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# Biological Contagion

Last updated: 2023/08/22, 11:48:25 EDT

## Principles of Complex Systems, Vols. 1, 2, & 3D
## CSYS/MATH 6701, 6713, & a pretend number, 2023–2024| @pocsvox

## Prof. Peter Sheridan Dodds | @peterdodds

Computational Story Lab | Vermont Complex Systems Center
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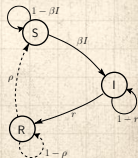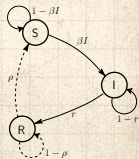Prediction
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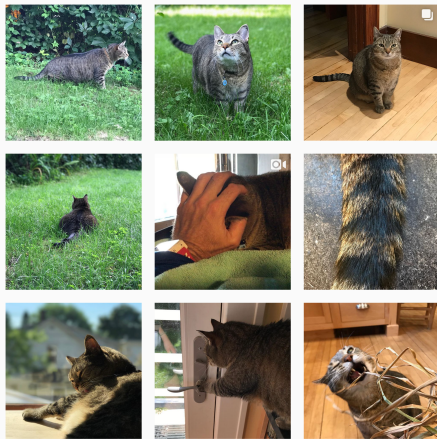Nutshell
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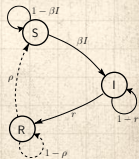SIR is the virus

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## Special Guest Executive Producer



📷 On Instagram at pratchett_the_cat↗

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## CLASSIFIED PHOENIX
### BIO HAZARD

IF FOUND REPEAT KEY PHRASE: ECHO-TANGO-X-RAY-9-4-7

## THE CONTAGION

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THE SUN · THE ... OF RETURN... · THE MANIFESTO · THE WALL OF CHAINS · THE CAGE OF IMPOSSIBLE ... · THE ... PATH · THE ... TRANSFORMATION · THE ... OF KNOWN VALUES · THE RICH GOT RICHER · THE DREAM OF ... · THE ... NESTED STORY · THE GARDEN OF ... · THE ...

THE ... OF MANY TALES · THE MEASURE · THE DATA ... · THE ... DATA · THE ... OF MANY HANDS · THE BRIDGE THAT ... BEYOND · THE MANIFEST OF ... SPACE · THE ... OF DISTRACTION · THE ... THINKING · THE ... OF ... · THE ... FORTITUDE

THE ... OF PRINTING · THE NETWORK'S COMPLEX · THE ELEMENTS OF ... · THE BRIDGE OF A FEATHER · THE BRIDGE OF ... A FEATHER · THE ... OF KNOWN ... · THE SMALLNESS OF WORLDS · THE ... OF SIX DEGREES · THE ... FREE ... SCALE

THE ... OF CONTAGION · THE PHRASE ... · THE ... EPIDEMIC · THE DARKNESS OF THE MIND · THE ... SOCIAL ... · THE ... OF GOD · THE ... OF FAME · THE ... NOSTALGIA · THE ... · THE ... NARRATIVES

THE STORYTELLER · THE ... · THE PATHS OF ... UNIVERSALITY · THE PATIENT ZERO · THE UNKNOWN MECHANISM · THE ... OF ... PATHS · THE NETWORK OF BLOOD · THE STARS OF CREATIVITY · THE ... OF DREAMS · THE LAND OF ... BRANCH ... · THE ...

OUR BEADS ON THE BRANCH · THE ... OF ... FIELDS · THE ... OF ... · THE OUTSIDER · THE FAMILY OF ... ONCE · THE FAMILY OF ... PRESSURE · THE ... PASSINGS · THE ... OF ... · THE CURVE ... · THE ... IN THE MIND · THE ... OF ... ENOUGH

THE ... · THE ... ANGLES · THE ... BETTER NEVER · THE ... DISTORTION · THE ... MISUNDERSTOOD · THE ... OF DISCONNECTION · THE CLARITY OF ... · THE ... ILL-... · THE NETWORK OF ... · THE CRADLE OF ... ENOUGH · THE END

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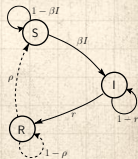Prediction
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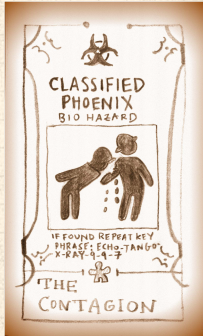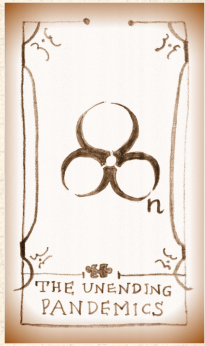Other kinds of prediction
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An awful recording: Wikipedia's list of epidemics⧉ from 430 BC on.



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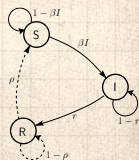
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# List of epidemics

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 | Known 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 | 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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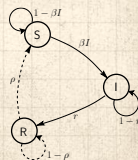More models
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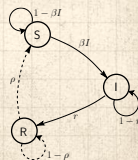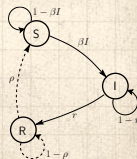Other kinds of prediction
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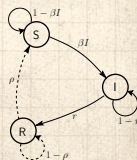More models
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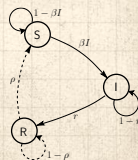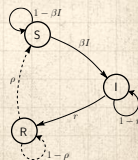Toy metapopulation
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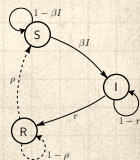Toy metapopulation
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- 🧩 Suicide, violence?

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- 🧊 Morality? Evil? Laziness? Stupidity? Happiness?

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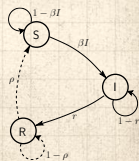Toy metapopulation
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- 🎲 Religion?

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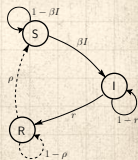Background
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- 🎲 Democracy ...?

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🧊 Suicide, violence?

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🧊 Religion?

🧊 Democracy ...?

🧊 Language? The alphabet? [10]

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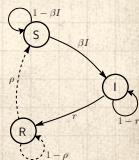Background
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- 🎲 Religion?
- 🎲 Democracy ...?
- 🎲 Language? The alphabet? [10]
- 🎲 Stories?

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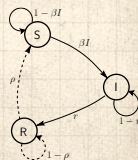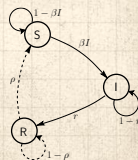Background
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🎲 "The feeling was contagious."

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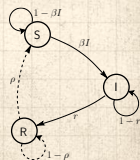Prediction
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- 🧊 "The feeling was contagious."
- 🧊 "The news spread like wildfire."

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&#9878; "The feeling was contagious."

&#9878; "The news spread like wildfire."

&#9878; "Freedom is the most contagious virus known to man."
—Hubert H. Humphrey, Johnson's vice president

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- ♻ "The feeling was contagious."

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- ♻ "Nothing is so contagious as enthusiasm."
  —Samuel Taylor Coleridge

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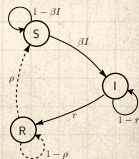Background
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## Optimism according to Ambrose Bierce: 

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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## 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. ... It is hereditary, but fortunately not contagious.

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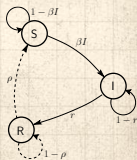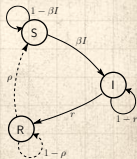Model output
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### Eric Hoffer, 1902–1983

There is a grandeur in the uniformity of the mass.

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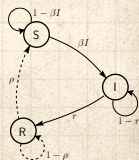Model output
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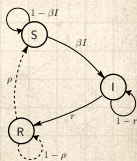Model output
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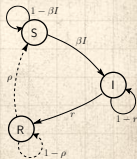Other kinds of prediction
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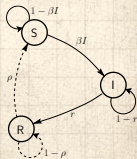Other kinds of prediction
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🎲 Hoffer☑ was an interesting fellow...

# The spread of fanaticism

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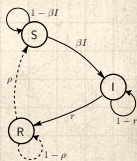Model output
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Hoffer's most famous work: "The True Believer:
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Aphorisms-aplenty:

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## Aphorisms-aplenty:

"We can be absolutely certain only about things
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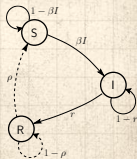Background
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Aphorisms-aplenty:

- "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."

# The spread of fanaticism

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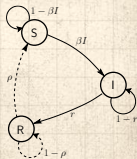Other kinds of prediction
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References

Hoffer's most famous work: "The True Believer:
Thoughts On The Nature Of Mass Movements"
(1951) [12]

## Aphorisms-aplenty:

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

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- "Where freedom is real, equality is the passion of the masses.

"

# The spread of fanaticism

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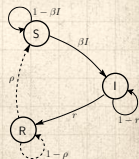models
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Hoffer's most famous work: "The True Believer:
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Aphorisms-aplenty:

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- "Where freedom is real, equality is the passion of
  the masses. Where equality is real, freedom is the
  passion of a small minority."

# Imitation

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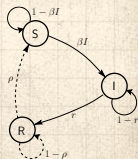Toy metapopulation
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"When people are free to do as they please, they usually imitate each other."

—Eric Hoffer
"The Passionate State of Mind" [13]

despair.com

# The collective...

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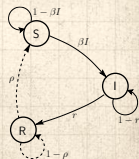Model output
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IDIOCY

NEVER UNDERESTIMATE THE POWER OF STUPID PEOPLE IN LARGE GROUPS.
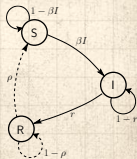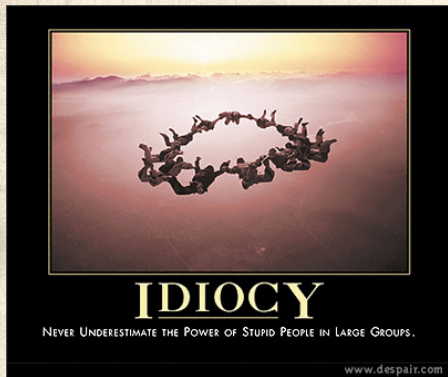
www.despair.com

despair.com

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

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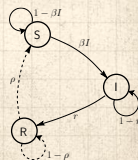Other kinds of prediction
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# Examples of non-disease spreading:

## Interesting infections:

🎲 Spreading of certain buildings in the US:

https://www.youtube.com/watch?v=EGzHBtoVvpc?rel=0

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# Marbleization of the US:

https://www.youtube.com/watch?v=9ihSeSToXOw?rel=0 ↗
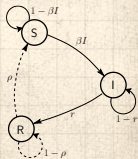
# The most terrifying contagious outbreak?

