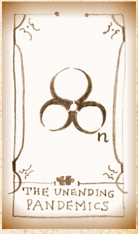

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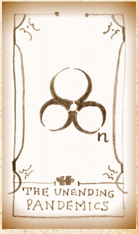

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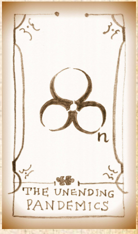

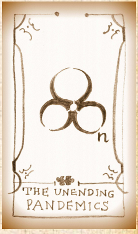

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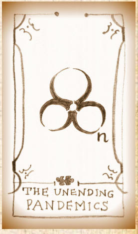

Size distributions

Size distributions are important elsewhere:

- earthquakes (Gutenberg-Richter law)
- city sizes, forest fires, war fatalities
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- ‘popularity’ (books, music, websites, ideas)
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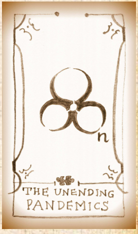

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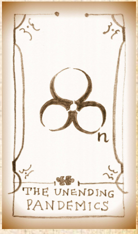

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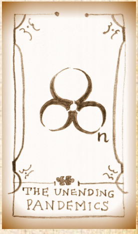

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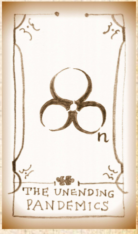

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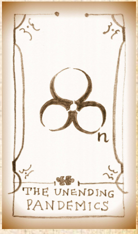

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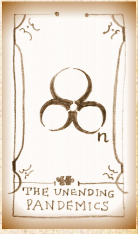

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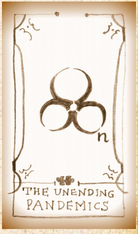

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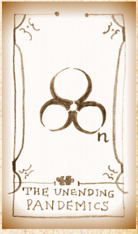

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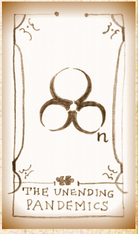

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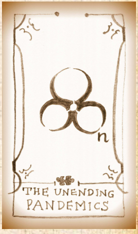

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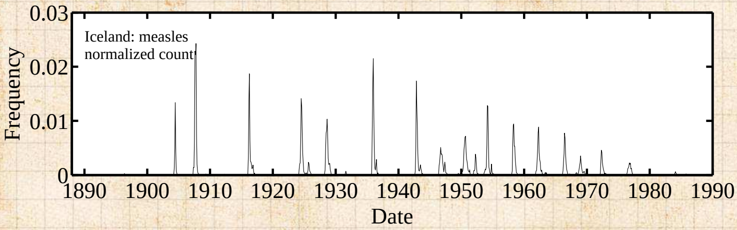
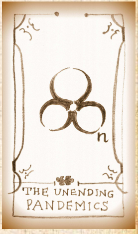
Feeling Ill in Iceland

Caseload recorded monthly for range of diseases in Iceland, 1888-1990

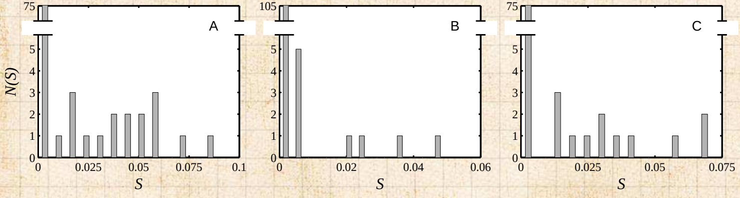


- Treat outbreaks separated in time as 'novel' diseases.

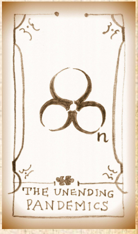


Really not so good at all in Iceland

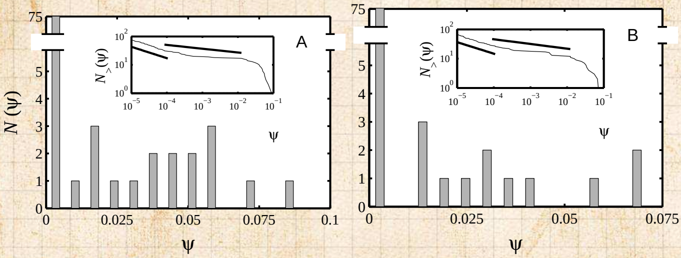
Epidemic size distributions $N(S)$ for Measles, Rubella, and Whooping Cough.

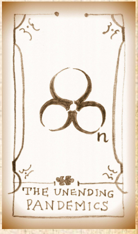


Spike near $S = 0$, relatively flat otherwise.



Measles & Pertussis





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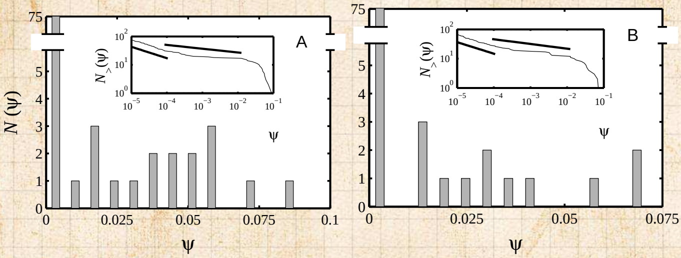
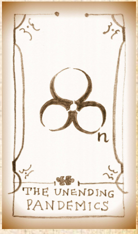


Insert plots:

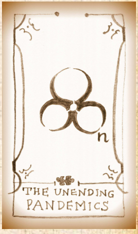
Complementary cumulative frequency distributions:

$$N(\Psi' > \Psi) \propto \Psi^{-\gamma+1}$$

Limited scaling with a possible break.



