Biological Contagion

Principles of Complex Systems | @pocsvox CSYS/MATH 300, Fall, 2015 | #FallPoCS2015

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



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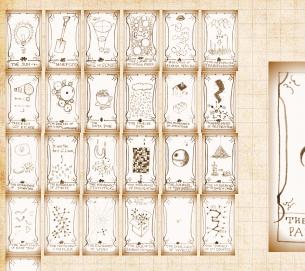
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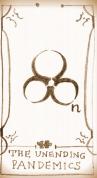




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► An awful recording: Wikipedia's list of epidemics from 430 BC on.



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List of epidemics

Article Talk

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 name of 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	Cocoliztii	viral hemorrhagic fever	লোবাল
2 - 2.5 million (50% of population)	Mexico	1576	Cocoliztii	viral hemorrhagic fever	(6)(7)(6)
	Seneca nation	1592-		measles	(9)



Plague panel with the triumph of death. 1807–36, Deutsches Historisches Museum Berlin



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

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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? Religion? Democracy. 2

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Naturomorphisms

- "The feeling was contagious." "The news spread like wildfire."
- "Hreedord is the most contagious virus known man." —Hubert H. Humphrey, Johnson's vice preside
 - -Samuel Taylor Coleridge

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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Optimism according to Ambrose Bierce:

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The doctrine that everything is beautiful, including what is ugly, everything good, especially the bad, and everything right that is wrong. ... It is hereditary, but fortunately not contagious.

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Eric Hoffer, 1902–1983 There is a grandeur in the uniformity of the mass.

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▶ Hoffer 🗹 was an interesting fellow...

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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 thing we do not understand."

"Mass movements can rise and spread without belief in a God, but never without belief in a dev "Where freedom is real, equality is the passion of the masses.

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Imitation



WHEN PEOPLE ARE FREE TO DO AS THEY PLEASE, THEY USUALLY IMITATE EACH OTHER.

www.despair.com

despair.com

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

—Eric Hoffer "The Passionate Stat of Mind" ^[12] PoCS | @pocsvox Biological Contagion

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The collective...



NEVER UNDERESTIMATE THE POWER OF STUPPL PEOPLE IN LARGE GROUPS.

www.despair.com

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

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Examples of non-disease spreading:

Interesting infections:

Spreading of certain buildings in the US:

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



Marbleization of the US:

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The most terrifying contagious outbreak?

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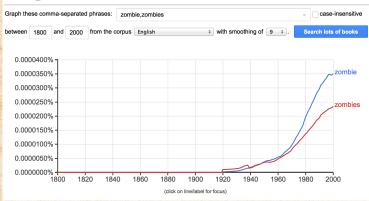
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Google books Ngram Viewer





Definitions

(1) The spreading of a quality or quantity betwee individuals in a population.

(2) A disease itself: the plague, a blight, the dreaded lurgi, ... from Latin: con = 'together with' + tongere 't touch.'

Contagion has unpleasant overtones... Just Spreading might be a more neutral wor But contagion is kind of exciting...

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Two main classes of contagion

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Two main classes of contagion 1. Infectious diseases

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Two main classes of contagion 1. Infectious diseases

2. Social contagion

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Two main classes of contagion

- 1. Infectious diseases:
 - tuberculosis, HIV, ebola, SARS, influenza, zombification, ...
- 2. Social contagion

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2. Social contagion:

fashion, word usage, rumors, uprisings, religion, stories about zombies, ...

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Archival footage from the Black Plague

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

Community—S2E6: Epidemiology

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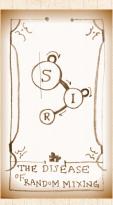
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The standard SIR model ^[17]

 = basic model of disease contagio
 Three states:

S(t) + I(t) + R(t) = 1Presumes random interactions (mass-actio principle) Interactions are independent (no memory)

Discrete and continuous time versions

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- ► S(t) + I(t) + R(t) = 1

Presumes random interactions (mass-action principle)

Interactions are independent (no memory

Discrete and continuous time versions

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The standard SIR model [17]