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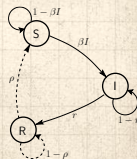SIR is the virus

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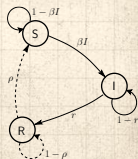Toy metapopulation
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## Definitions

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

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### Definitions

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

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

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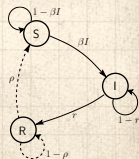Toy metapopulation
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## Definitions

- (1) The spreading of a quality or quantity between individuals in a population.
- (2) A disease itself:
  the plague, a blight, the dreaded lurgi, …
- from Latin: *con* = 'with' + *tangere* 'to touch.'

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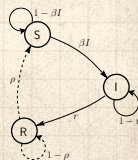models
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- Contagion has unpleasant overtones...

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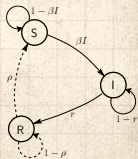Prediction
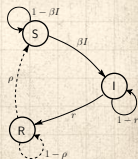More models
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🎲 Contagion has unpleasant overtones...

🎲 Just Spreading might be a more neutral word

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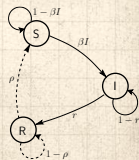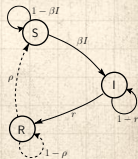models
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- ⬢ (1) The spreading of a quality or quantity between individuals in a population.
- ⬢ (2) A disease itself:
  the plague, a blight, the dreaded lurgi, ...
- ⬢ from Latin: *con* = 'with' + *tangere* 'to touch.'
- ⬢ Contagion has unpleasant overtones...
- ⬢ Just Spreading might be a more neutral word
- ⬢ But contagion is kind of exciting...

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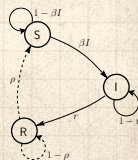More models
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Two main classes of contagion

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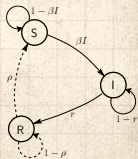Other kinds of prediction
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Two main classes of contagion

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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Two main classes of contagion

1. **Infectious diseases**:
   tuberculosis, HIV, ebola, SARS, influenza,
   zombification, ...

2. **Social contagion**:
   fashion, word usage, rumors, uprisings, religion,
   stories about zombies, ...

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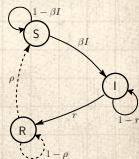More models
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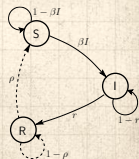Other kinds of prediction
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# Archival footage from the Black Plague

https://www.youtube.com/watch?v=GU0d8kpybVg?rel=0

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# Community—S2E06: Epidemiology

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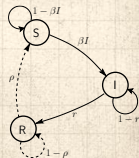models
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The standard SIR model [18]

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🎲 = basic model of disease contagion

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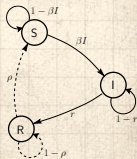Other kinds of prediction
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🎲 = basic model of disease contagion

🎲 Three states:

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## The standard SIR model [18]

🎲 = basic model of disease contagion

🎲 Three states:

    1. S = Susceptible

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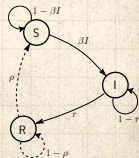
## The standard SIR model [18]

- = basic model of disease contagion
- Three states:
  1. S = Susceptible
  2. I = Infective/Infectious

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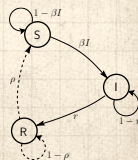Nutshell
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## The standard SIR model [18]

⬡ = basic model of disease contagion

⬡ Three states:
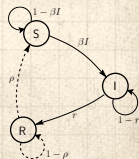  1. S = Susceptible
  2. I = Infective/Infectious
  3. R = Recovered

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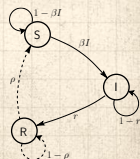Other kinds of prediction
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## The standard SIR model [18]

🎲 = basic model of disease contagion

🎲 Three states:
1. S = Susceptible
2. I = Infective/Infectious
3. R = Recovered or Removed or Refractory

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&#x266F; = basic model of disease contagion

&#x266F; Three states:

1. S = Susceptible
2. I = Infective/Infectious
3. R = Recovered  or Removed or Refractory

&#x266F; $S(t) + I(t) + R(t) = 1$

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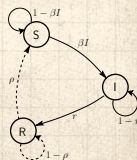The standard SIR model [18]

⚄ = basic model of disease contagion

⚄ Three states:
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2. I = Infective/Infectious
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⚄ $S(t) + I(t) + R(t) = 1$

⚄ Presumes random interactions (mass-action principle)

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## The standard SIR model [18]

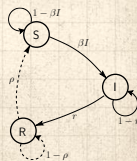🧩 = basic model of disease contagion

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🧩 Presumes random interactions (mass-action principle)

🧩 Interactions are independent (no memory)

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## The standard SIR model [18]

- = basic model of disease contagion
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  2. I = Infective/Infectious
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- $S(t) + I(t) + R(t) = 1$

- Presumes random interactions (mass-action principle)
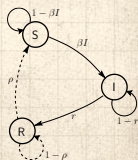
- Interactions are independent (no memory)

- Discrete and continuous time versions

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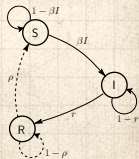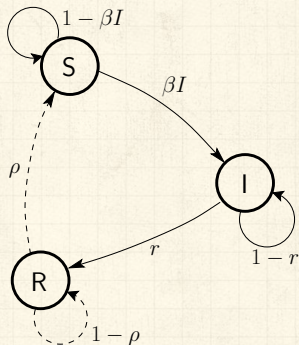More models
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Transition Probabilities:

$\beta$ for being infected given contact with infected

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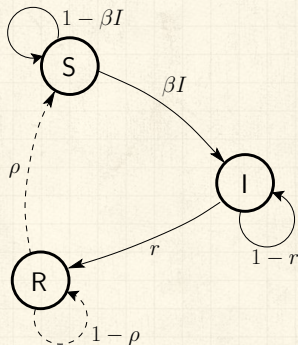Model output
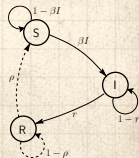Nutshell
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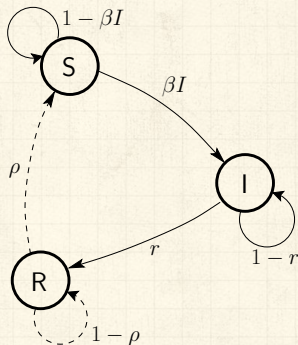SIR is the virus

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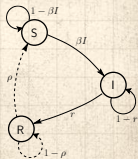
Discrete time automata example:



Transition Probabilities:

$\beta$ for being infected given
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$r$ for recovery

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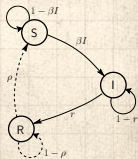
Discrete time automata example:



Transition Probabilities:

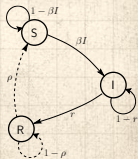$\beta$ for being infected given
contact with infected
$r$ for recovery
$\rho$ for loss of immunity

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Original models attributed to

🎲 1920's: Reed and Frost

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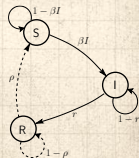Toy metapopulation
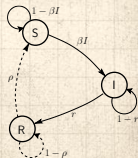models
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Original models attributed to

- 🎲 1920's: Reed and Frost
- 🎲 1920's/1930's: Kermack and McKendrick [14, 16, 15]

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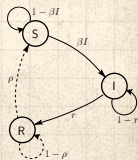models
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Original models attributed to

- 1920's: Reed and Frost
- 1920's/1930's: Kermack and McKendrick [14, 16, 15]
- Coupled differential equations with a mass-action principle

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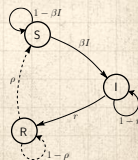Differential equations for continuous model

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

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

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

$\beta$, $r$, and $\rho$ are now rates.

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Reproduction Number $R_0$ ⌤

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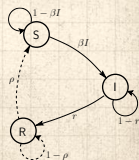Other kinds of prediction
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## Reproduction Number $R_0$ 🗗

🎲 $R_0$ = expected number of infected individuals
  resulting from a single initial infective

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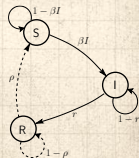SIR is the virus

References

## 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.

# Reproduction Number $R_0$

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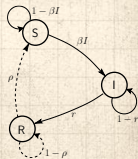Other kinds of prediction
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References

## 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 of
   generations.

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## Reproduction Number $R_0$ ⤴

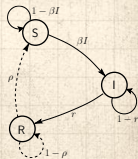- 🧊 $R_0$ = expected number of infected individuals resulting from a single initial infective

- 🧊 Epidemic threshold: If $R_0 > 1$, 'epidemic' occurs.

- 🧊 Exponential take off: $R_0^n$ where $n$ is the number of generations.

- 🧊 Fantastically awful notation convention: $R_0$ and the $R$ in $SIR$.

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Discrete version:

🎲 Set up: One Infective in a randomly mixing population of Susceptibles

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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

# Reproduction Number $R_0$

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References

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 = $\beta$

# Reproduction Number $R_0$

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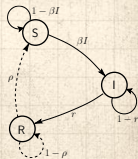SIR is the virus

References

Discrete version:

&#x1F4E6; Set up: One Infective in a randomly mixing population of Susceptibles

&#x1F4E6; At time $t = 0$, single infective random bumps into a Susceptible

&#x1F4E6; Probability of transmission = $\beta$

&#x1F4E6; At time $t = 1$, single Infective remains infected with probability $1 - r$

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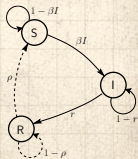models
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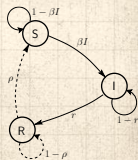SIR is the virus

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Discrete version:

&#x1F8; Set up: One Infective in a randomly mixing
population of Susceptibles

&#x1F8; At time $t = 0$, single infective random bumps into a
Susceptible

&#x1F8; Probability of transmission = $\beta$

&#x1F8; At time $t = 1$, single Infective remains infected with
probability $1 - r$

&#x1F8; At time $t = k$, single Infective remains infected
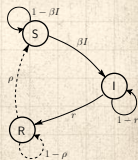with probability $(1 - r)^k$

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Discrete version:

 Expected number infected by original infective:

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

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Discrete version:

🎲 Expected number infected by original infective:

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

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

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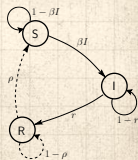Other kinds of prediction
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# Reproduction Number $R_0$

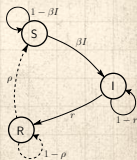## Discrete version:

Expected number infected by original infective:

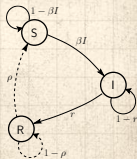$$R_0 = \beta + (1-r)\beta + (1-r)^2\beta + (1-r)^3\beta + \ldots$$

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

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

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## Discrete version:

Expected number infected by original infective:

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

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

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

# Reproduction Number $R_0$

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## Discrete version:

Expected number infected by original infective:

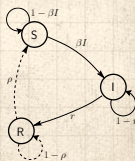$$R_0 = \beta + (1-r)\beta + (1-r)^2\beta + (1-r)^3\beta + \dots$$

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

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

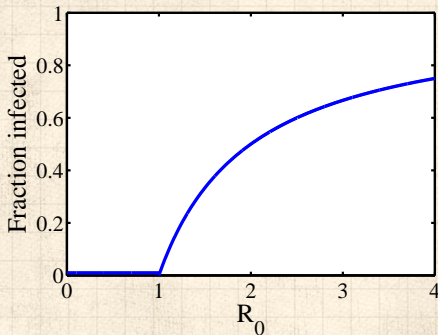For $S(0) \simeq 1$ initial susceptibles
$(1 - S(0) = R(0)$ = fraction initially immune):

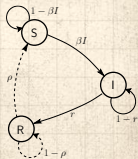$$R_0 = S(0)\beta/r$$

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Example of epidemic threshold:



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

# Independent Interaction models

## For the continuous version

Second equation:

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

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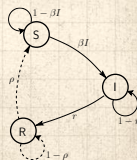spreading models

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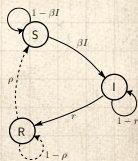Model output
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## For the continuous version

Second equation:

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

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

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## For the continuous version

&#x2318; Second equation:

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

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

&#x2318; Number of infectives grows initially if

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

where $S(0) \simeq 1$.

