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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 Santa Fe Institute | University of Vermont



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Simple Disease Spreading Models Background Prediction

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### Contagion

#### Definition:

- (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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### Contagion

#### Definition:

- (1) The spreading of a quality or quantity between individuals in a population.
- (2) A disease itself: the plague, a blight, the dreaded lurgi, ...

#### Two main classes of contagion:

- Infectious diseases: tuberculosis, HIV, ebola, SARS, influenza, ...
- 2. Social contagion: fashion, word usage, rumors, riots, religion, ...

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Some large questions concerning network contagion:

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Some large questions concerning network contagion:

1. For a given spreading mechanism on a given network, what's the probability that there will be global spreading?

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Some large questions concerning network contagion:

- 1. For a given spreading mechanism on a given network, what's the probability that there will be global spreading?
- 2. If spreading does take off, how far will it go?

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Some large questions concerning network contagion:

- 1. For a given spreading mechanism on a given network, what's the probability that there will be global spreading?
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- 1. For a given spreading mechanism on a given network, what's the probability that there will be global spreading?
- 2. If spreading does take off, how far will it go?
- 3. How do the details of the network affect the outcome?
- 4. How do the details of the spreading mechanism affect the outcome?
- 5. What if the seed is one or many nodes?

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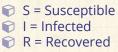
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#### 🚳 Three states:



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- A Three states:
  - S = Susceptible ♥ I = Infected R = Recovered

$$S(t) + I(t) + R(t) = 1$$

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- A Three states:
  - S = Susceptible I = Infected R = Recovered

🚳 Presumes random interactions

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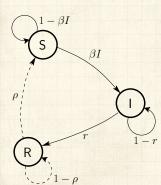




- Three states:
  - S = Susceptible
     I = Infected
     R = Recovered
    - R = Recovered

S(t) + I(t) + R(t) = 1 Presumes randominteractions

#### Discrete time example:



#### **Transition Probabilities:**

 $\beta$  for being infected given contact with infected r for recovery  $\rho$  for loss of immunity The PoCSverse Contagion 8 of 83

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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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#### Reproduction Number $R_0$ :

- $R_0$  = expected number of infected individuals resulting from a single initial infective.
- $\bigotimes$  Epidemic threshold: If  $R_0 > 1$ , 'epidemic' occurs.

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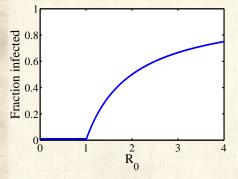
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#### Reproduction Number $R_0$ :

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🚳 Example:



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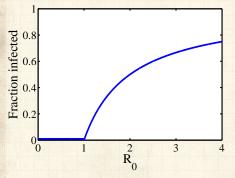
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#### Reproduction Number $R_0$ :

- $R_0$  = expected number of infected individuals resulting from a single initial infective.
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🚳 Example:



Continuous phase transition.

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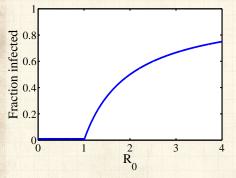
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- $R_0$  = expected number of infected individuals resulting from a single initial infective.
- $\mathfrak{F}$  Epidemic threshold: If  $R_0 > 1$ , 'epidemic' occurs.

🚳 Example:



Continuous phase transition.

Fine idea from a simple model.

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### Disease spreading models

#### For 'novel' diseases:

- 1. Can we predict the size of an epidemic?
- 2. How important/useful is the reproduction number  $R_0$ ?
- 3. What is the population size *N*?

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### $R_0$ and variation in epidemic sizes

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

1918-19 "Spanish Flu" ~ 500,000 deaths in US
 1957-58 "Asian Flu" ~ 70,000 deaths in US
 1968-69 "Hong Kong Flu" ~ 34,000 deaths in US
 2003 "SARS Epidemic" ~ 800 deaths world-wide



#### Elsewhere, event size distributions are important:

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

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Power laws distributions are common but not obligatory...

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#### Elsewhere, event size distributions are important:

- 🗞 earthquakes (Gutenberg-Richter law)
- 🗞 city sizes, forest fires, war fatalities
- 🚳 wealth distributions
- 🚳 'popularity' (books, music, websites, ideas)
- 🚳 What about Epidemics?

Power laws distributions are common but not obligatory...

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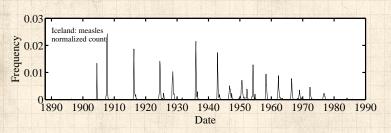
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### Feeling icky in Iceland

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



Treat outbreaks separated in time as 'novel' diseases.