- = basic model of disease contagion
- Three states:
 - 1. S = Susceptible
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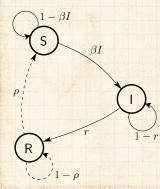
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Discrete time automata example:



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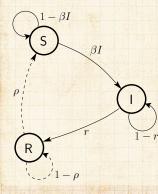
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Discrete time automata example:



Transition Probabilities:

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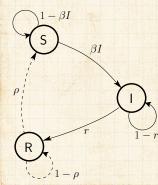
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Discrete time automata example:



Transition Probabilities:

 β for being infected given contact with infected

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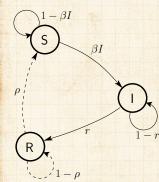
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Discrete time automata example:



Transition Probabilities:

 β for being infected given contact with infected r for recovery

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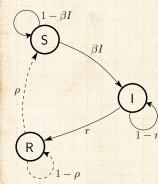
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Discrete time automata example:



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 Coupled differential equations with a massprinciple

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Differential equations for continuous model

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

$$\frac{\mathrm{d}}{\mathrm{d}t}I = \beta IS - rI$$

$$\frac{\mathsf{d}}{\mathsf{d}t}R = rI - \rho R$$

 β , r, and ρ are now rates.

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Reproduction Number R_0

 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 generations.

Fantastically awful notation convention: R_0 a the R in *SIR*.

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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 Susceptible

Probability of transmission = β

At time t = 1, single infective remains infected w probability 1 - r

At time t = k, single Infective remains infected with probability $(1 - r)^k$

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Discrete version:

Expected number infected by original infective:

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

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

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

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

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

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

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For the continuous version

Second equation:

$$\frac{\mathsf{d}}{\mathsf{d}t}I = \beta SI - rI$$

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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Second equation:

$$\frac{\mathsf{d}}{\mathsf{d}t}I = \beta SI - rI$$

$$\frac{\mathsf{d}}{\mathsf{d}t}I = (\beta S - r)I$$

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Same story as for discrete mode

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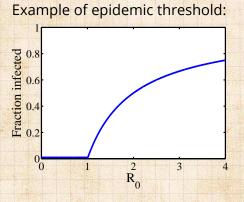
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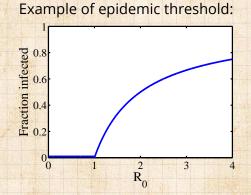
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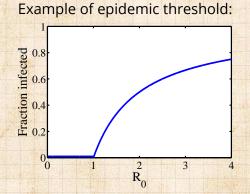
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Continuous phase transition.

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Continuous phase transition.
Fine idea from a simple model.

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Many variants of the SIR model:

SIS: susceptible-infective-susceptible SIRS: susceptible-infective-recovered-susceptible compartment models (age or gender partitions more categories such as 'exposed' (SEIRS) recruitment (migration, birth)

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Watch someone else pretend to save the world:



COTILIARD DAMON FISHBURNE LAW PALTROW WINSLET NOTHING SPREADS LIKE FEAR CONTAG ON TAG ION



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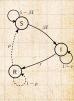
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Save the world yourself:



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

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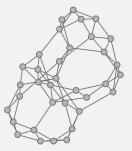




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Neural reboot—Save another pretend world with Vax:

Lesson 4: Quarantine



Vaccines take time to 'kick in' so they're ineffective if an infection has already begun to spread.

 Start >

 Networks
 Epidemics
 Vaccines
 Quarantine

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Pandemic severity index (PSI)

Classification during/post pandemic:



Assumes 30% illness rate and unmitigated pandemic without interventions U.S. Gov. Category based.

- ▶ 1-5 scale.
- Modeled on the Saffir-Simpson hurricane scale .

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CDC

Can we predict the size of an epidemic? How important is the reproduction number *R* PoCS | @pocsvox

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1. Can we predict the size of an epidemic?

How important is the reproduction number R

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

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

R₀ approximately same for all of the following:
 1918-19 "Spanish Flu" ~ 75,000,000 world-wide, 500,000 deaths in US.
 1957-58 "Asian Flu" ~ 2,000,000 world-wide, 70,000 deaths in US.
 1968-69 "Hong Kong Flu" ~ 1,000,000 world-wid 34,000 deaths in US.
 2003 "SARS Epidemic" ~ 800 deaths world-wide.