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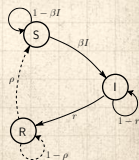Prediction
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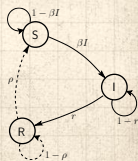Other kinds of prediction
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# Independent Interaction models

## For the continuous version

♣ Second equation:

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

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

♣ Number of infectives grows initially if

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

where $S(0) \simeq 1$.

# Independent Interaction models

## For the continuous version

Second equation:

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

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

Number of infectives grows initially if

$$\beta S(0) - r > 0 \Rightarrow \beta S(0) > r \Rightarrow \beta S(0)/r > 1$$
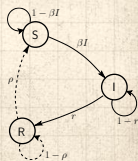
where $S(0) \simeq 1$.

# Independent Interaction models

## For the continuous version

⊞ Second equation:

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

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

⊞ Number of infectives grows initially if

$$\beta S(0) - r > 0 \Rightarrow \beta S(0) > r \Rightarrow \beta S(0)/r > 1$$

where $S(0) \simeq 1$.

⊞ Same story as for discrete model.

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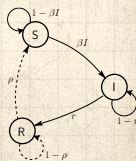
Many variants of the SIR model:

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Many variants of the SIR model:

🦠 SIS: susceptible-infective-susceptible

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Many variants of the SIR model:

- SIS: susceptible-infective-susceptible
- SIRS: susceptible-infective-recovered-susceptible

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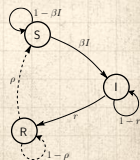Prediction
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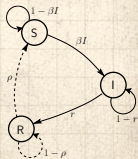SIR is the virus

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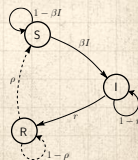
Many variants of the SIR model:

🎲 SIS: susceptible-infective-susceptible

🎲 SIRS: susceptible-infective-recovered-susceptible

🎲 compartment models (age or gender partitions)

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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)

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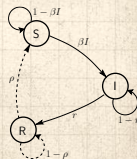
Many variants of the SIR model:

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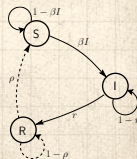- SIRS: susceptible-infective-recovered-susceptible
- compartment models (age or gender partitions)
- more categories such as 'exposed' (SEIRS)
- recruitment (migration, birth)

# Watch someone else pretend to save the world:

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# Save the world yourself: 🗗





And you can be the virus. 🗗

Also contagious?: Cooperative games ...

Neural reboot—Save another pretend world with Vax: ⧉

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# Pandemic severity index (PSI) ☑

Classification during/post pandemic:



| Case Fatality Ratio | 5 | Projected Number of U.S. Deaths (Pop. 2006) |
|---|---|---|
| > 2.0% | | >1,800,000 |
| 1.0% - <2.0% | 4 | 900,000 - <1,800,000 |
| 0.5% - <1.0% | 3 | 450,000 - <900,000 |
| 0.1% - <0.5% | 2 | 90,000 - <450,000 |
| <0.1% | 1 | <90,000 |

Assumes 30% illness rate
and unmitigated pandemic
without interventions

CDC                                    U.S. Gov.

Category based.

1–5 scale.

Modeled on the
Saffir-Simpson hurricane
scale ☑.

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For novel diseases:

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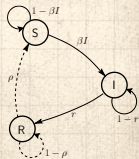Prediction
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## For novel diseases:

1. Can we predict the size of an epidemic?



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For novel diseases:

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


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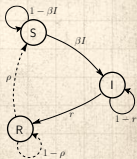Toy metapopulation
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For novel diseases:

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:

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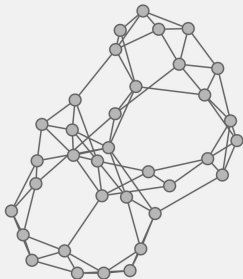Prediction
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For novel diseases:

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$R_0$ approximately same for all of the following:

- 1918-19 "Spanish Flu" $\sim$ 75,000,000 world-wide, 500,000 deaths in US.

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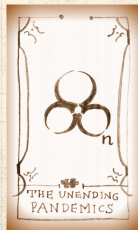Background
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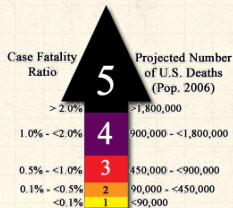Other kinds of prediction
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For novel diseases:

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$R_0$ 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.

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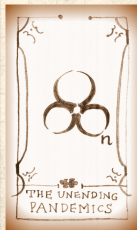Other kinds of prediction
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References

For novel diseases:

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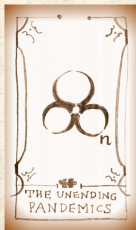$R_0$ approximately same for all of the following:

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- 🎲 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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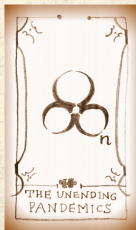$R_0$ approximately same for all of the following:

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🎲 1968-69 "Hong Kong Flu" $\sim$ 1,000,000 world-wide, 34,000 deaths in US.

🎲 2003 "SARS Epidemic" $\sim$ 800 deaths world-wide.

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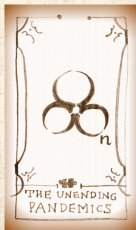
# Size distributions

As we know, heavy-tailed size distributions are somewhat prevalent in complex systems:

# Size distributions

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As we know, heavy-tailed size distributions are
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🎲 earthquakes (Gutenberg-Richter law)

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As we know, heavy-tailed size distributions are somewhat prevalent in complex systems:

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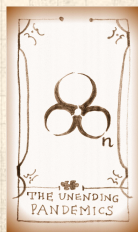Background
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- ♻ wealth distributions

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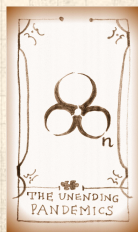Model output
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As we know, heavy-tailed size distributions are
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- city sizes, forest fires, war fatalities
- wealth distributions
- 'popularity' (books, music, websites, ideas)

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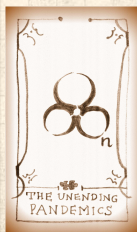Other kinds of prediction
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As we know, heavy-tailed size distributions are somewhat prevalent in complex systems:

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🎲 city sizes, forest fires, war fatalities

🎲 wealth distributions

🎲 'popularity' (books, music, websites, ideas)

🎲 Epidemics?



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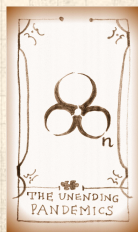
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- Epidemics?

Power law distributions are common but not obligatory...

# Size distributions

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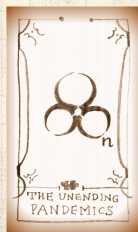As we know, heavy-tailed size distributions are somewhat prevalent in complex systems:

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Power law distributions are common but not obligatory...

Really, what about epidemics?



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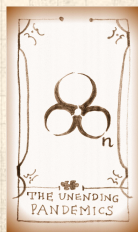As we know, heavy-tailed size distributions are somewhat prevalent in complex systems:

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Really, what about epidemics?
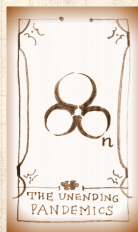
- Simply hasn't attracted much attention.

# Size distributions

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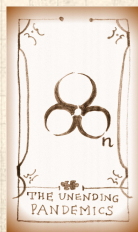- 🎲 Epidemics?

Power law distributions are common but not obligatory...

Really, what about epidemics?

- 🎲 Simply hasn't attracted much attention.
- 🎲 Data not as clean as for other phenomena.

# Feeling Ill in Iceland 🔗

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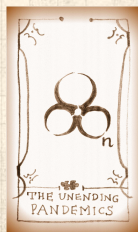
Caseload recorded monthly for range of diseases in
Iceland, 1888-1990



Iceland: measles normalized count

- 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.

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# 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.
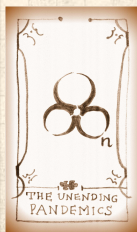
# Power law distributions

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Measured values of $\gamma$:

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Measured values of $\gamma$:

🎲 measles: 1.40 (low $\Psi$) and 1.13 (high $\Psi$)

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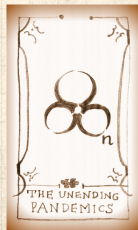
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📦 Expect $2 \leq \gamma < 3$ (finite mean, infinite variance)

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🎲 When $\gamma < 1$, can't normalize

# Power law distributions

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Measured values of $\gamma$:

- measles: 1.40 (low $\Psi$) and 1.13 (high $\Psi$)
- pertussis: 1.39 (low $\Psi$) and 1.16 (high $\Psi$)

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

# Resurgence—example of SARS

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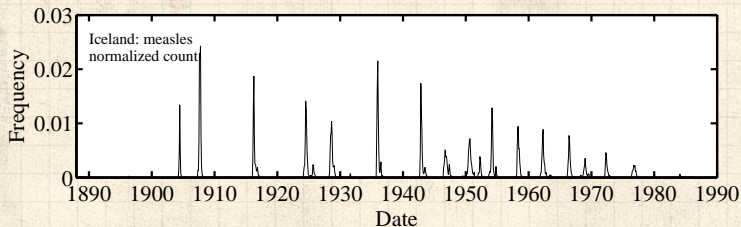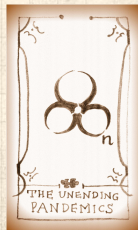SIR is the virus

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# Resurgence—example of SARS

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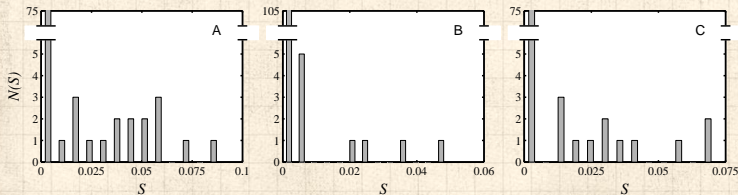Prediction
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Epidemic slows...