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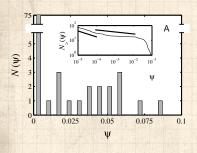
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#### Measles



Insert plots: Complementary cumulative frequency distributions:

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

 $\Psi$  = fractional epidemic size

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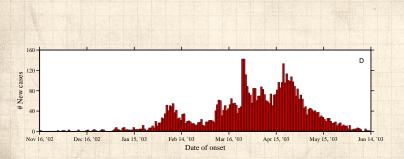
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#### Measured values of $\gamma$ :

measles: 1.40 (low  $\Psi$ ) and 1.13 (high  $\Psi$ )
Expect  $2 \le \gamma < 3$  (finite mean, infinite variance)
Distribution is rather flat...





#### Resurgence—example of SARS

Epidemic discovers new 'pools' of susceptibles: Resurgence. The PoCSverse Contagion 16 of 83

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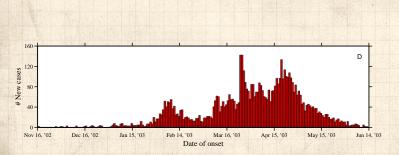
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#### Resurgence—example of SARS

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Epidemic discovers new 'pools' of susceptibles: Resurgence.

Importance of rare, stochastic events.



### A challenge

# So... can a simple model produce1. broad epidemic distributions

#### and

2. resurgence?

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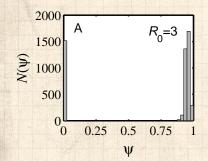
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Simple models typically produce bimodal or unimodal size distributions. The PoCSverse Contagion 18 of 83

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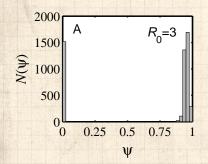
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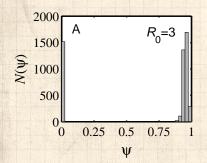
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This includes network models: random, small-world, scale-free, ...





Simple models typically produce bimodal or unimodal size distributions. The PoCSverse Contagion 18 of 83

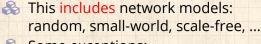
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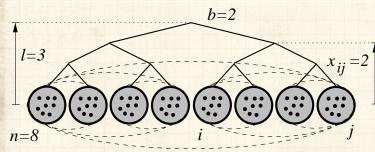


- 🗞 Some exceptions:
  - 1. Forest fire models
  - 2. Sophisticated metapopulation models



# A toy agent-based model

Geography: allow people to move between contexts:



P = probability of travel
Movement distance:  $Pr(d) \propto exp(-d/\xi)$   $\xi$  = typical travel distance

Principles of Complex Systems @pocsyox What's the Story?

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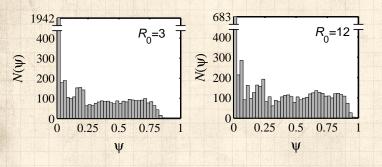
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# Example model output: size distributions



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 The PoCSverse Contagion 20 of 83

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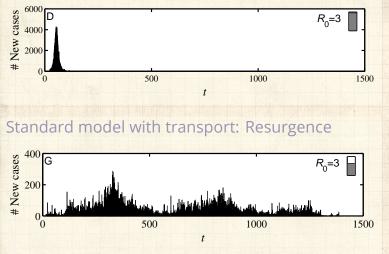
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#### Standard model:



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Principles of Complex Systems @pocsvox What's the Story?

Disease spread highly sensitive to population structure

🗞 Rare events may matter enormously

# Simple disease spreading models

#### Attempts to use beyond disease:

- Adoption of ideas/beliefs (Goffman & Newell, 1964)
- 🗞 Spread of rumors (Daley & Kendall, 1965)
- 🚳 Diffusion of innovations (Bass, 1969)
- Spread of fanatical behavior (Castillo-Chávez & Song, 2003)

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#### **Examples abound:**



- \delta being polite/rude
  - strikes
- 🚵 innovation
- 🚳 residential segregation
- \lambda ipods
- \delta obesity

🗞 Harry Potter \lambda voting 🚳 gossip 🙈 Rubik's cube 💐 🚳 religious beliefs leaving lectures

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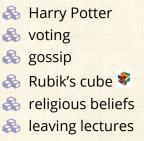
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#### **Examples abound:**



- \delta being polite/rude
  - strikes
- 🚵 innovation
- Residential segregation
- \lambda ipods
- \delta obesity



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#### SIR and SIRS contagion possible