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Size distributions are important elsewhere:
earthquakes (Gutenberg-Richter law)
city sizes, forest fires, war fatalities
wealth distributions
'popularity' (books, music, websites, ideas)
Epidemics?

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Size distributions are important elsewhere:

- earthquakes (Gutenberg-Richter law)
- city sizes, forest fires, war fatalities
- wealth distributions
 - 'popularity' (books, music, websites, ideas

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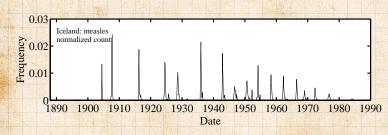
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Feeling III in Iceland

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



 Treat outbreaks separated in time as 'novel' diseases.

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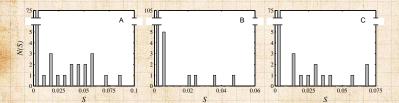
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Really not so good at all in Iceland

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



Spike near S = 0, relatively flat otherwise.

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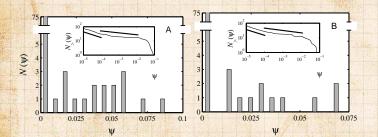
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Measles & Pertussis



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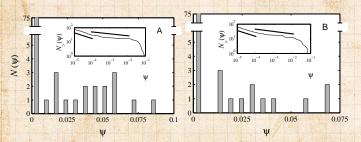
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Measles & Pertussis



Insert plots: Complementary cumulative frequency distributions:

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

Limited scaling with a possible break.

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Measured values of γ :

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

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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)

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Expect 2 ≤ γ < 3 (finite mean, infinite variance) When γ < 1, can't normalize

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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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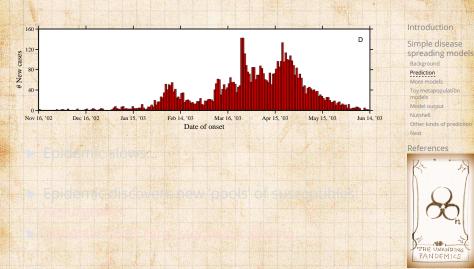




Resurgence—example of SARS

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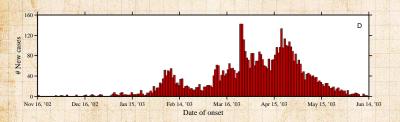




Resurgence—example of SARS

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Epidemic slows...



Background

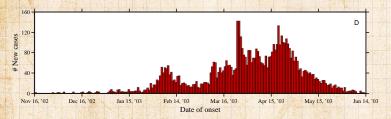
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Resurgence—example of SARS



 Epidemic slows... then an infective moves to a new context.

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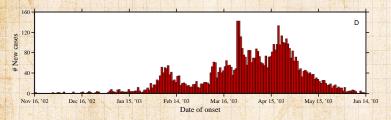
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Resurgence—example of SARS



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

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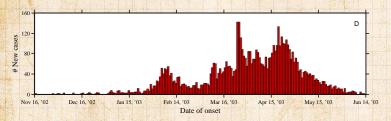
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Resurgence—example of SARS



- Epidemic slows... then an infective moves to a new context.
- Epidemic discovers new 'pools' of susceptibles: Resurgence.
- Importance of rare, stochastic events.

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Community—S2E6: Epidemiology

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The challenge

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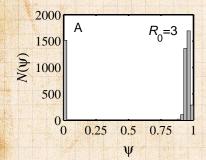
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So... can a simple model produce

- 1. broad epidemic distributions and
- 2. resurgence?



Simple models typically produce bimodal or unimodal size distributions. PoCS | @pocsvox

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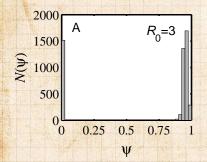
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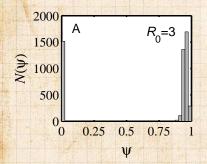
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 This includes network models: random, small-world, scale-free, ...