# Resurgence—example of SARS

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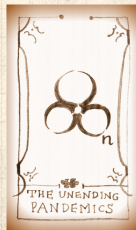Nutshell
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Epidemic slows...
then an infective moves to a new context.

# Resurgence—example of SARS

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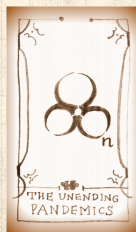Background
Prediction
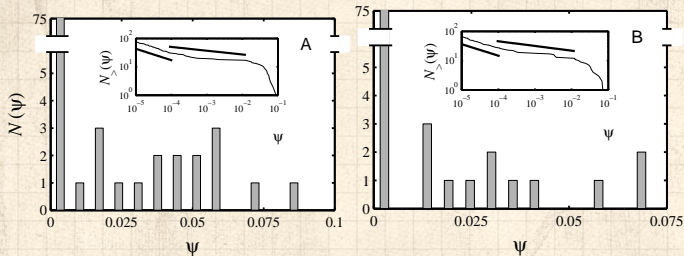More models
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- Epidemic slows...
  then an infective moves to a new context.
- Epidemic discovers new 'pools' of susceptibles:
  Resurgence.

# Resurgence—example of SARS

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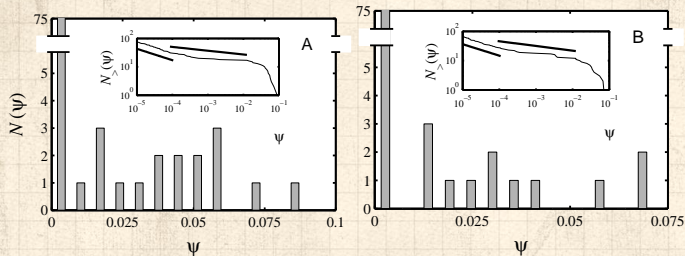More models
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- Epidemic slows…
  then an infective moves to a new context.
- Epidemic discovers new 'pools' of susceptibles:
  Resurgence.
- Importance of rare, stochastic events.

# Community—S2E06: Epidemiology

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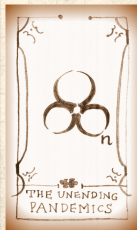Background
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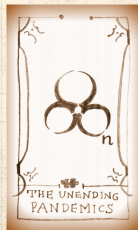Toy metapopulation
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So... can a simple model produce

1. broad epidemic distributions
   and

2. resurgence ?

# Size distributions

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Simple models
typically produce
bimodal or unimodal
size distributions.

# Size distributions
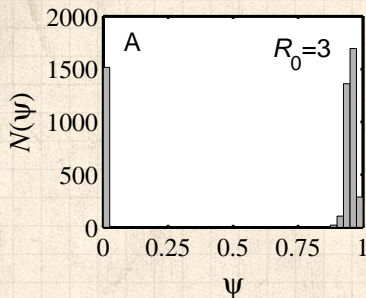
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🎲 This includes network models:
random, small-world, scale-free, ...

# Size distributions
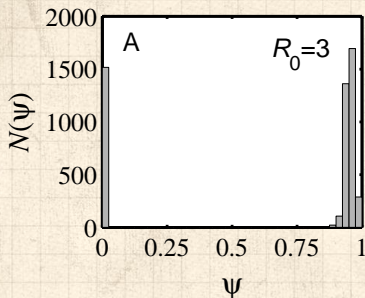
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A    $R_0=3$

Simple models
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This includes network models:
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Exceptions:

# Size distributions
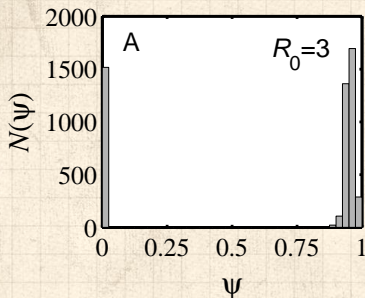
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&#x1F4E6; This includes network models:
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&#x1F4E6; Exceptions:
   1. Forest fire models

# Size distributions
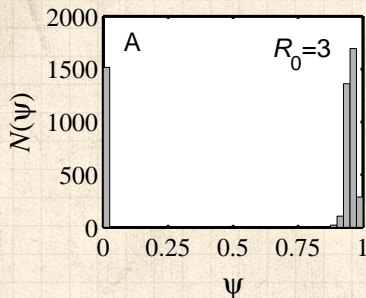
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Simple models
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- This includes network models:
  random, small-world, scale-free, ...
- Exceptions:
  1. Forest fire models
  2. Sophisticated metapopulation models
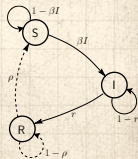
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Forest fire models: [19]

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Forest fire models: [19]

Rhodes & Anderson, 1996

# Burning through the population

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Forest fire models: [19]

🎲 Rhodes & Anderson, 1996

🎲 The physicist's approach:
"if it works for magnets, it'll work for people..."

# Burning through the population

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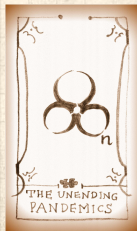Prediction
**More models**
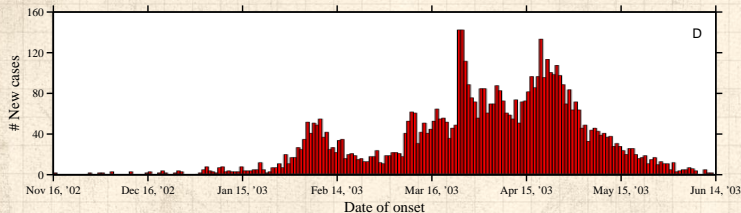Toy metapopulation
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- Rhodes & Anderson, 1996
- The physicist's approach:
  "if it works for magnets, it'll work for people..."

A bit of a stretch:

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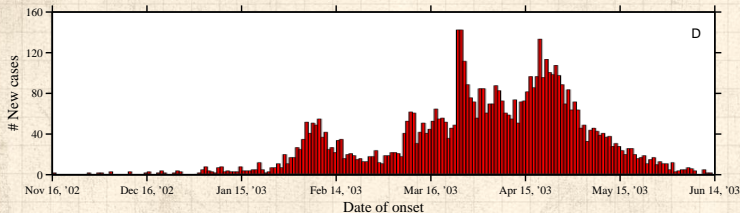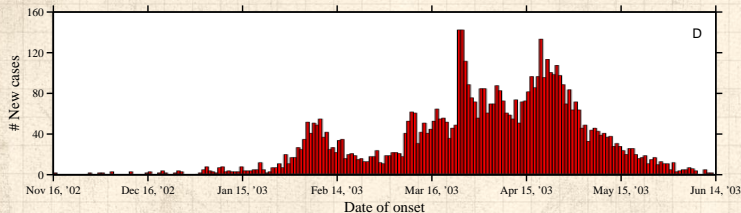models
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🎲 Rhodes & Anderson, 1996
🎲 The physicist's approach:
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A bit of a stretch:

1. Epidemics ≡ forest fires
   spreading on 3-d and 5-d lattices.

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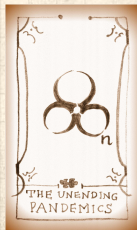Background
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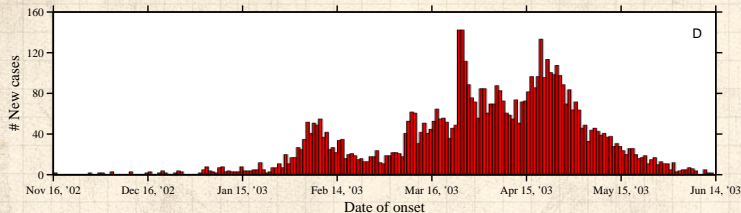models
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Forest fire models: [19]

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

A bit of a stretch:

1. Epidemics ≡ forest fires
   spreading on 3-d and 5-d lattices.
2. Claim Iceland and Faroe Islands exhibit power law
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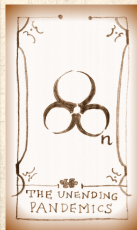Background
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Forest fire models: [19]

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

A bit of a stretch:

1. Epidemics ≡ forest fires
   spreading on 3-d and 5-d lattices.
2. Claim Iceland and Faroe Islands exhibit power law
   distributions for outbreaks.
3. Original forest fire model not completely
   understood.

# Size distributions

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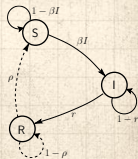Other kinds of prediction
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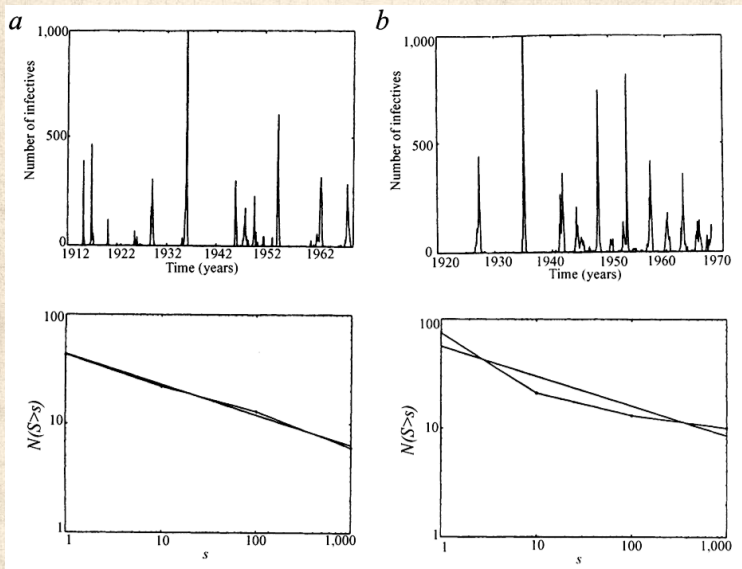
From Rhodes and Anderson, 1996.

# Sophisticated metapopulation models:

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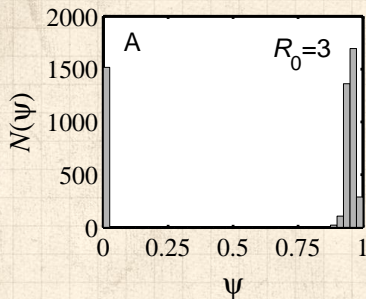Other kinds of prediction
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- Multiscale models suggested earlier by others but not formalized (Bailey [1], Cliff and Haggett [6], Ferguson et al.)

- Community based mixing (two scales)—Longini. [17]

- Eubank et al.'s EpiSims/TRANSIMS☑—city simulations. [9]

- Spreading through countries—Airlines: Germann et al., Colizza et al. [7]



- GLEAM☑: Global pandemic simulations by Vespignani et al.