Power law distributions



Measured values of γ:

- measles: 1.40 (low Ψ) and 1.13 (high Ψ)
- pertussis: 1.39 (low Ψ) and 1.16 (high Ψ)

- Expect $2 \le \gamma < 3$ (finite mean, infinite variance)
- When $\gamma < 1$, can't normalize
- Distribution is quite flat.

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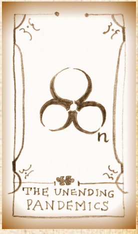

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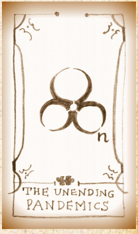

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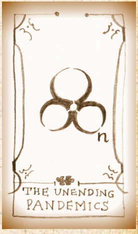

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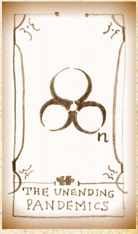

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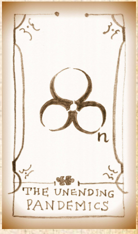

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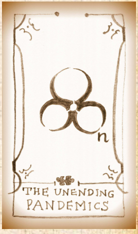
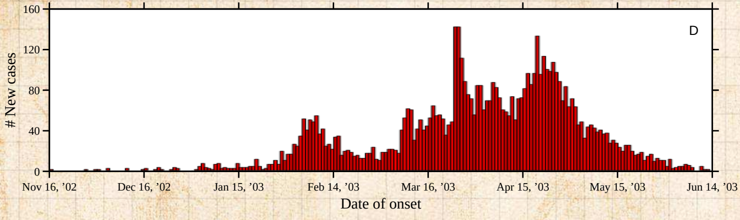


Resurgence—example of SARS



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- Epidemic discovers new ‘pools’ of susceptibles: Resurgence.
- Importance of rare, stochastic events.

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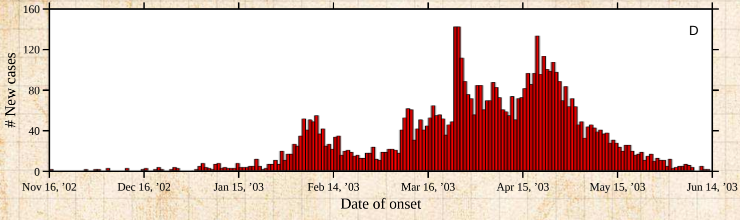

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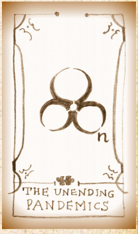

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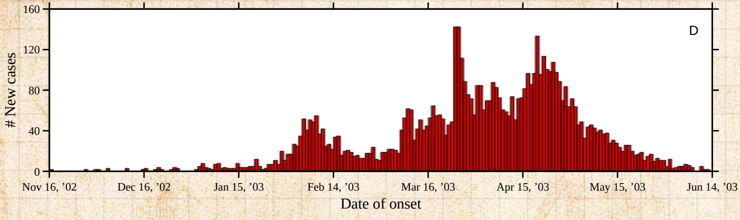

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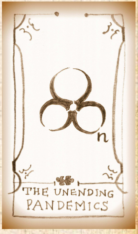

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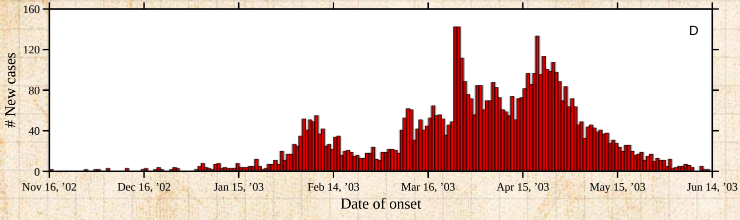

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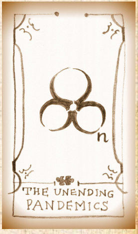
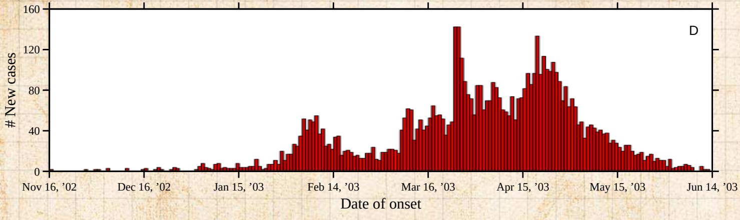


Resurgence—example of SARS



- Epidemic slows...
  then an infective moves to a new context.
- Epidemic discovers new 'pools' of susceptibles: Resurgence.
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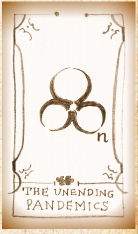
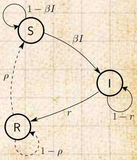


Community—S2E6: Epidemiology

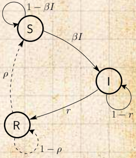
Outline



The challenge

So... can a simple model produce

1. broad epidemic distributions
   and
2. resurgence ?



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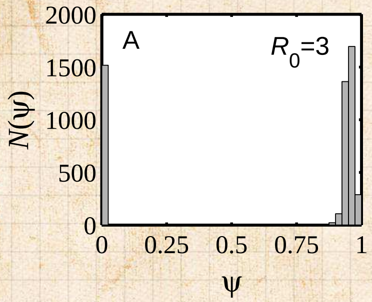
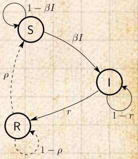


Simple models typically produce bimodal or unimodal size distributions.