Classes of behavior versus specific behavior: dieting



#### Two focuses for us:

Widespread media influence
Word-of-mouth influence

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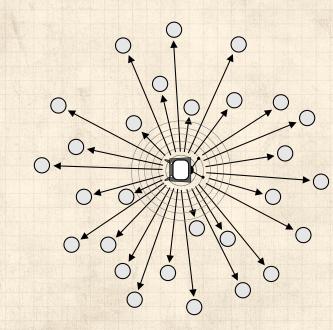
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# The hypodermic model of influence:



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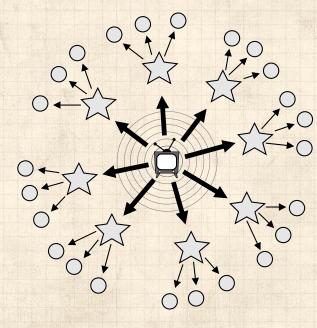
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# The two step model of influence:



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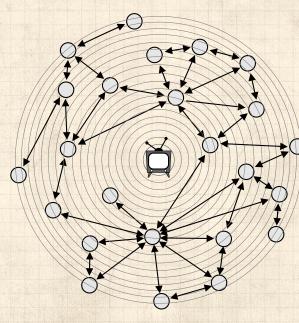
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# The general model of influence:



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#### Why do things spread?

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#### Why do things spread?

Because of system level properties?

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#### Why do things spread?

Because of system level properties?
Or properties of special individuals?

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#### Why do things spread?

- Because of system level properties?
- Or properties of special individuals?
- Is the match that lights the forest fire the key? (Katz and Lazarsfeld; Gladwell)



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#### Why do things spread?

- Because of system level properties?
- Or properties of special individuals?
- Is the match that lights the forest fire the key? (Katz and Lazarsfeld; Gladwell)
- Yes. But only because we are narrative-making machines...

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- 🚳 System/group properties harder to understand

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#### Why do things spread?

- Because of system level properties?
- Or properties of special individuals?
- Is the match that lights the forest fire the key? (Katz and Lazarsfeld; Gladwell)
- Yes. But only because we are narrative-making machines...
- line system/group properties harder to understand
- Always good to examine what is said before and after the fact...

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"Becoming Mona Lisa: The Making of a Global Icon"—David Sassoon





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 Escalation through theft, vandalism, parody, ...





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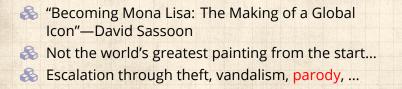
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# The completely unpredicted fall of Eastern Europe:



Timur Kuran: "Now Out of Never: The Element of Surprise in the East European Revolution of 1989"

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#### Some important models:

Tipping models—Schelling (1971)
 Simulation on checker boards
 Idea of thresholds

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#### Some important models:

Tipping models—Schelling (1971)
 Simulation on checker boards
 Idea of thresholds

🚳 Threshold models—Granovetter (1978)

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#### Some important models:

- Tipping models—Schelling (1971)
   Simulation on checker boards
   Idea of thresholds
- Threshold models—Granovetter (1978)
  - Herding models—Bikhchandani, Hirschleifer, Welch (1992)
    - Social learning theory, Informational cascades,...

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#### Thresholds:

Basic idea: individuals adopt a behavior when a certain fraction of others have adopted The PoCSverse Contagion 33 of 83

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#### Thresholds:

- Basic idea: individuals adopt a behavior when a certain fraction of others have adopted
- Others' may be everyone in a population, an individual's close friends, any reference group.

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#### Thresholds:

- Basic idea: individuals adopt a behavior when a certain fraction of others have adopted
- Others' may be everyone in a population, an individual's close friends, any reference group.
  - Response can be probabilistic or deterministic.

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#### Thresholds:

- Basic idea: individuals adopt a behavior when a certain fraction of others have adopted
- Others' may be everyone in a population, an individual's close friends, any reference group.
- 🚳 Response can be probabilistic or deterministic.
- 🚳 Individual thresholds vary.

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#### Some possible origins of thresholds:

- Desire to coordinate, to conform.
- Lack of information: impute the worth of a good or behavior based on degree of adoption (social proof)
- Economics: Network effects or network externalities
  - ア Telephones, Facebook, operating systems, ...

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## Imitation



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

www.despair.com

despair.com

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

—Eric Hoffer "The Passionate State of Mind" <sup>[11]</sup> The PoCSverse Contagion 35 of 83

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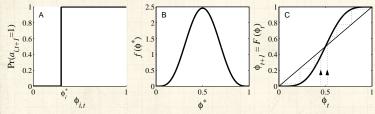
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# Granovetter's threshold model:

#### Action based on perceived behavior of others:



🚳 Two states: S and I.