Simple models typically produce bimodal or unimodal size distributions. PoCS | @pocsvox

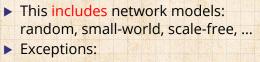
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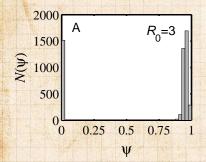
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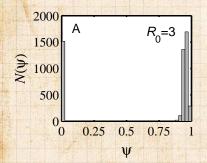
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 This includes network models: random, small-world, scale-free, ...

- Exceptions:
 - 1. Forest fire models



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- 1. Forest fire models
- 2. Sophisticated metapopulation models

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Forest fire models: [18]

Rhodes & Anderson, 1996 The physicist's approach: "if it works for magnets, it'll PoCS | @pocsvox

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A bit of a stretch:

- Epidemics \equiv forest fires
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- Original forest fire model not completely understood.

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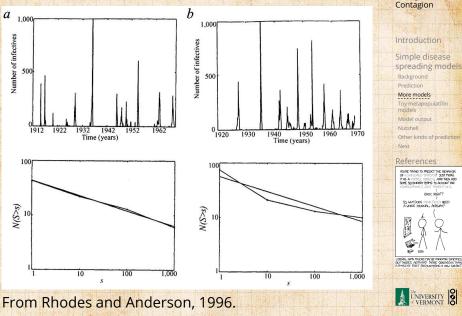
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Sophisticated metapopulation models:

- 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 C: Global pandemic simulations by Vespignani et al. PoCS | @pocsvox Biological

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Vital work but perhaps hard to generalize from...
 Create a simple model involving multiscale travel
 Very big question: What is 7
 Should we model SARS in Hong Kong as spreading in a neighborhood, in Hong Kong, Asia, or the world?
 For simple models, we need to know the final size beforehand...

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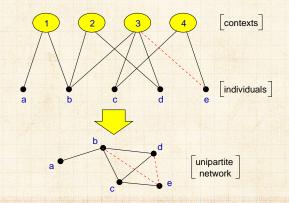
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Contexts and Identities—Bipartite networks



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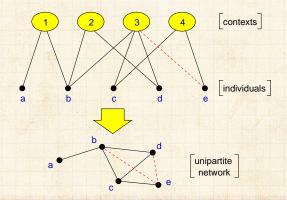
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Contexts and Identities—Bipartite networks



boards of directors

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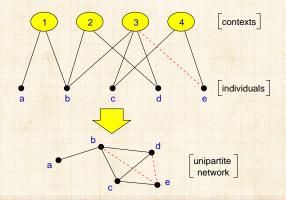
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Contexts and Identities—Bipartite networks



- boards of directors
- movies

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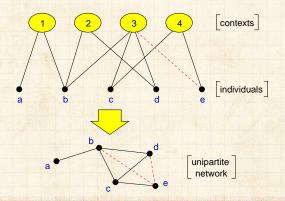
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Contexts and Identities—Bipartite networks



- boards of directors
- movies

transportation modes (subway)

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Idea for social networks: incorporate identity

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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

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Improving simple models

Idea for social networks: incorporate identity

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Groups are crucial...

formed by people with at least one simila attribute Attributes ⇔ Contexts ⇔ Interactions ⇔ Networks.

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Groups are crucial...

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

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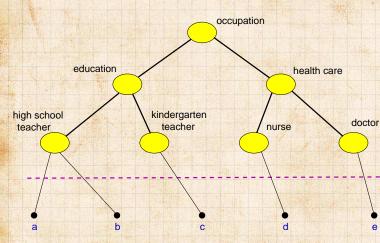
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Infer interactions/network from identities



Distance makes sense in identity/context space.

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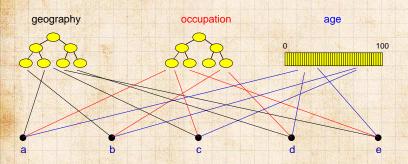
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Generalized context space



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

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"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 mixed discrete time simulation
 β = infection probability
 γ = recovery probability
 P = probability of travel
 Movement distance: Pr(u) ~ exp(-d/s)
 ξ = typical travel distance

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Geography: allow people to move between contexts

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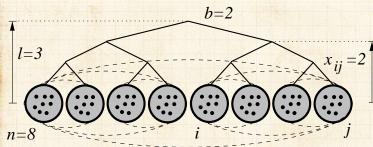
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Define P₀ = Expected number of infected individuals leaving initially infected context.