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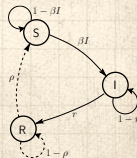
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"The hidden geometry of complex,
network-driven contagion phenomena" ⤤
Brockmann and Helbing,
Science, **342**, 1337–1342, 2013. [5]

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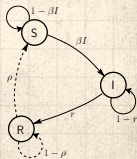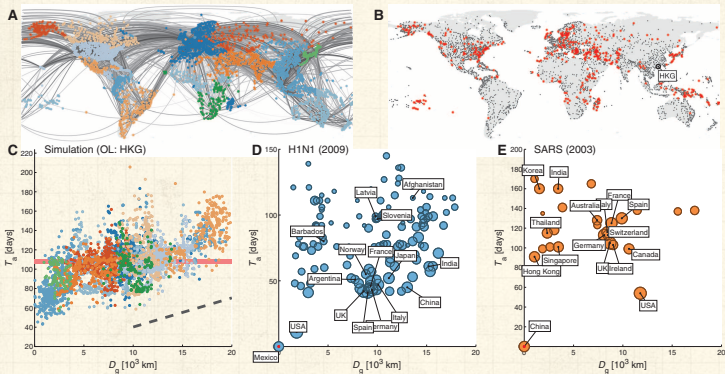
**Fig. 1. Complexity in global, network-driven contagion phenomena. (A)** The global mobility network (GMN). Gray lines represent passenger flows along direct connections between 4069 airports worldwide. Geographic regions are distinguished by color [classified according to network modularity maximization (39)]. **(B)** Temporal snapshot of a simulated global pandemic with initial outbreak location (OL) in Hong Kong (HKG). The simulation is based on the metapopulation model defined by Eq. 3 with parameters $R_0 = 1.5$, $\beta = 0.285$ day$^{-1}$, $\gamma = 2.8 \times 10^{-3}$ day$^{-1}$, $\varepsilon = 10^{-6}$. Red symbols depict locations with epidemic arrival times in the time window 105 days $\leq T_a \leq$ 110 days. Because of the multiscale structure of the underlying network, the spatial distribution of disease prevalence (i.e., the fraction of infected individuals) lacks geometric coherence. No clear wavefront is visible, and based on this dynamic state, the OL cannot be easily deduced. **(C)** For the same simulation as in (B), the panel depicts arrival times $T_a$ as a function of geographic distance $D_g$ from the OL [nodes are colored according to geographic region as in (A)] for each of the 4069 nodes in the network. On a

global scale, $T_a$ weakly correlates with geographic distance $D_g$ ($R^2 = 0.34$). A linear fit yields an average global spreading speed of $v_g = 331$ km/day (see also fig. S7). Using $D_g$ and $v_g$ to estimate arrival times for specific locations, however, does not work well owing to the strong variability of the arrival times for a given geographic distance (see also fig. S7). The red horizontal bar corresponds to the arrival time window shown in (B). **(D)** Arrival times versus geographic distance from the source (Mexico) for the 2009 H1N1 pandemic. Symbols represent 140 affected countries, and symbol size quantifies total traffic per country. Arrival times are defined as the date of the first confirmed case in a given country after the initial outbreak on 17 March 2009. As in the simulated scenario, arrival time and geographic distance are only weakly correlated ($R^2 = 0.0394$). **(E)** In analogy to (D), the panel depicts the arrival times versus geographic distance from the source (China) of the 2003 SARS epidemic for 29 affected countries worldwide. Arrival times are taken from WHO published data (2). As in (C) and (D), arrival time correlates weakly with geographic distance.

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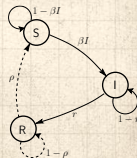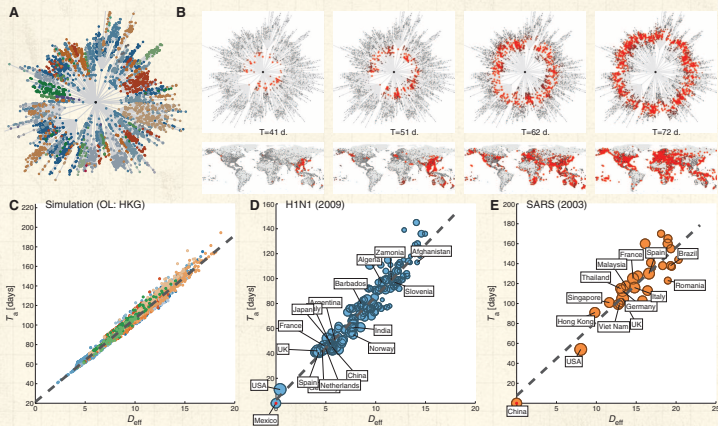
**Fig. 2. Understanding global contagion phenomena using effective distance. (A)** The structure of the shortest path tree (in gray) from Hong Kong (central node). Radial distance represents effective distance $D_{eff}$ as defined by Eqs. 4 and 5. Nodes are colored according to the same scheme as in Fig. 1A. **(B)** The sequence (from left to right) of panels depicts the time course of a simulated model disease with initial outbreak in Hong Kong (HKG), for the same parameter set as used in Fig. 1B. Each panel compares the state of the system in the conventional geographic representation (bottom) with the effective distance representation (top). The complex spatial pattern in the conventional view is equivalent to a homoge-neous wave that propagates outwards at constant effective speed in the effective distance representation. **(C)** Epidemic arrival time $T_a$ versus effective distance $D_{eff}$ for the same simulated epidemic as in (B). In contrast to geographic distance (Fig. 1C), effective distance correlates strongly with arrival time ($R^2 = 0.973$), i.e., effective distance is an excellent predictor of arrival times. **(D and E)** Linear relationship between effective distance and arrival time for the 2009 H1N1 pandemic (D) and the 2003 SARS epidemic (E). The arrival time data are the same as in Fig. 1, D and E. The effective distance was computed from the projected global mobility network between countries. As in the model system, we observe a strong correlation between arrival time and effective distance.

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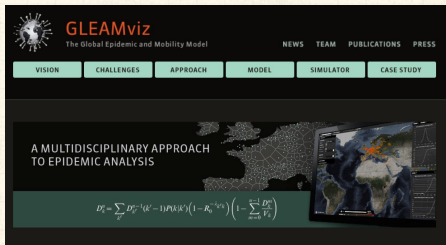SIR is the virus

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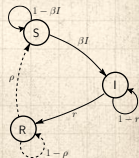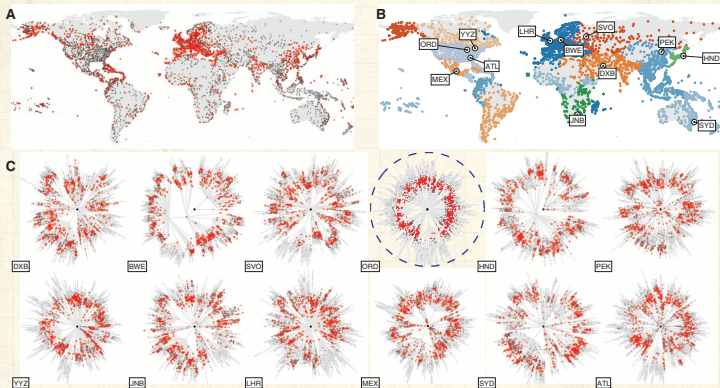
**Fig. 3. Qualitative outbreak reconstruction based on effective distance.** (A) Spatial distribution of prevalence $j_n(t)$ at time $T = 81$ days for OL Chicago (parameters $\beta = 0.28$ day$^{-1}$, $R_0 = 1.9$, $\gamma = 2.8 \times 10^{-3}$ day$^{-1}$, and $\varepsilon = 10^{-6}$). After this time, it is difficult, if not impossible, to determine the correct OL from snapshots of the dynamics. (B) Candidate OLs chosen from different geographic regions. (C) Panels depict the state of the system shown in (A) from the perspective of each candidate OL, using each OL's shortest path tree representation. Only the actual OL (ORD, circled in blue) produces a circular wavefront. Even for comparable North American airports [Atlanta (ATL), Toronto (YYZ), and Mexico City (MEX)], the wavefronts are not nearly as concentric. Effective distances thus permit the extraction of the correct OL, based on information on the mobility network and a single snapshot of the dynamics.

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🎲 Vital work but perhaps hard to generalize from...

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🎲 Vital work but perhaps hard to generalize from...

🎲 ⇒ Create a simple model involving multiscale
travel

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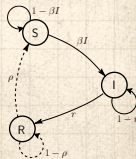
- Vital work but perhaps hard to generalize from...
- $\Rightarrow$ Create a simple model involving multiscale travel
- Very big question: What is $N$?
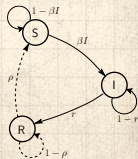
# Size distributions

- Vital work but perhaps hard to generalize from...
- $\Rightarrow$ 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?
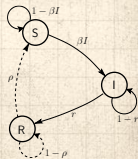
# Size distributions

- Vital work but perhaps hard to generalize from...
- $\Rightarrow$ 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?
- For simple models, we need to know the final size beforehand...

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## Contexts and Identities—Bipartite networks

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contexts

individuals

unipartite
network

🎲 boards of directors

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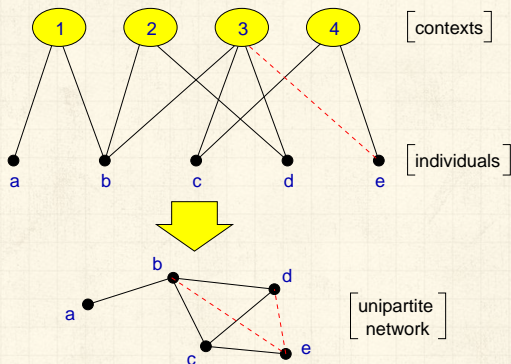
🎲 boards of directors
🎲 movies

# Improving simple models

## Contexts and Identities—Bipartite networks

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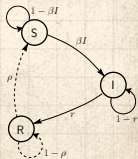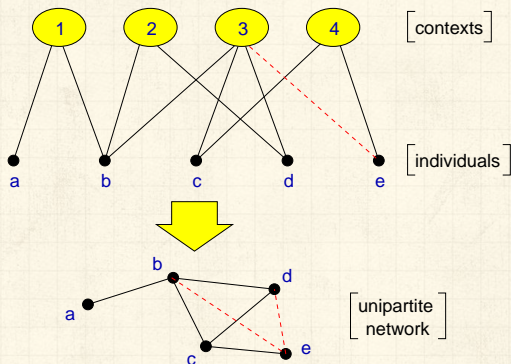
🎲 boards of directors

🎲 movies

🎲 transportation modes (subway)

# Improving simple models

Idea for social networks: incorporate identity

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Idea for social networks: incorporate identity

Identity is formed from attributes such as:

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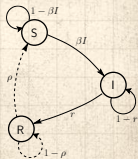spreading models
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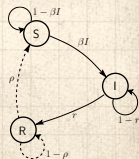Other kinds of prediction
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Idea for social networks: incorporate identity

Identity is formed from attributes such as:

🧊 Geographic location

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Idea for social networks: incorporate identity

Identity is formed from attributes such as:

🧩 Geographic location

🧩 Type of employment

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Idea for social networks: incorporate identity

Identity is formed from attributes such as:

- 🔷 Geographic location
- 🔷 Type of employment
- 🔷 Age

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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

# Improving simple models

Idea for social networks: incorporate identity

Identity is formed from attributes such as:

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

Groups are crucial...