- This includes network models: random, small-world, scale-free, ...
- Exceptions:
  1. Forest fire models
  2. Sophisticated metapopulation models



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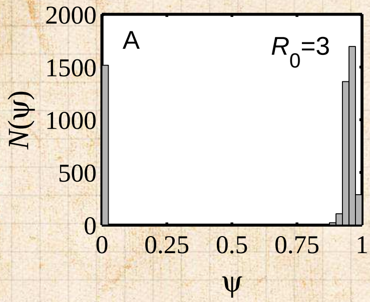

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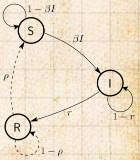

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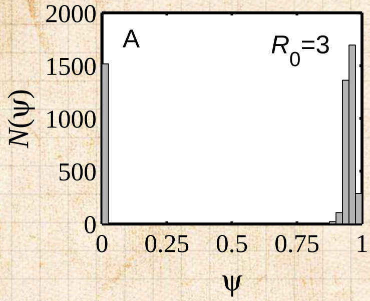

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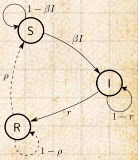

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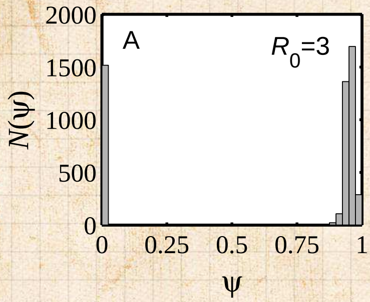

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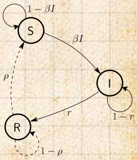

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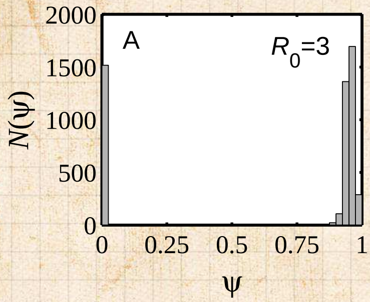

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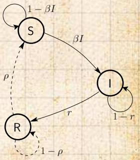

Burning through the population

Forest fire models: [18]

- Rhodes & Anderson, 1996
- The physicist's approach:
  "if it works for magnets, it'll work for people..."

A bit of a stretch:

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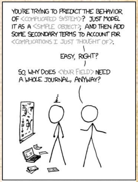

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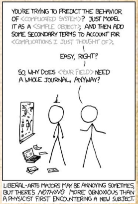

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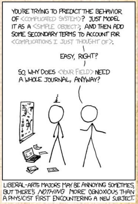

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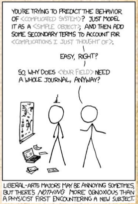

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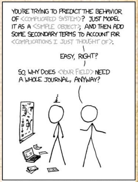

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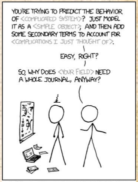

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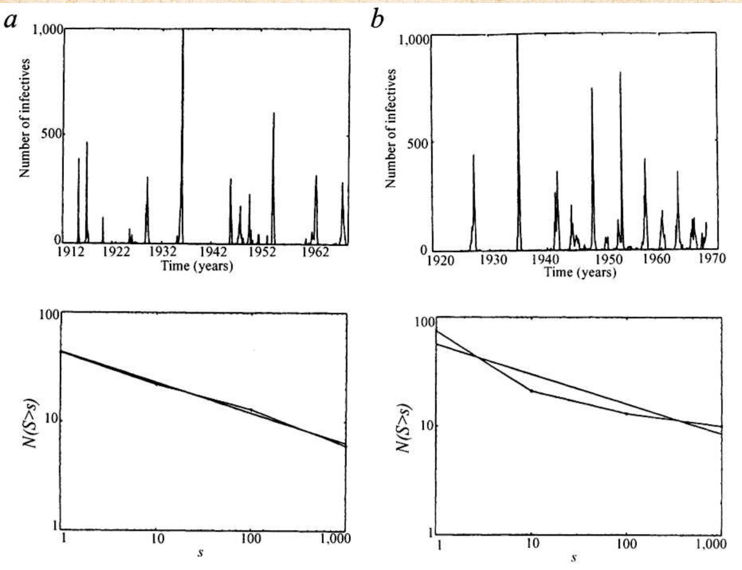

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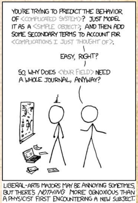
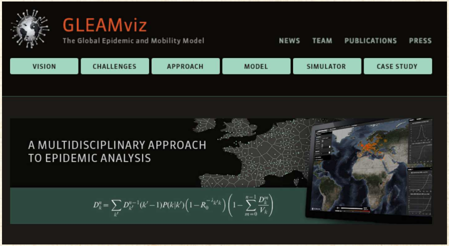
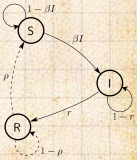


Sophisticated metapopulation models:

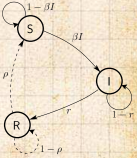
- Multiscale models suggested earlier by others but not formalized (Bailey [1], Cliff and Haggett [5], Ferguson et al.)
- Community based mixing (two scales)—Longini. [16]
- Eubank et al.'s EpiSims/TRANSIMS—city simulations. [8]
- Spreading through countries—Airlines: Germann et al., Colizza et al. [6]



- GLEAM: Global pandemic simulations by Vespignani et al.