 $\langle \langle \phi \rangle = fraction of contacts 'on' (e.g., rioting)$ 

$$\phi_{t+1} = \int_0^{\phi_t} f(\gamma) \mathrm{d}\gamma = F(\gamma) \big|_0^{\phi_t} = F(\phi_t)$$

2

A This is a Critical Mass model

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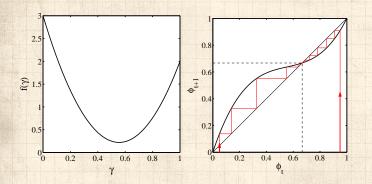
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# Social Sciences: Threshold models



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🗞 Example of single stable state model



# Social Sciences—Threshold models

# Implications for collective action theory: 1. Collective uniformity ⇒ individual uniformity

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# Social Sciences—Threshold models

#### Implications for collective action theory:

- 1. Collective uniformity  $\Rightarrow$  individual uniformity
- 2. Small individual changes  $\Rightarrow$  large global changes

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# Threshold model on a network

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# Threshold model on a network

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# Threshold model on a network

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# Snowballing

### The Cascade Condition:

If one individual is initially activated, what is the probability that an activation will spread over a network? The PoCSverse Contagion 42 of 83

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# Snowballing

### The Cascade Condition:

- If one individual is initially activated, what is the probability that an activation will spread over a network?
- What features of a network determine whether a cascade will occur or not?

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#### Vulnerables:

Individuals who can be activated by just one 'infected' contact The PoCSverse Contagion 43 of 83

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#### Vulnerables:

- Individuals who can be activated by just one 'infected' contact
- For global cascades on random networks, must have a global cluster of vulnerables

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#### Vulnerables:

- Individuals who can be activated by just one 'infected' contact
- For global cascades on random networks, must have a global cluster of vulnerables
- 🗞 Cluster of vulnerables = critical mass

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#### Vulnerables:

- Individuals who can be activated by just one 'infected' contact
- For global cascades on random networks, must have a global cluster of vulnerables
- 🚳 Cluster of vulnerables = critical mass
- Solution Network story: 1 node  $\rightarrow$  critical mass  $\rightarrow$  everyone.

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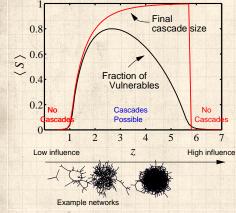
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## Cascades on random networks



Cascades occur only if size of max vulnerable cluster > 0. The PoCSverse Contagion 44 of 83

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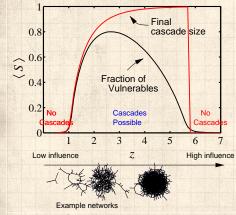
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(n.b.:  $z \equiv \langle k \rangle \equiv \bar{k}$ )

## Cascades on random networks



(n.b.:  $z \equiv \langle k \rangle \equiv \bar{k}$ )

 Cascades occur only if size of max vulnerable cluster > 0.
 System may be 'robust-yet-

fragile'.

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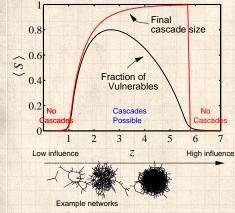
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## Cascades on random networks



(n.b.:  $z\equiv \langle k
angle\equiv ar{k}$ )

🙈 Cascades occur only if size of max vulnerable cluster > 0.System may be 3 'robust-yetfragile'. 'Ignorance' facilitates spreading.

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# Cascade window for random networks

30 25 no cascades Models 20 0.4 Network version 15 N influence Winning: it's not 10 for everyone cascades 5 References 0.05 0.1 0.15 0.20.25 = uniform individual threshold Ø

 $\clubsuit$  'Cascade window' widens as threshold  $\phi$ decreases.

lower thresholds enable spreading.





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## Cascade window for random networks

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#### Threshold model completely solved (by 2008):

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Threshold model completely solved (by 2008): A Cascade condition: [22]

$$\sum_{k=1}^\infty \frac{kP_k}{\langle k\rangle}\cdot\beta_k\cdot(k-1)\geq 1.$$

where  $\beta_k$  = probability a degree k node is vulnerable.

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Threshold model completely solved (by 2008):
 Cascade condition: <sup>[22]</sup>

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Final size of spread figured out by Gleeson and Calahane<sup>[9, 8]</sup>. The PoCSverse Contagion 47 of 83

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Solution involves finding fixed points of an iterative map of the interval.