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- Define P₀ = Expected number of infected individuals leaving initially infected context.
- Need P₀ > 1 for disease to spread (independent of R₀).

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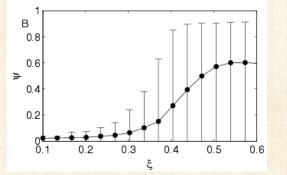
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- Define P₀ = Expected number of infected individuals leaving initially infected context.
- Need P₀ > 1 for disease to spread (independent of R₀).
- Limit epidemic size by restricting frequency of travel and/or range

Varying ξ :



 Transition in expected final size based on typical movement distance

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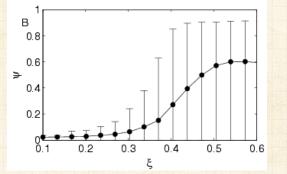
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Varying ξ :



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

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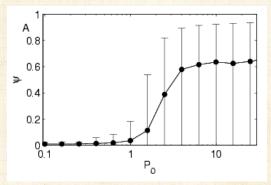
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Varying P_0 :



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

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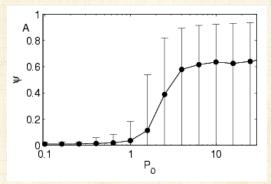
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Varying P_0 :



 Transition in expected final size based on typical number of infectives leaving first group (also sensible)

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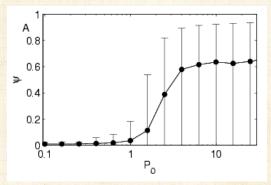
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Varying P_0 :



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 .

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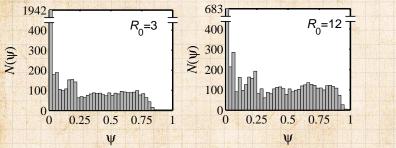
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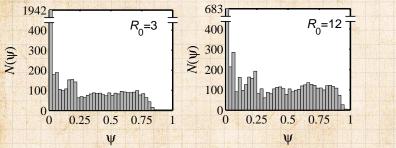
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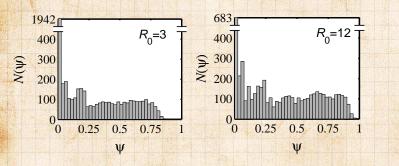
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Flat distributions are possible for certain ξ and P.



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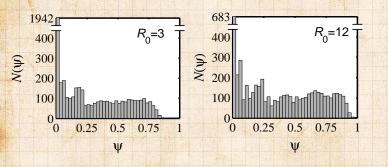
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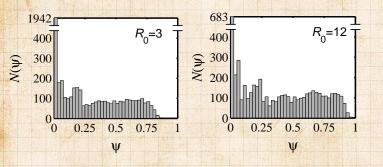
Flat distributions are possible for certain ξ and P.
 Different R₀'s may produce similar distributions



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Flat distributions are possible for certain ξ and P.
 Different R₀'s may produce similar distributions
 Same epidemic sizes may arise from different R₀'s



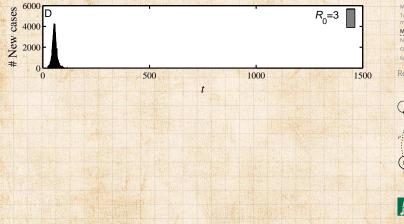


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Model output—resurgence

Standard model:



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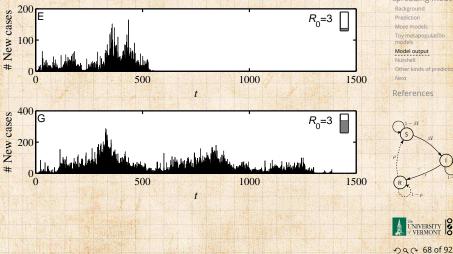
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Model output—resurgence

Standard model with transport:



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The upshot

Simple multiscale population structure

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The upshot

Simple multiscale population structure + stochasticity

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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

Problem: R_0 summarises one epidemic after the fact and enfolds movement, the price of banana: everything.