Community—S2E6: Epidemiology



Size distributions

- Vital work but perhaps hard to generalize from...
- ⇒ Create a simple model involving multiscale travel
- Very big question: What is N?
- Should we model SARS in Hong Kong as spreading in a neighborhood, in Hong Kong, Asia, or the world?
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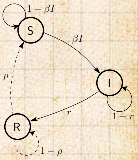

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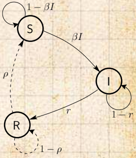

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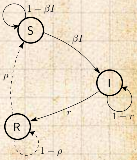

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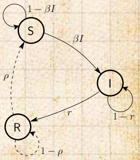

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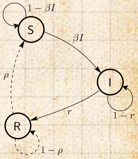
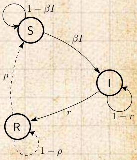
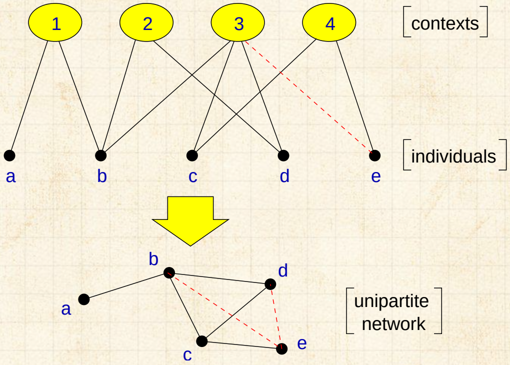


Outline

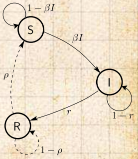


Improving simple models

Contexts and Identities—Bipartite networks



- boards of directors
- movies
- transportation modes (subway)



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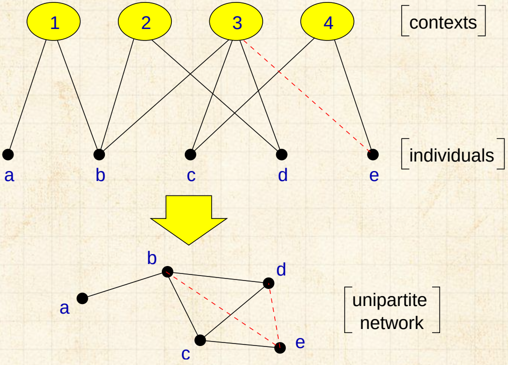

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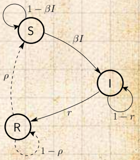

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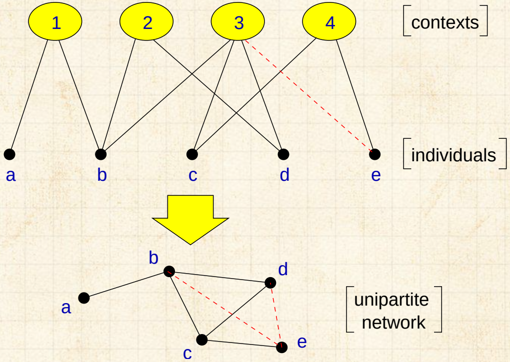

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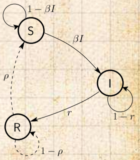

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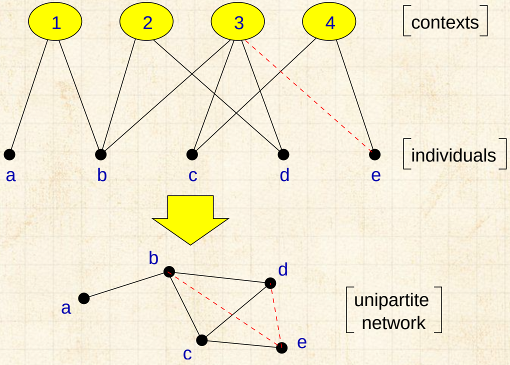

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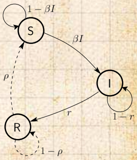

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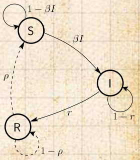
Idea for social networks: incorporate identity

Identity is formed from attributes such as:

- Geographic location
- Type of employment
- Age
- Recreational activities

Groups are crucial...

- formed by people with at least one similar attribute
- Attributes ⇔ Contexts ⇔ Interactions ⇔ Networks.[22]



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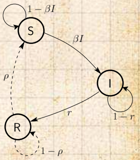

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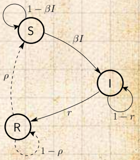

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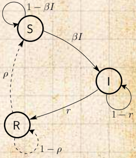

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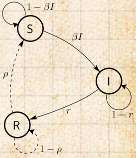

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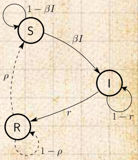

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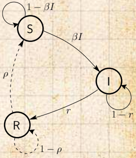

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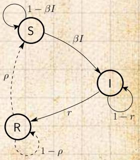

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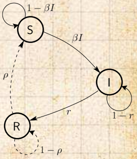
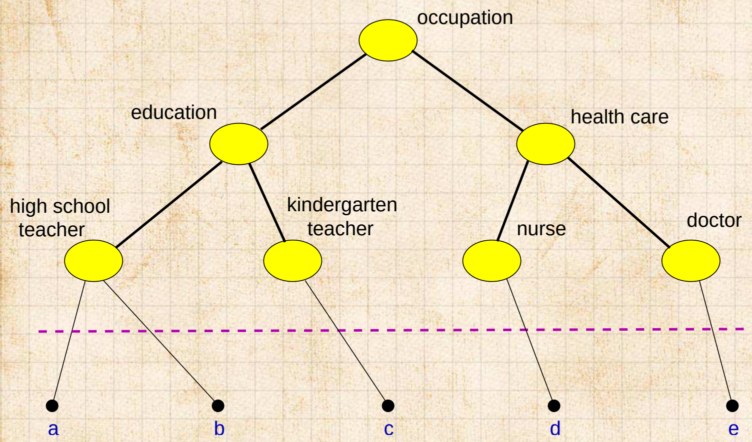
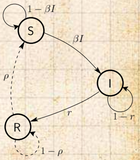


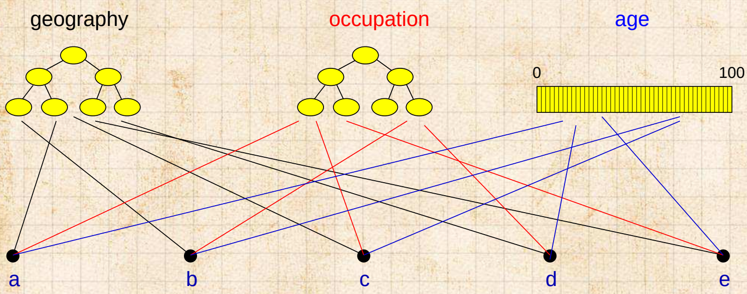
Infer interactions/network from identities



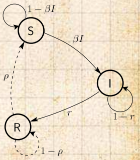
Distance makes sense in identity/context space.