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- Spreading takes off: expansion

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where  $\beta_k$  = probability a degree k node is vulnerable.

- Final size of spread figured out by Gleeson and Calahane<sup>[9, 8]</sup>.
- Solution involves finding fixed points of an iterative map of the interval.
- Spreading takes off: expansion
  - Spreading reaches a particular node: contraction

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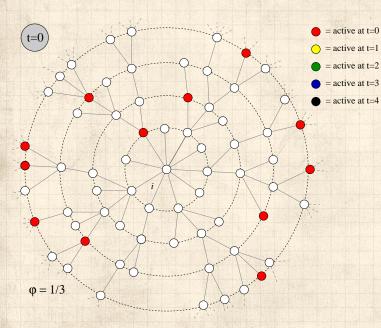
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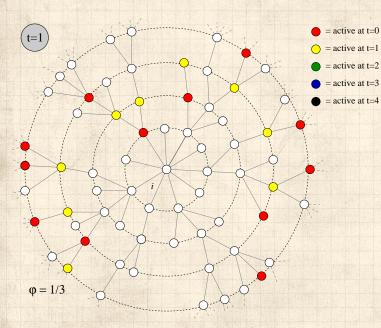
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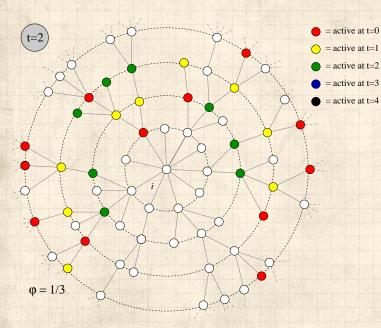
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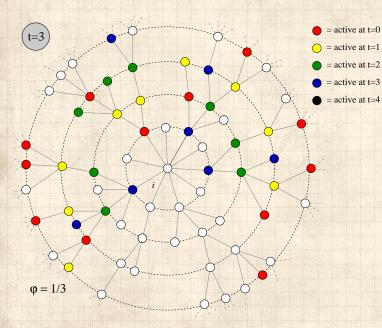
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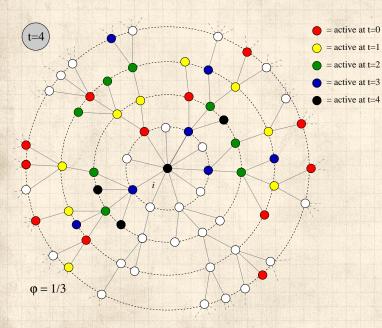
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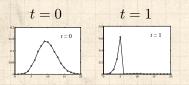
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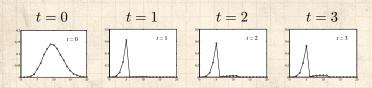
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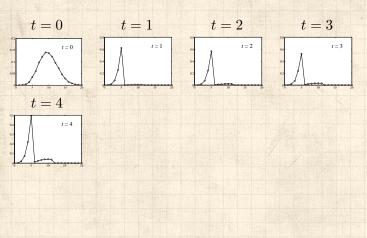
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#### $P_{k,t}$ versus k



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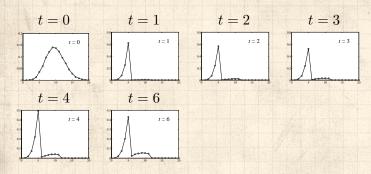
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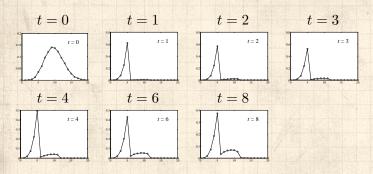
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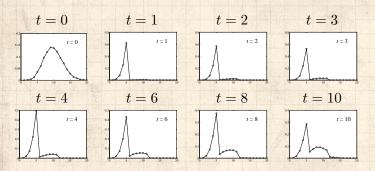
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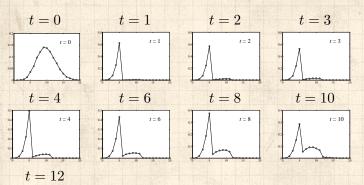
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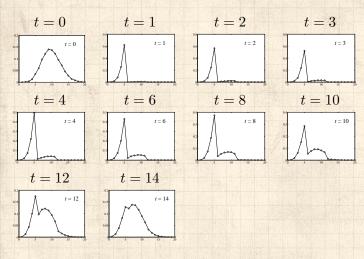
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## Early adopters—degree distributions