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Nutshelling

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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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 - 1. how likely the observed epidemic size was,
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Disease's spread is highly sensitive to population structure.

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 Disease's spread is highly sensitive to population structure.

Rare events may matter enormously:

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Disease's spread is highly sensitive to population structure.

 Rare events may matter enormously: e.g., an infected individual taking an international flight.

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Disease's spread is highly sensitive to population structure.

 Rare events may matter enormously: e.g., an infected individual taking an international flight.

More support for controlling population movement:

Disease's spread is highly sensitive to population structure.

- Rare events may matter enormously: e.g., an infected individual taking an international flight.
- More support for controlling population movement:

e.g., travel advisories, quarantine

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What to do:

Need to separate movement from disease R_0 needs a friend or two.

Need $R_0 > 1$ and $P_0 > 1$ and ξ sufficiently large for disease to have a chance of spreading And in general: keep building up the kitchen si models.

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- And in general: keep building up the kitchen sink models.

More wondering:

Exactly how important are rare events in disease spreading? Again, what is *N*?

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"The growth of the Internet will slow drastically, as the flaw in "Metcalfe's law"—

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"The growth of the Internet will slow drastically, as the flaw in "Metcalfe's law"—which states that the number of potential connections in a network is proportional to the square of the number of participants—becomes apparent:

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"The growth of the Internet will slow drastically, as the flaw in "Metcalfe's law"—which states that the number of potential connections in a network is proportional to the square of the number of participants—becomes apparent: most people have nothing to say to each other! PoCS | @pocsvox

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"The growth of the Internet will slow drastically, as the flaw in "Metcalfe's law"—which states that the number of potential connections in a network is proportional to the square of the number of participants—becomes apparent: most people have nothing to say to each other! By 2005 or so, it will become clear that the Internet's impact on the economy has been no greater than the fax machine's."1

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"The growth of the Internet will slow drastically, as the flaw in "Metcalfe's law"—which states that the number of potential connections in a network is proportional to the square of the number of participants—becomes apparent: most people have nothing to say to each other! By 2005 or so, it will become clear that the Internet's impact on the economy has been no greater than the fax machine's."1

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¹http://www.redherring.com/mag/issue55/economics.html



Alan Greenspan (September 18, 2007):

Tve been dealing with these big nathematical models of forecasting the economy ...

I could figure out a way to determin whether of not people are more earful or changing to more euphoric, don't need any of this other stuff.

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Jon Stewart:

"You just bummed the @*!# out of me."



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



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"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 yo wish you had not made?"
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New York Times, October 23, 2008

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What does that say about the field of economic which claims to be a science?

From the New York Times, 11/02/2008

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Adoption of ideas/beliefs (Goffman & Newell, 1964)^[10]

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Social contagion:

SIR may apply sometimes ... But we need new fundamental models Next up: Thresholds.

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"Epidemiological modeling of online social network dynamics" Spechler and Cannarella, Culture & Psychology, **21**, 359–379, 2014. ^[20] PoCS | @pocsvox

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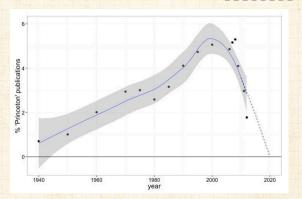
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The Facebook Data Science team's response C:



Mike Develin, Lada Adamic, and Sean Taylor.

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200 84 of 92

References I

- [1] N. T. J. Bailey. The Mathematical Theory of Infectious Diseases and Its Applications. Griffin, London, Second edition, 1975. F. Bass. [2] A new product growth model for consumer durables. Manage. Sci., 15:215–227, 1969. pdf [3] P. M. Blau and J. E. Schwartz. Crosscutting Social Circles. Academic Press, Orlando, FL, 1984.
- [4] R. L. Breiger. The duality of persons and groups. Social Forces, 53(2):181–190, 1974. pdf C

PoCS | @pocsvox

Biological Contagion

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References





20 0 85 of 92

References II

[5] A. D. Cliff, P. Haggett, J. K. Ord, and G. R. Versey. Spatial diffusion: an historical geography of epidemics in an island community. Cambridge University Press, Cambridge, UK, 1981.