Generalized context space



(Blau & Schwartz [3], Simmel [19], Breiger [4])



A toy agent-based model:

"Multiscale, resurgent epidemics in a hierarchcial metapopulation model"
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162, 2005. [23]

Geography: allow people to move between contexts

- Locally: standard SIR model with random mixing
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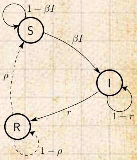

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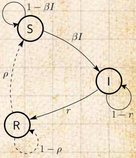

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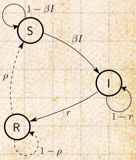

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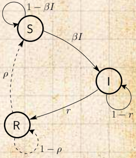

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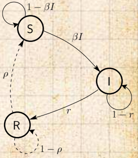

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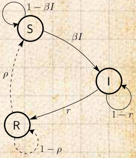

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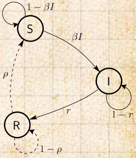

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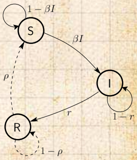
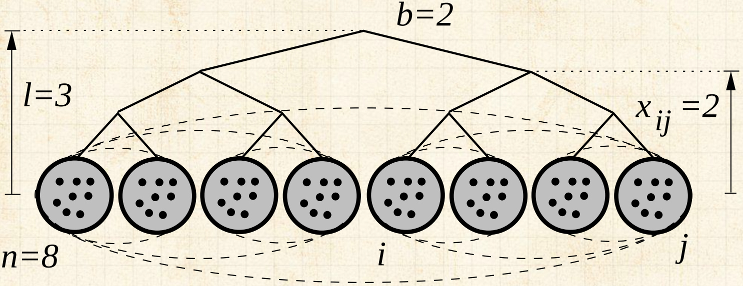
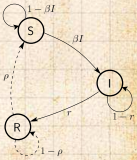


A toy agent-based model

Schematic:





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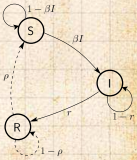
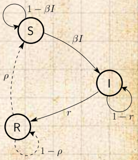


Model output

- Define P_0 = Expected number of infected individuals leaving initially infected context.
- Need $P_0 > 1$ for disease to spread (independent of R_0).
- Limit epidemic size by restricting frequency of travel and/or range



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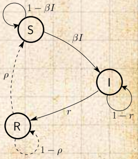

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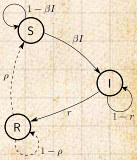
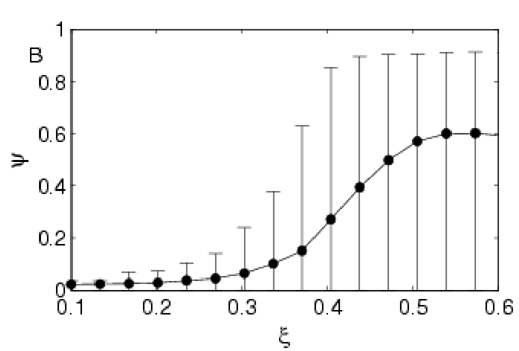
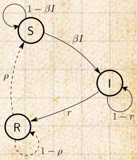


Model output

Varying ξ:



- Transition in expected final size based on typical movement distance



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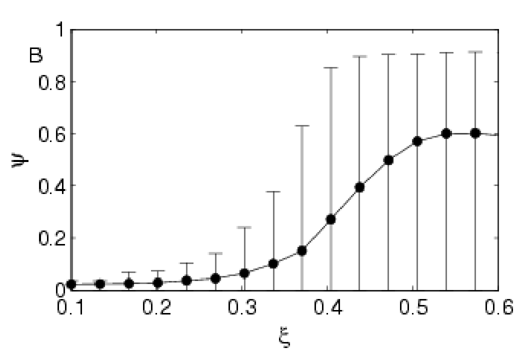
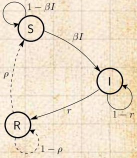
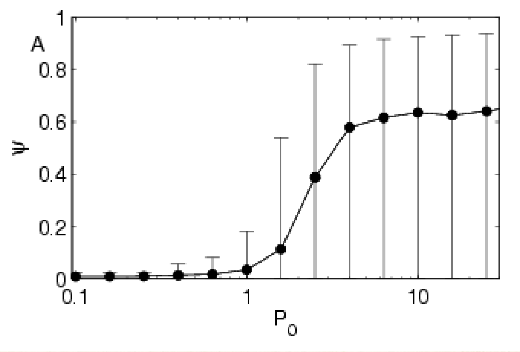


- Transition in expected final size based on typical movement distance (sensible)



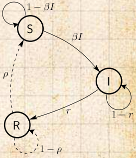
Model output

Varying P_0:



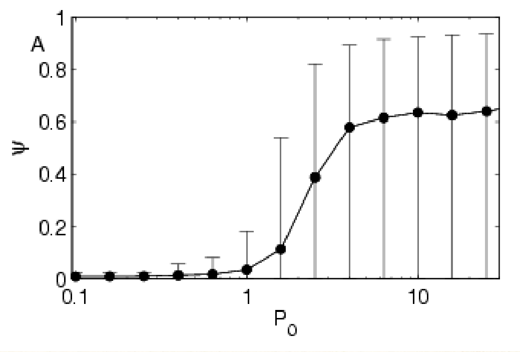
- Transition in expected final size based on typical number of infectives leaving first group

- Travel advisories: ξ has larger effect than P_0.