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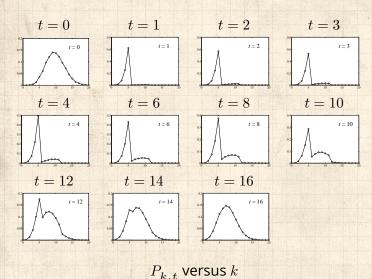
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## Early adopters—degree distributions



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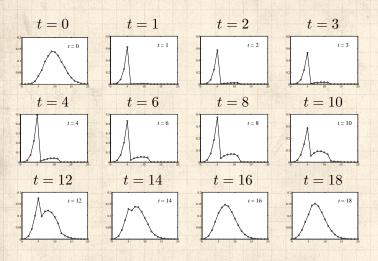
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Principles of Complex Systems ®pocsyox What's the Story?

## Early adopters—degree distributions



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## The power of groups...



A Few Harmless Flakes Working Together Can Unleash an Avalanche of Destruction.

www.despair.com

"A few harmless flakes working together can unleash an avalanche of destruction." The PoCSverse Contagion 51 of 83

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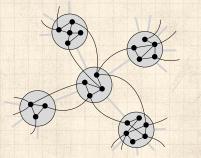
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despair.com

# Group structure—Ramified random networks



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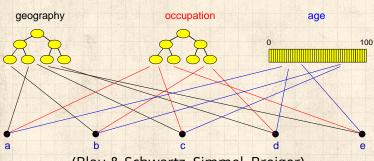
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p = intergroup connection probability q = intragroup connection probability.



## Generalized affiliation model



(Blau & Schwartz, Simmel, Breiger)

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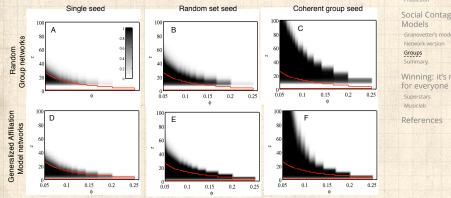
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## Cascade windows for group-based networks





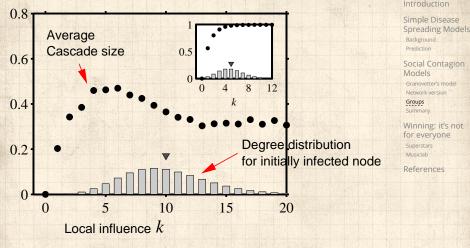
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## Assortativity in group-based networks



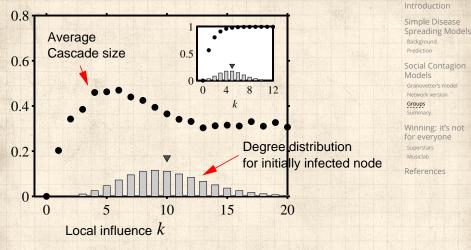
The most connected nodes aren't always the most 'influential.'



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## Assortativity in group-based networks



- The most connected nodes aren't always the most 'influential.'
- Degree assortativity is the reason.



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#### Summary:

#### linfluential vulnerables' are key to spread.

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#### Summary:

Influential vulnerables' are key to spread.
 Early adopters are mostly vulnerables.

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#### Summary:

- linfluential vulnerables' are key to spread.
- line adopters are mostly vulnerables.
- Vulnerable nodes important but not necessary.

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#### Summary:

- linfluential vulnerables' are key to spread.
- 🚳 Early adopters are mostly vulnerables.
- linerable nodes important but not necessary.
- 🚳 Groups may greatly facilitate spread.

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#### Summary:

- linfluential vulnerables' are key to spread.
- line adopters are mostly vulnerables.
- linerable nodes important but not necessary.
- 🚳 Groups may greatly facilitate spread.
- Extreme/unexpected cascades may occur in highly connected networks

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### Summary:

- linfluential vulnerables' are key to spread.
- 🗞 Early adopters are mostly vulnerables.
- linerable nodes important but not necessary.
- 🚳 Groups may greatly facilitate spread.
- Extreme/unexpected cascades may occur in highly connected networks
- 🚳 Many potential 'influentials' exist.

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### Summary:

- linfluential vulnerables' are key to spread.
- 🗞 Early adopters are mostly vulnerables.
- linerable nodes important but not necessary.
- 🚳 Groups may greatly facilitate spread.
- Extreme/unexpected cascades may occur in highly connected networks
- 🚳 Many potential 'influentials' exist.
- Average individuals may be more influential system-wise than locally influential individuals.