[6] V. Colizza, A. Barrat, M. Barthelmey, A.-J. Valleron, and A. Vespignani. Modeling the worldwide spread of pandemic influenza: Baseline case and containment interventions. PLoS Med., 4:e13, 2007. pdf

[7] D. J. Daley and D. G. Kendall.
 Stochastic rumours.
 J. Inst. Math. Appl., 1:42–55, 1965.

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References

- [8] S. Eubank, H. Guclu, V. S. A. Kumar, M. V. Marathe, A. Srinivasan, Z. Toroczkai, and N. Wang. Modelling disease outbreaks in realistic urban social networks. Nature, 429:180–184, 2004. pdf^C
- [9] J. Gleick. <u>The Information: A History, A Theory, A Flood</u>. Pantheon, 2011.
- [10] W. Goffman and V. A. Newill. Generalization of epidemic theory: An application to the transmission of ideas. Nature, 204:225–228, 1964. pdf^C





20 P 87 of 92

References IV

[11] E. Hoffer. The True Believer: On The Nature Of Mass Movements. Harper and Row, New York, 1951. [12] E. Hoffer. The Passionate State of Mind: And Other Aphorisms. Buccaneer Books, 1954. [13] W. O. Kermack and A. G. McKendrick. A contribution to the mathematical theory of epidemics.

Proc. R. Soc. Lond. A, 115:700–721, 1927. pdf

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Biological Contagion

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Simple disease spreading models Background Prediction More models Toy metapopulation models Model output Nutshell Other kinds of prediction Next

References





20 0 88 of 92

References V

[14] W. O. Kermack and A. G. McKendrick. A contribution to the mathematical theory of epidemics. III. Further studies of the problem of endemicity.

Proc. R. Soc. Lond. A, 141(843):94–122, 1927. pdf

[15] W. O. Kermack and A. G. McKendrick. Contributions to the mathematical theory of epidemics. II. The problem of endemicity. Proc. R. Soc. Lond. A, 138(834):55–83, 1927. pdf C

[16] I. M. Longini. A mathematical model for predicting the geographic spread of new infectious agents. Math. Biosci., 90:367–383, 1988.

PoCS | @pocsvox

Biological Contagion

ntroduction

Simple disease spreading models Background Prediction More models Toy metapopulation models Model output Nutshell Other kinds of prediction

References





20 B9 of 92

References VI

[17] J. D. Murray. <u>Mathematical Biology</u>. Springer, New York, Third edition, 2002.

[18] C. J. Rhodes and R. M. Anderson. Power laws governing epidemics in isolated populations. Nature, 381:600–602, 1996. pdf 7

[19] G. Simmel. The number of members as determining the sociological form of the group. I. American Journal of Sociology, 8:1–46, 1902.

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Biological Contagion

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Simple disease spreading models Background Prediction More models Toy metapopulation models Model output Nutshell Other kinds of prediction Next

References





200 90 of 92

References VII

[20] J. A. Spechler and J. Cannarella. Epidemiological modeling of online social network dynamics. Availabe online at http://arxiv.org/abs/1401.4208, 2014. pdf

[21] Z. J. Warren and S. A. Power. It's contagious: Rethinking a metaphor dialogically. Culture & Psychology, 21:359–379, 2015. pdf

[22] D. J. Watts, P. S. Dodds, and M. E. J. Newman. Identity and search in social networks. Science, 296:1302–1305, 2002. pdf

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Simple disease spreading models Background Prediction More models Toy metapopulation models Model output Nutshell Other kinds of prediction

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200 91 of 92

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References





[23] D. J. Watts, R. Muhamad, D. Medina, and P. S. Dodds.
 Multiscale, resurgent epidemics in a hierarchcial metapopulation model.
 <u>Proc. Natl. Acad. Sci.</u>, 102(32):11157–11162, 2005.
 pdf

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