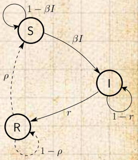


Model output

Varying P_0:

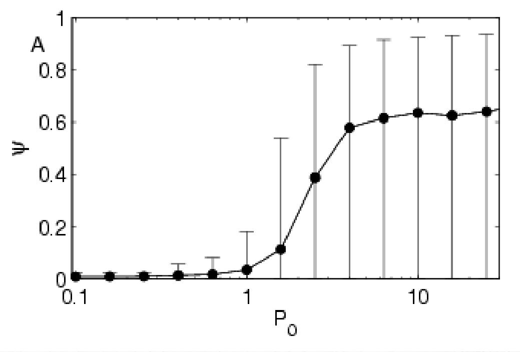


- Transition in expected final size based on typical number of infectives leaving first group (also sensible)
- Travel advisories: ξ has larger effect than P_0.



Model output

Varying P_0:



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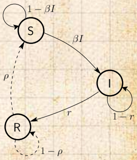
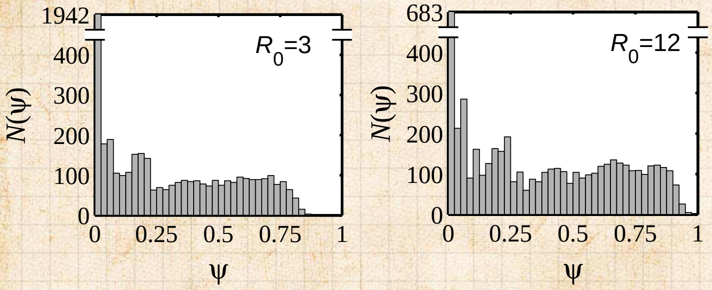
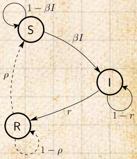


Example model output: size distributions



- Flat distributions are possible for certain ξ and P.
- Different R_0's may produce similar distributions
- Same epidemic sizes may arise from different R_0's



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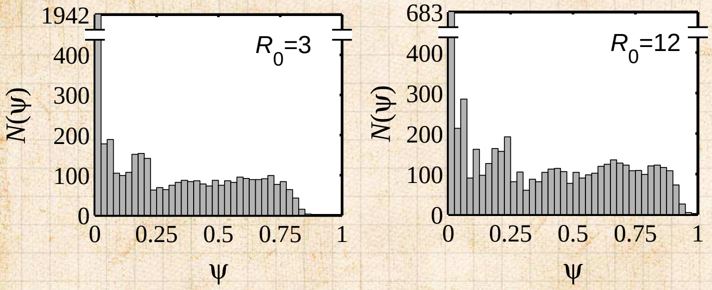

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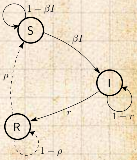

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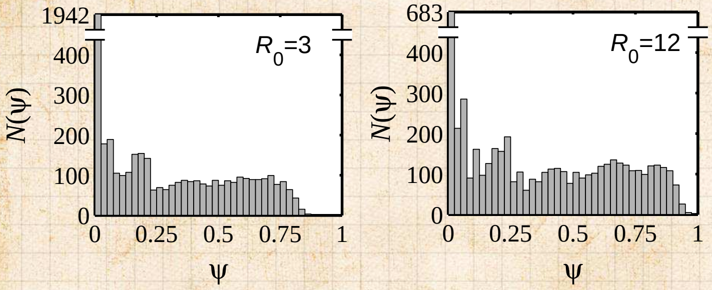

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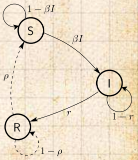

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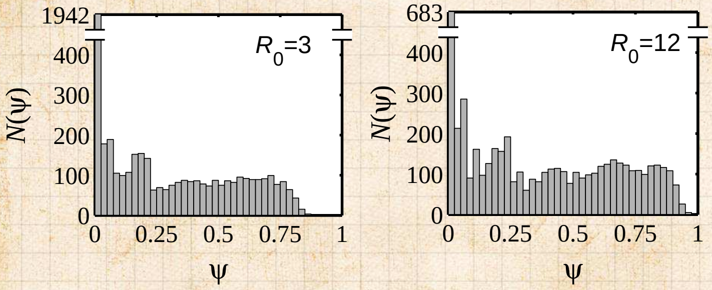

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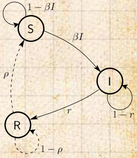

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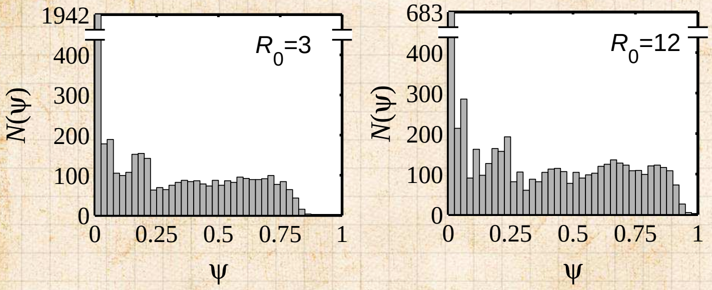

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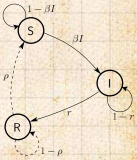
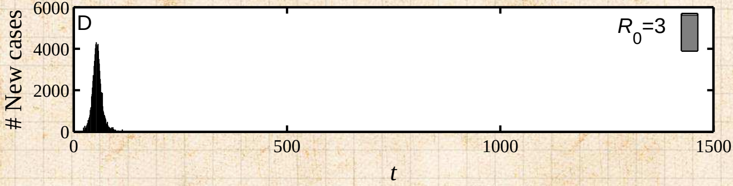
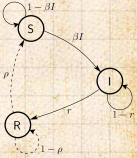