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### Summary:

- linfluential vulnerables' are key to spread.
- 🗞 Early adopters are mostly vulnerables.
- Vulnerable nodes important but not necessary.
- 🚳 Groups may greatly facilitate spread.
- Extreme/unexpected cascades may occur in highly connected networks
- 🗞 Many potential 'influentials' exist.
- Average individuals may be more influential system-wise than locally influential individuals.
- linfluentials' are posterior constructs.

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#### Implications:

line and the influential vulnerables.

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#### Implications:

- \lambda Focus on the influential vulnerables.
- Create entities that many individuals 'out in the wild' will adopt and display rather than broadcast from a few 'influentials.'
- Displaying can be passive = free (yo-yo's, fashion), or active = harder to achieve (political messages).

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- Accept that movement of entities will be out of originator's control.
- Possibly only simple ideas can spread by word-of-mouth.

(Idea of opinion leaders has spread well...)

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### Messing with social connections:

- Ads based on message content (e.g., Google and email)
- 🚳 Buzz media
- 🚳 Facebook's advertising (Beacon)

Arguably not always a good idea...

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## The collective...



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." The PoCSverse Contagion 60 of 83

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## Where do superstars come from?

Rosen (1981): "The Economics of Superstars"

### Examples:

- $\clubsuit$  Full-time Comedians ( $\approx 200$ )
- 🚳 Soloists in Classical Music
- \lambda Economic Textbooks (the usual myopic example)

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lighly skewed distributions again...

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### Rosen's theory:

 $\bigotimes$  Individual quality q maps to reward R(q)

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### Rosen's theory:

Solution Individual quality q maps to reward R(q)R(q) is 'convex' (d<sup>2</sup> $R/dq^2 > 0$ ) The PoCSverse Contagion 63 of 83

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### Rosen's theory:

- $\mathfrak{R}$  Individual quality q maps to reward R(q)
- $\Re R(q)$  is 'convex' (d<sup>2</sup>R/dq<sup>2</sup> > 0)
- \lambda Two reasons:
  - 1. Imperfect substitution:

A very good surgeon is worth many mediocre ones

2. Technology:

Media spreads & technology reduces cost of reproduction of books, songs, etc.

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\lambda Two reasons:

1. Imperfect substitution:

A very good surgeon is worth many mediocre ones

2. Technology:

Media spreads & technology reduces cost of reproduction of books, songs, etc.

No social element—success follows 'inherent quality'

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#### Adler (1985): "Stardom and Talent"

linherent quality'

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### Adler (1985): "Stardom and Talent"

Assumes extreme case of equal 'inherent quality'
 Argues desire for coordination in knowledge and culture leads to differential success

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#### Superstars

#### Adler (1985): "Stardom and Talent"

- Assumes extreme case of equal 'inherent quality'
   Argues desire for coordination in knowledge and culture leads to differential success
- line struction Success is then purely a social construction

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### **Dominance hierarchies**

Chase et al. (2002): "Individual differences versus social dynamics in the formation of animal dominance hierarchies" The aggressive female Metriaclima zebra **C**:

Pecking orders for fish...

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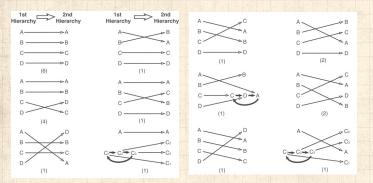
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### **Dominance hierarchies**

#### Fish forget—changing of dominance hierarchies:



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# 22 observations: about 3/4 of the time, hierarchy changed



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#### multiple 'worlds' Inter-world variability

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FREE MUSIC DOWNLOADS

#### 48 songs 30,000 participants



48 songs 30,000 participants



multiple 'worlds' Inter-world variability

- low probable is the world?
- lity?
  - Superstars dominate but are unpredictable. Why?