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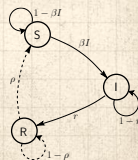Background
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# Improving simple models

## 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

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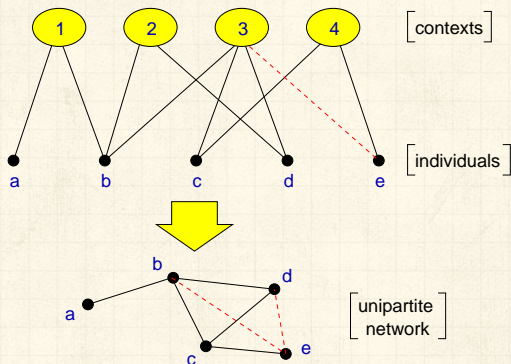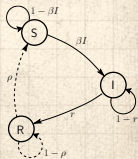models
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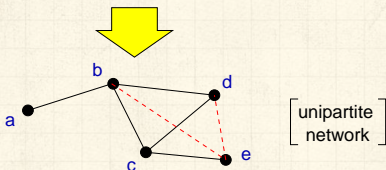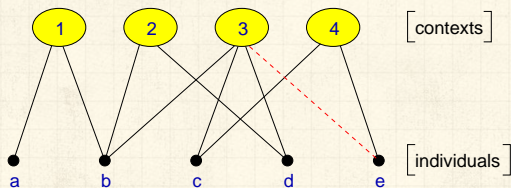Other kinds of prediction
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Idea for social networks: incorporate identity

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. [23]
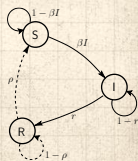
# Infer interactions/network from identities

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occupation

education

health care

high school
teacher

kindergarten
teacher

nurse

doctor

a     b     c     d     e

Distance makes sense in identity/context space.

# Generalized context space

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geography          occupation          age

0          100

a          b          c          d          e
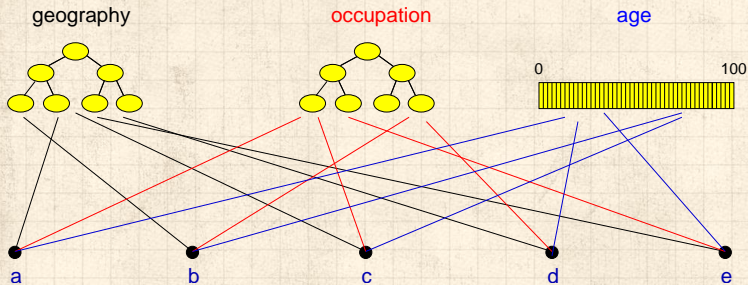
(Blau & Schwartz [3], Simmel [20], Breiger [4])

# A toy agent-based model:

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"Multiscale, resurgent epidemics in a
hierarchial metapopulation model" ↗
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]

Geography: allow people to move between
contexts

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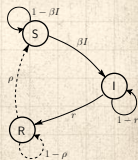Background
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"Multiscale, resurgent epidemics in a hierarchcial metapopulation model" ↗
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162, 2005. [24]

**Geography:** allow people to move between contexts

🎲 Locally: standard SIR model with random mixing

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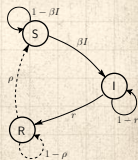Background
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"Multiscale, resurgent epidemics in a
hierarchcial metapopulation model" ⧉
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]

Geography: allow people to move between
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🧩 Locally: standard SIR model with random mixing

🧩 discrete time simulation

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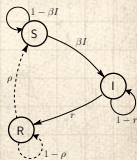Nutshell
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"Multiscale, resurgent epidemics in a hierarchical metapopulation model" 🗗
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]
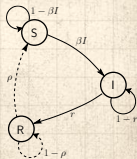
Geography: allow people to move between contexts

🧱 Locally: standard SIR model with random mixing

🧱 discrete time simulation

🧱 $\beta$ = infection probability

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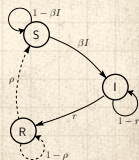spreading models
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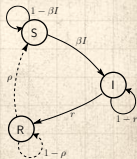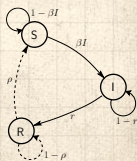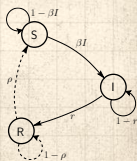
# A toy agent-based model:



"Multiscale, resurgent epidemics in a
hierarchcial metapopulation model" ☐
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]

## Geography: allow people to move between
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🧊 Locally: standard SIR model with random mixing

🧊 discrete time simulation

🧊 $\beta$ = infection probability

🧊 $\gamma$ = recovery probability

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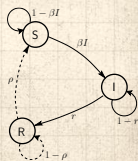References

"Multiscale, resurgent epidemics in a
hierarchcial metapopulation model" ☐
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]

Geography: allow people to move between
contexts

- 🧊 Locally: standard SIR model with random mixing
- 🧊 discrete time simulation
- 🧊 $\beta$ = infection probability
- 🧊 $\gamma$ = recovery probability
- 🧊 $P$ = probability of travel

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"Multiscale, resurgent epidemics in a hierarchcial metapopulation model" 🡕
Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162, 2005. [24]

## Geography: allow people to move between contexts

- 🧱 Locally: standard SIR model with random mixing
- 🧱 discrete time simulation
- 🧱 $\beta$ = infection probability
- 🧱 $\gamma$ = recovery probability
- 🧱 $P$ = probability of travel
- 🧱 Movement distance: $\Pr(d) \propto \exp(-d/\xi)$

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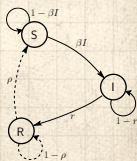spreading models
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"Multiscale, resurgent epidemics in a hierarchcial metapopulation model" ⌕

Watts et al.,
Proc. Natl. Acad. Sci., **102**, 11157–11162,
2005. [24]

## Geography: allow people to move between contexts

- 🧊 Locally: standard SIR model with random mixing
- 🧊 discrete time simulation
- 🧊 $\beta$ = infection probability
- 🧊 $\gamma$ = recovery probability
- 🧊 $P$ = probability of travel
- 🧊 Movement distance: $\Pr(d) \propto \exp(-d/\xi)$
- 🧊 $\xi$ = typical travel distance

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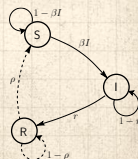Background
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Define $P_0$ = Expected number of infected
individuals leaving initially infected context.

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⚙ Define $P_0$ = Expected number of infected
individuals leaving initially infected context.

⚙ Need $P_0 > 1$ for disease to spread (independent of
$R_0$).

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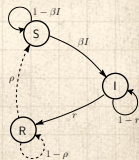
- Define $P_0$ = Expected number of infected individuals leaving initially infected context.
- Need $P_0 > 1$ for disease to spread (independent of $R_0$).
- Limit epidemic size by restricting frequency of travel and/or range
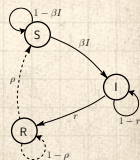
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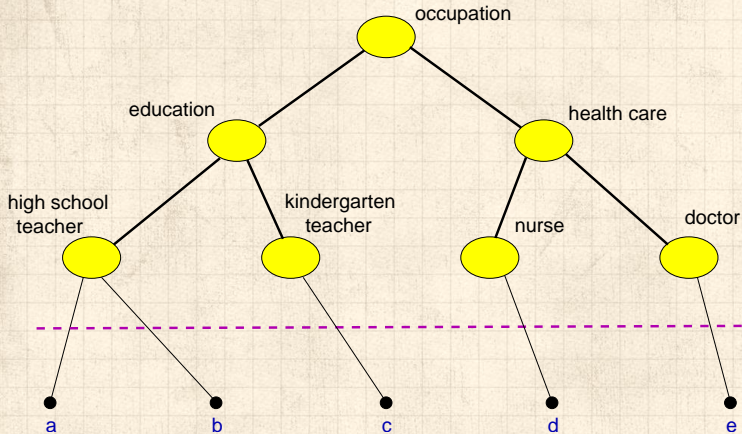Background
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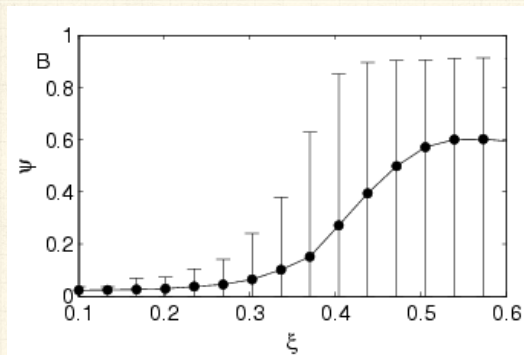
Varying $\xi$:



🎲 Transition in expected final size based on typical
movement distance

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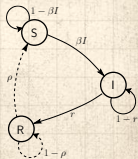Toy metapopulation
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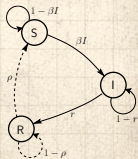Other kinds of prediction
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References
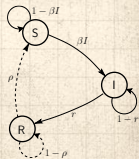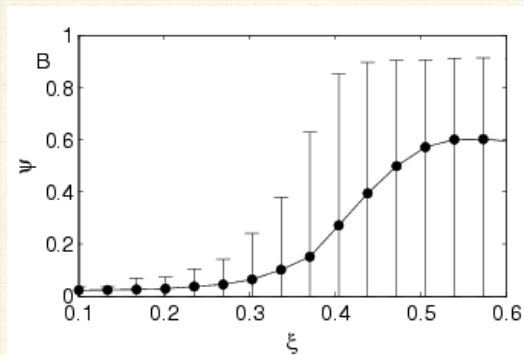
Varying $\xi$:



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

# Model output

Varying $P_0$:
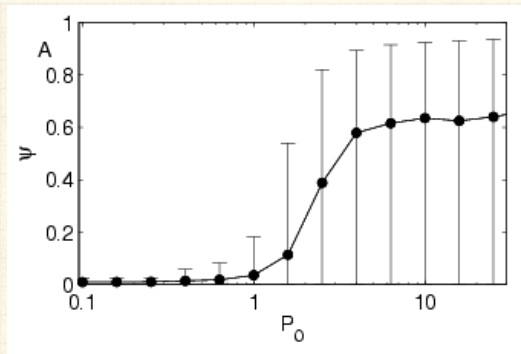
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Transition in expected final size based on typical
number of infectives leaving first group

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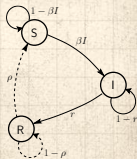Background
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Transition in expected final size based on typical number of infectives leaving first group (also sensible)

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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: $\xi$ has larger effect than $P_0$.