Model output—resurgence

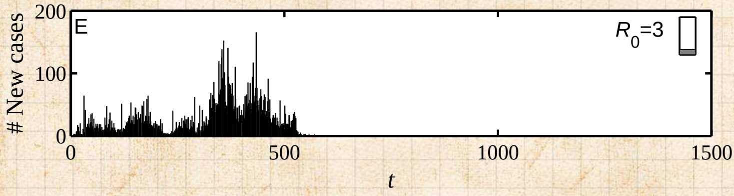
Standard model:

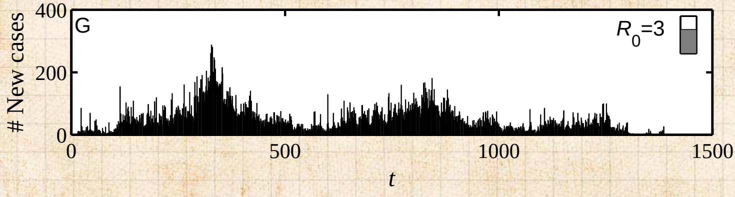


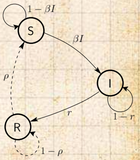


Model output—resurgence

Standard model with transport:

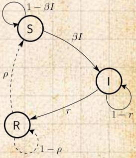






The upshot

Simple multiscale population structure



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Simple multiscale population structure
+
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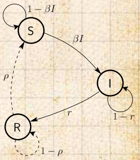
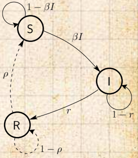


The upshot

Simple multiscale population structure
+
stochasticity

leads to

resurgence
+
broad epidemic size distributions



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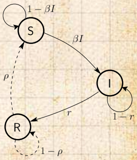
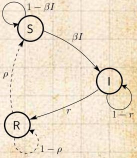


Nutshelling

- For the hierarchical movement model, epidemic size is highly unpredictable
- Model is more complicated than SIR but still simple.
- We haven't even included normal social responses such as travel bans and self-quarantine.
- The reproduction number R_0 is not terribly useful.
- R_0, however measured, is not informative about
  1. how likely the observed epidemic size was,
  2. and how likely future epidemics will be.
- Problem: R_0 summarises one epidemic after the fact and enfolds movement, the price of bananas, everything.



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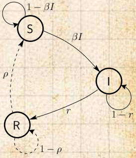

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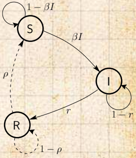

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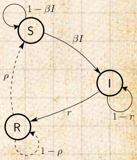

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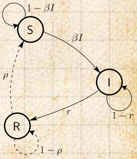

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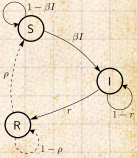

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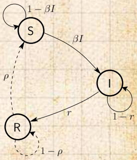

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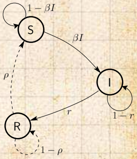

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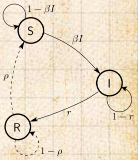
- Disease's spread is highly sensitive to population structure.
- Rare events may matter enormously.
- More support for controlling population movement.



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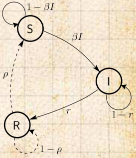

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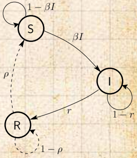

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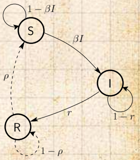

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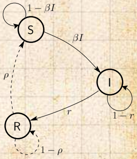

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More wondering:

- Exactly how important are rare events in disease spreading?
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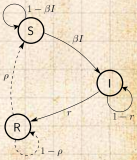

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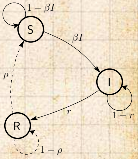

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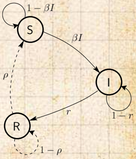

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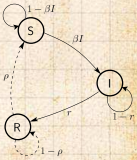

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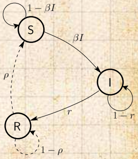

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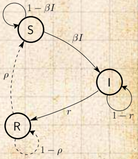

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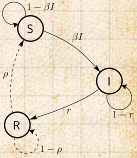

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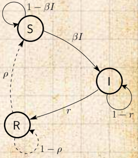


THE SUN
THE GOLDEN AGE OF REDUCTIONISM
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THE WELL OF SCALES
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THE SUPPLY MOST FAIR
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THE CHARMS OF THE MANY WRONG PATHS
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THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE ARK OF THE RANDOM NETWORK
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THE SMALLNESS OF WORLDS
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THE ADJACENT NARRATIVES
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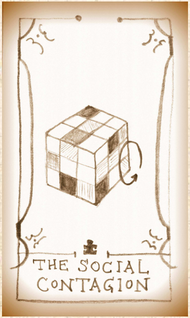
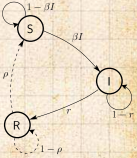

THE SOCIAL CONTAGION

Outline



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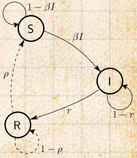

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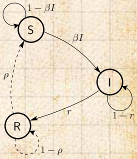

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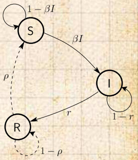

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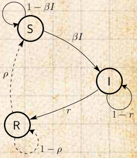

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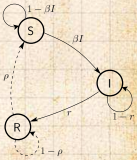

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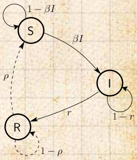

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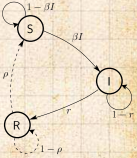

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Alan Greenspan (September 18, 2007):

"I've been dealing with these big mathematical models of forecasting the economy ...