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1	DEEP ENOUGH TO DIE: "for the sky"	17	PARKER THEORY: "she said"	47	UP FOR NOTHING: "In sight of"	13
	THE THRIFT SYNDICATE: "2003 a tragedy"	20	MISS OCTOBER: "pink agression"	27	SILVERFOX: "gnaw"	17
	THE BROKEN PROMISE: "the end in friend"	19	POST BREAK TRAGEDY: "Revence"	34	STRANGER: "one drop"	10
	THIS NEW DAWN: "the belief above the answer"	12	FORTHFADING: "fear"	24	FAR FROM KNOWN: "noute 9"	18
	NOONER AT NINE: 'walk away''	6	THE CALEFACTION: "trapped in an orange peel"	20	STUNT MONKEY: "inside out"	46
	MORAL HAZARD: "waste of my life"	8	52METRO: "lockdown"	17	DANTE: "Ifes mystery"	14
	NOT FOR SCHOLARS: "as seasons change"	27	SIMPLY WAITING: "went with the count"	16	FADING THROUGH: "wish me luck"	10
	SECRETARY: "keep your eyes on the ballistics"	5	STAR CLIMBER: "tell me"	38	UNKNOWN CITIZENS: "falling over"	34
	ART OF KANLY: "seductive intro, melodic breakdown"	10	THE FASTLANE: "til death do us part (i dont)"	31	BY NOVEMBER: "If icould take you"	20
	HYDRAULIC SANDWICH: "separation anxiety"	20	A BLINDING SILENCE: "miseries and misacles"	17	DRAWN IN THE SKY: "tap the ride"	12
	EMBER SKY: 'this upcoming winter'	25	SUM RANA: "the bokhevik boogie"	15	SELSIUS: "stars of the city"	22
	SALUTE THE DAWN: "I am emor"	13	CAPE RENEWAL: "baseball warlock v1"	12	SIBRIAN: "eye patch"	14
	RYAN ESSMAKER: "detout_the still"	14	UP FALLS DOWN: "a brighter burning star"	11	EVAN GOLD: "robert downey jr"	10
	BEERBONG: "father to son"	12	SUMMERSWASTED: "a plan behind destruction"	17	BENEFIT OF A DOUBT: "run away"	38
	HALL OF FAME: "best mistakes"	19	SILENT FILM "all (have to say"	61	SHIPWRECK UNION:	16

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Salganik et al. (2006) "An experimental study of inequality and unpredictability in an artificial cultural market"



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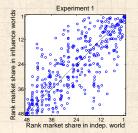
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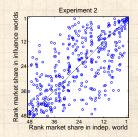
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#### Experiments 2-4

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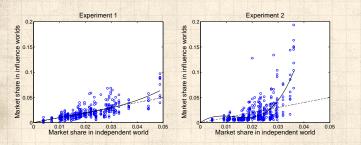
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🚳 Variability in final rank.





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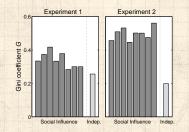
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#### 🚳 Variability in final number of downloads.





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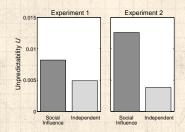
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#### 🚳 Inequality as measured by Gini coefficient:

$$G = \frac{1}{(2N_{\rm S}-1)} \sum_{i=1}^{N_{\rm S}} \sum_{j=1}^{N_{\rm S}} |m_i - m_j|$$





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🚳 Unpredictability

$$U = \frac{1}{N_{\rm S} \binom{N_{\rm W}}{2}} \sum_{i=1}^{N_{\rm S}} \sum_{j=1}^{N_{\rm W}} \sum_{k=j+1}^{N_{\rm W}} |m_{i,j} - m_{i,k}|$$



#### Sensible result:



Stronger social signal leads to greater following and greater inequality.

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#### Sensible result:



Stronger social signal leads to greater following and greater inequality.

#### Peculiar result:

🚳 Stronger social signal leads to greater unpredictability.

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#### Sensible result:



Stronger social signal leads to greater following and greater inequality.

#### Peculiar result:

🚳 Stronger social signal leads to greater unpredictability.

#### Very peculiar observation:

The most unequal distributions would suggest the greatest variation in underlying 'quality.'

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#### Sensible result:



Stronger social signal leads to greater following and greater inequality.

#### Peculiar result:

🚳 Stronger social signal leads to greater unpredictability.

#### Very peculiar observation:

- The most unequal distributions would suggest the greatest variation in underlying 'quality.'
- But success may be due to social construction through following...

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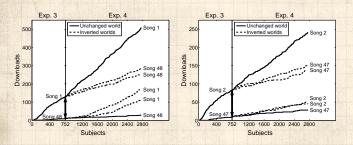
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### Music Lab Experiment—Sneakiness



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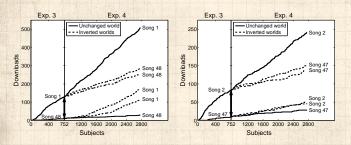
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🚳 Inversion of download count



### Music Lab Experiment—Sneakiness



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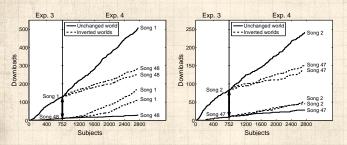
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Inversion of download count
 The 'pretend rich' get richer ...



### Music Lab Experiment—Sneakiness



Inversion of download count
The 'pretend rich' get richer ...
... but at a slower rate

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