# Example model output: size distributions

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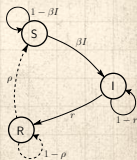Background
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# Example model output: size distributions

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$R_0=3$

$R_0=12$

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Flat distributions are possible for certain $\xi$ and $P$.

# Example model output: size distributions
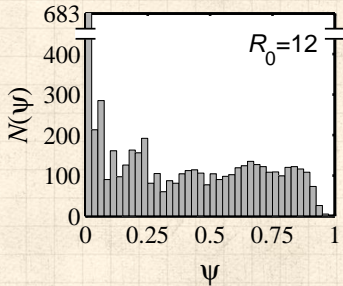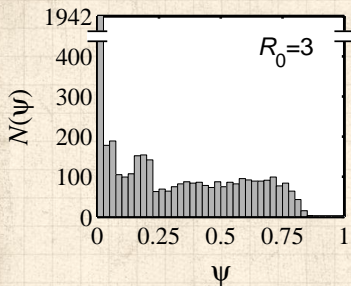
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- Flat distributions are possible for certain $\xi$ and $P$.
- Different $R_0$'s may produce similar distributions

# Example model output: size distributions
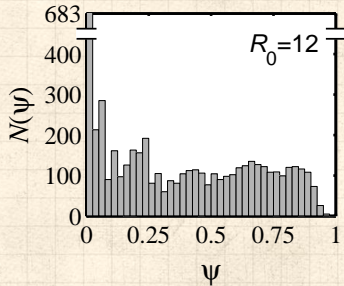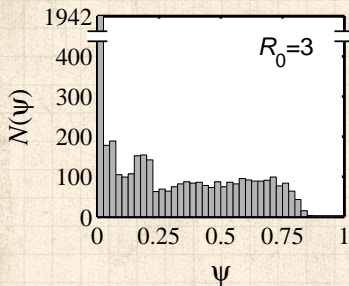
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- Flat distributions are possible for certain $\xi$ and $P$.
- Different $R_0$'s may produce similar distributions
- Same epidemic sizes may arise from different $R_0$'s
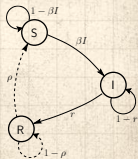
# Model output—resurgence

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Standard model:

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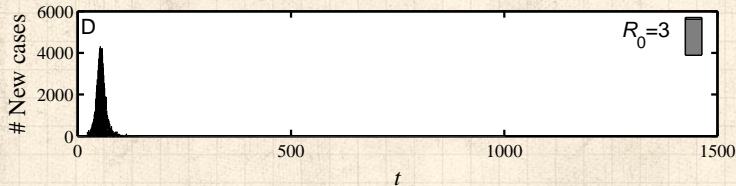
Standard model with transport:

# The upshot

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Simple multiscale population structure

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Simple multiscale population structure
+
stochasticity

# The upshot

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Simple multiscale population structure
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leads to

resurgence
+
broad epidemic size distributions

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Bomb.

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Start bombing.

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Bomb this city...

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and everyone in it.

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-Is this where
they bombed?
-Tess: Yeah.

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They hit most
of the big cities
like this.

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They had to slow
the spread somehow.

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Worked here, but it...
didn't in most places.

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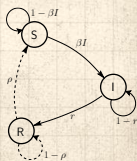Prediction
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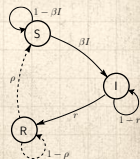Model output
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They're connected.

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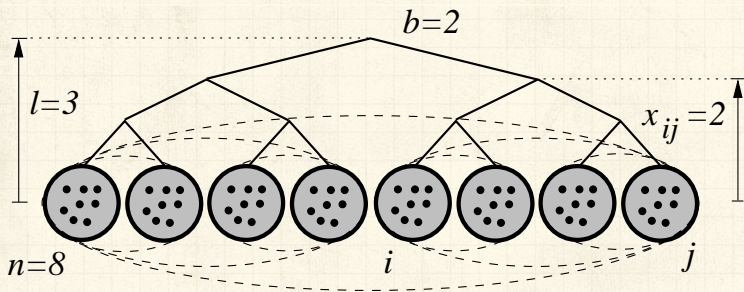models
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More than you know.

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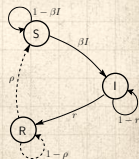Background
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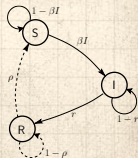Nutshell
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Long fibers
like wires,

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some of them
stretching over a mile.

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Now, you step on a patch
of cordyceps in one place,

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and you can wake a dozen Infected from somewhere else.

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Now they know where you are,
now they come.

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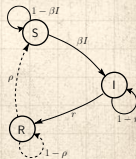Background
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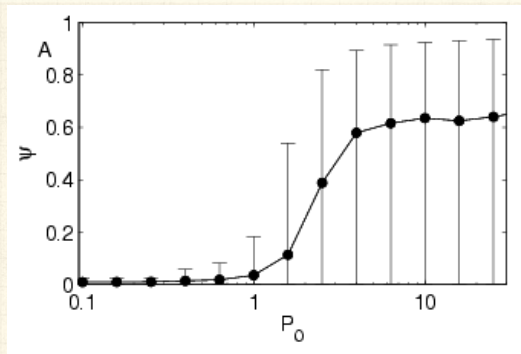Model output
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🎲 For the hierarchical movement model, epidemic size is highly unpredictable

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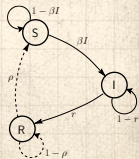Background
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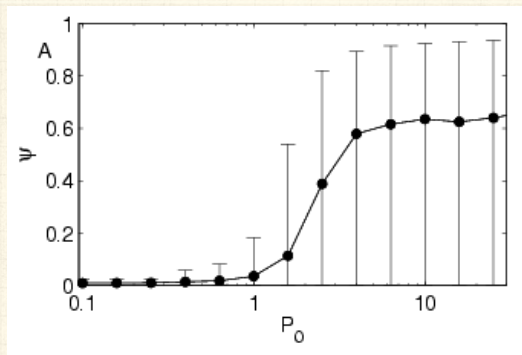Model output
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- ♣ For the hierarchical movement model, epidemic size is highly unpredictable
- ♣ Model is more complicated than SIR but still simple.

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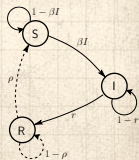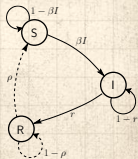Background
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- For the hierarchical movement model, epidemic size is highly unpredictable

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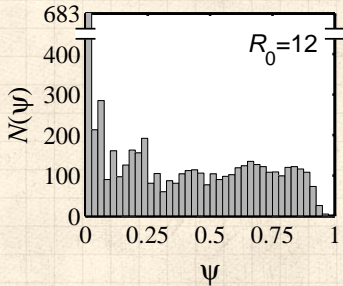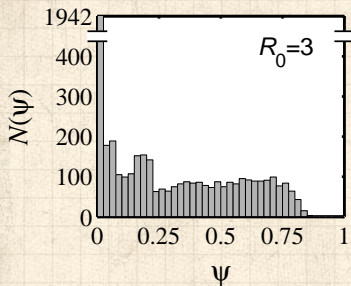Prediction
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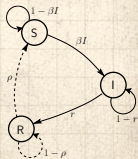
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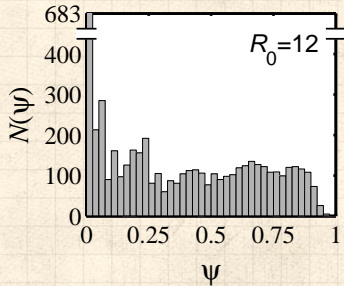Nutshell
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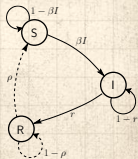SIR is the virus

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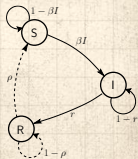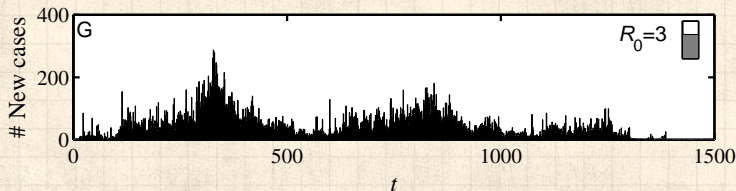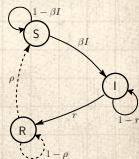SIR is the virus

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- ⬢ 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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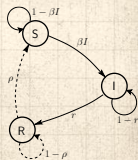Background
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🦠 Disease's spread is highly sensitive to population
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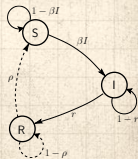More models
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🎲 Disease's spread is highly sensitive to population structure.

🎲 Rare events may matter enormously:

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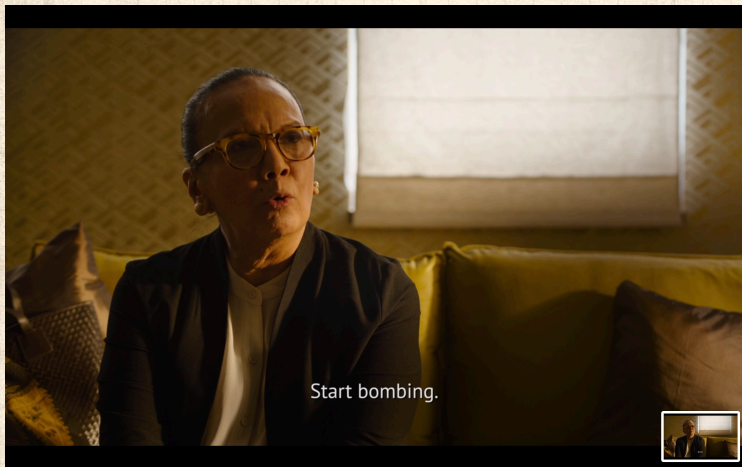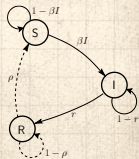More models
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🎲 Disease's spread is highly sensitive to population structure.

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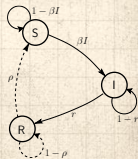More models
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⊞ Disease's spread is highly sensitive to population structure.

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

⊞ More support for controlling population movement:

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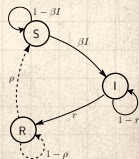More models
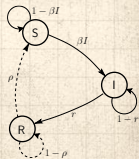Toy metapopulation
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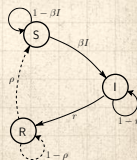
🎲 Disease's spread is highly sensitive to population structure.