If I could figure out a way to determine whether or not people are more fearful or changing to more euphoric,

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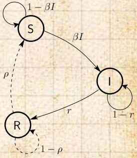

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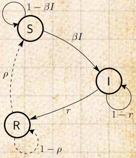

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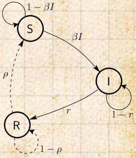

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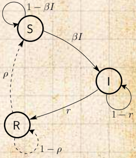

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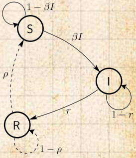

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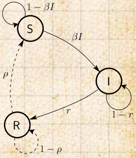

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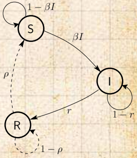

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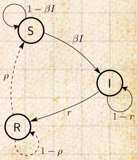

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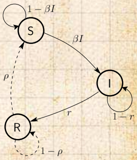

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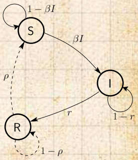

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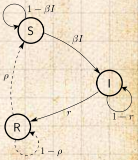

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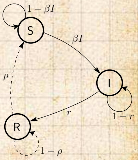

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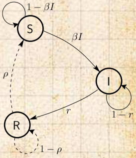
Jon Stewart:

“You just bummed the @*!# out of me.”

wildbluffmedia.com

- From the Daily Show (September 18, 2007)
- The full inteview is here.



Predicting social catastrophe isn't easy...

"Greenspan Concedes Error on Regulation"

- ...humbled Mr. Greenspan admitted that he had put too much faith in the self-correcting power of free markets ...
- "Those of us who have looked to the self-interest of lending institutions to protect shareholders' equity, myself included, are in a state of shocked disbelief"
- Rep. Henry A. Waxman: "Do you feel that your ideology pushed you to make decisions that you wish you had not made?"
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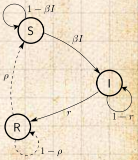
New York Times, October 23, 2008



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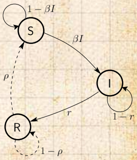

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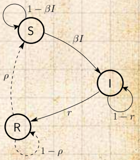

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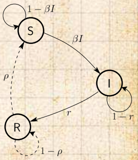

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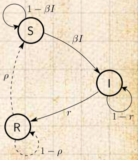

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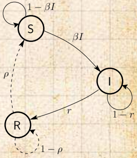

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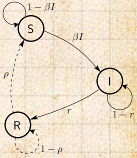

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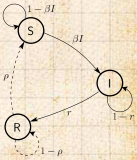

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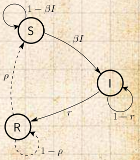

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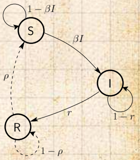

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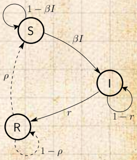

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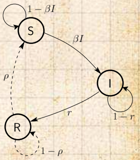

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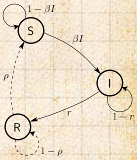

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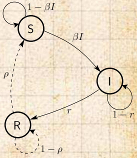

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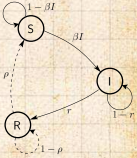

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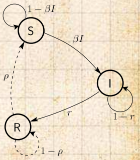

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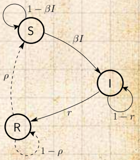

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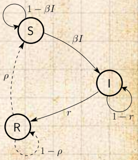

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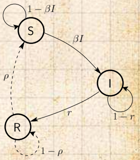

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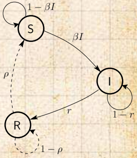

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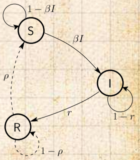

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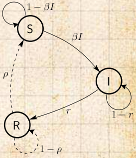

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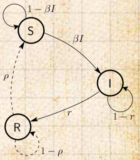

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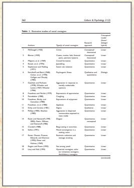

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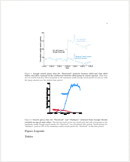

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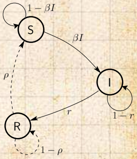

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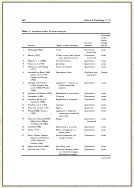

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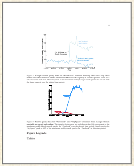

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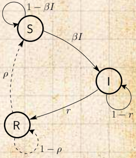

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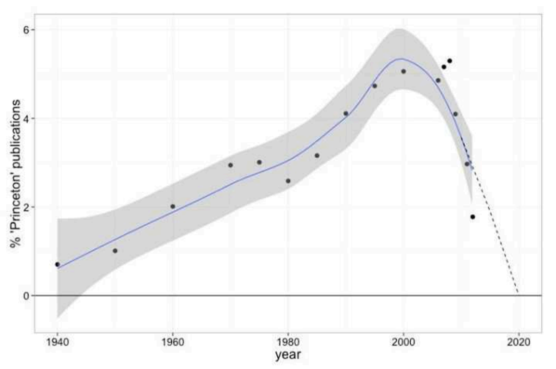

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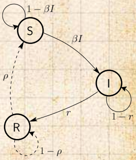

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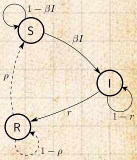

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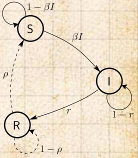

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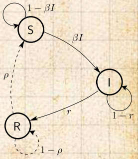

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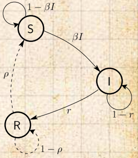

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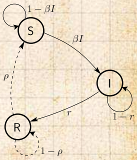

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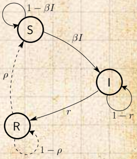

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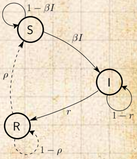

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