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

🎲 More support for controlling population movement:
e.g., travel advisories, quarantine

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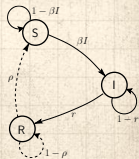Background
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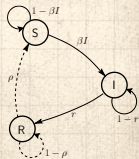Background
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## What to do:

🎲 Need to separate movement from disease

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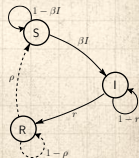Background
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What to do:

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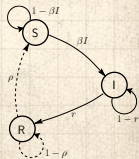Background
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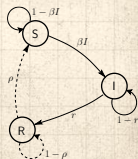Toy metapopulation
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## What to do:

- 🎲 Need to separate movement from disease
- 🎲 $R_0$ needs a friend or two.
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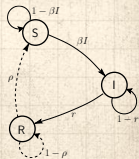Background
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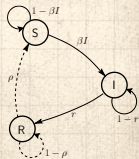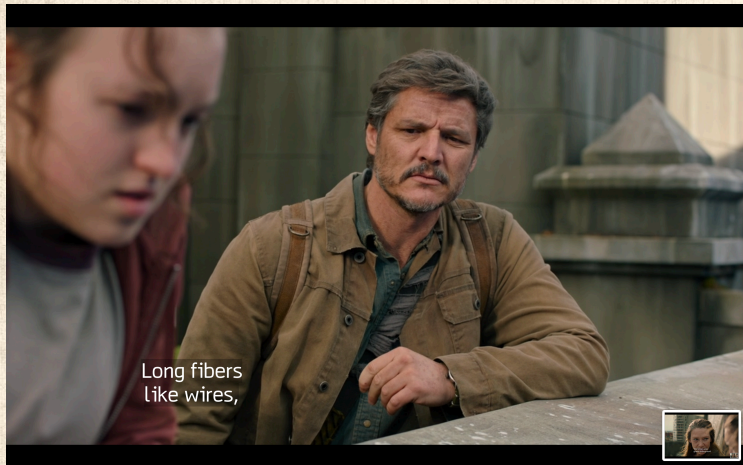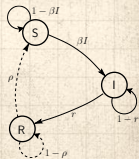Background
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## More wondering:

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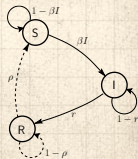Background
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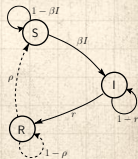models
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- And in general: keep building up the kitchen sink models.

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- Exactly how important are rare events in disease spreading?

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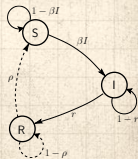Background
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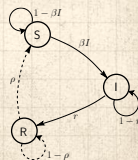SIR is the virus

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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 $\xi$ sufficiently large for disease to have a chance of spreading
- ♻ And in general: keep building up the kitchen sink models.

## More wondering:

- ♻ Exactly how important are rare events in disease spreading?
- ♻ Again, what is $N$?
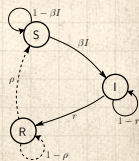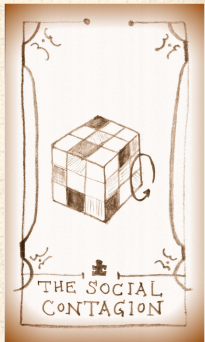
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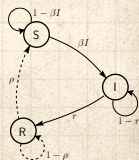Model output
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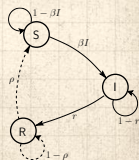Nutshell
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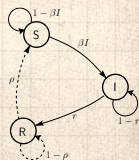SIR is the virus

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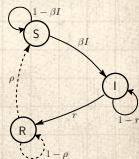Other kinds of prediction
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[1] http://www.redherring.com/mag/issue55/economics.html

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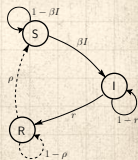Background
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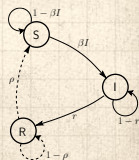Other kinds of prediction
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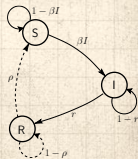
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## Greenspan continues:

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## Greenspan continues:

"The trouble is that we can't figure that out. I've been in the forecasting business for 50 years.

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"The trouble is that we can't figure that out. I've been in the forecasting business for 50 years. I'm no better than I ever was,

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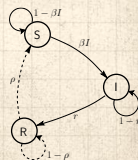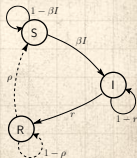Background
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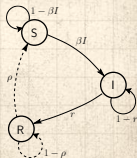models
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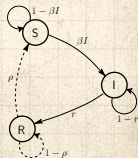models
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## Jon Stewart:

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



wildbluffmedia.com

🎲 From the Daily Show ☐ (September 18, 2007)
🎲 The full episode is here:
http://www.cc.com/video-clips/cenrt5/the-daily-show-with-jon-st
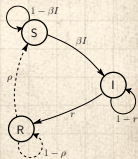
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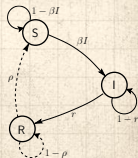Nutshell
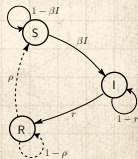Other kinds of prediction
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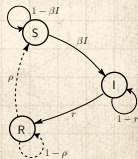Other kinds of prediction
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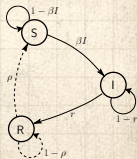Background
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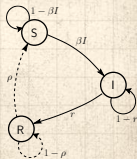Background
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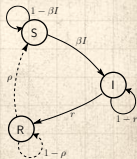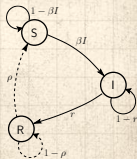Background
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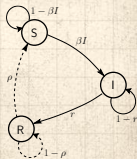Background
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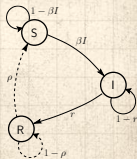Background
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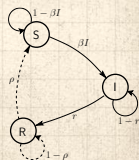Background
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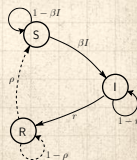Background
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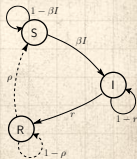More models
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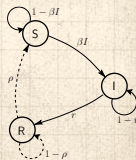
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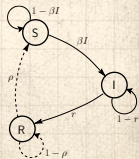Other kinds of prediction
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From the New York Times, 11/02/2008

# Outline

# "Waiter! There's an SIR model ramdomly mixing in my soup."[1]

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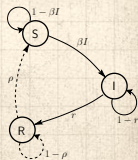More models
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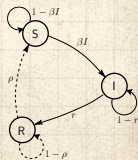Nutshell
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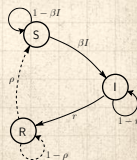Model output
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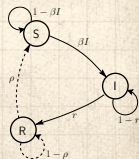Other kinds of prediction
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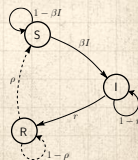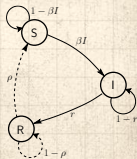More models
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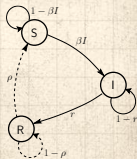Other kinds of prediction
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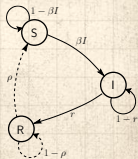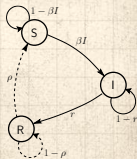
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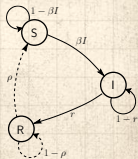
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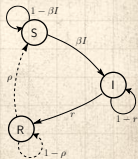- Spread of Feynmann diagrams (Bettencourt et al., 2006)

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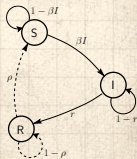
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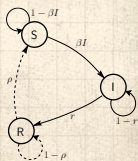
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Culture & Psychology, **21**, 359–379,
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Culture & Psychology, **21**, 359–379, 2015. [22]

"Facebook will lose 80% of users by 2017, say Princeton researchers" ☐ (Guardian, 2014)
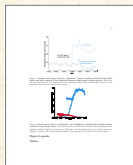
"Epidemiological modeling of online social network dynamics" ☐
Spechler and Cannarella,
Available online at
https://arxiv.org/abs/1401.4208, 2014. [21]

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The Facebook Data Science team's response🔗:
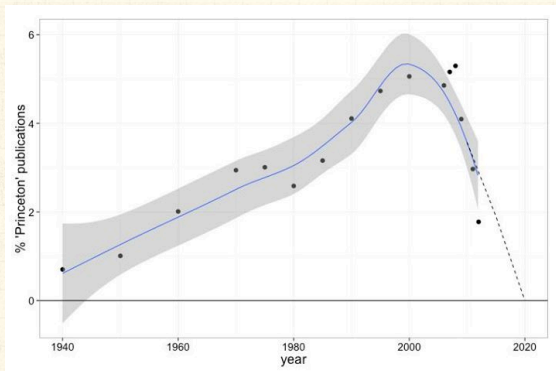


🎲 Mike Develin, Lada Adamic, and Sean Taylor.

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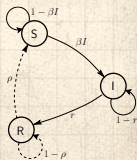Background
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References

[1]  N. T. J. Bailey.
     The Mathematical Theory of Infectious Diseases
     and Its Applications.
     Griffin, London, Second edition, 1975.

[2]  F. Bass.
     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 ⬀

# References II

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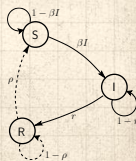
References

[5] D. Brockmann and D. Helbing.
The hidden geometry of complex, network-driven
contagion phenomena.
Science, 342:1337–1342, 2013. pdf ⧉

[6] 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.

[7] 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 ⧉

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# References III

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

[9]   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 🗗

[10]  J. Gleick.
      The Information: A History, A Theory, A Flood.
      Pantheon, 2011.

[11]  W. Goffman and V. A. Newill.
      Generalization of epidemic theory: An application
      to the transmission of ideas.
      Nature, 204:225–228, 1964. pdf 🗗

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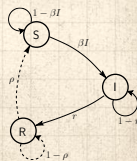
References

# References IV

[12] E. Hoffer.
The True Believer: On The Nature Of Mass
Movements.
Harper and Row, New York, 1951.

[13] E. Hoffer.
The Passionate State of Mind: And Other
Aphorisms.
Buccaneer Books, 1954.

[14] 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☐

# References V

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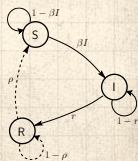
References

[15] W. O. Kermack and A. G. McKendrick.
A contribution to the mathematical theory of
epidemics. III. Further studies of the problem of
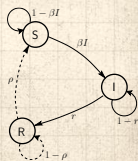endemicity.
Proc. R. Soc. Lond. A, 141(843):94–122, 1927.
pdf ⬈

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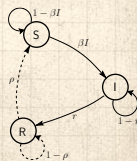Proc. R. Soc. Lond. A, 138(834):55–83, 1927. pdf ⬈

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

# References VI

The PoCSverse
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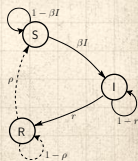Model output
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References

[18] J. D. Murray.
Mathematical Biology.
Springer, New York, Third edition, 2002.

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

[20] 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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[21] J. A. Spechler and J. Cannarella.
Epidemiological modeling of online social
network dynamics.
Available online at
https://arxiv.org/abs/1401.4208, 2014. pdf ☑

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

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

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