Contagion

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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:

- 1. Infectious diseases
- 2. Social contagion

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Definition:

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

Two main classes of contagion:

- 1. 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:

- 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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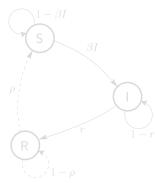
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The standard SIR model:

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

Discrete time example:



► S(t) + I(t) + R(t) = 1

 Presumes random interactions

Transition Probabilities:

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

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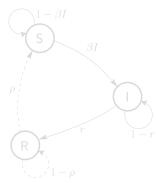
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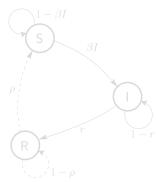
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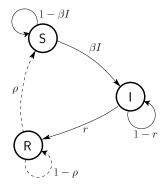
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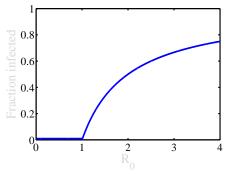
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Reproduction Number R_0 :

- R₀ = expected number of infected individuals resulting from a single initial infective.
- Epidemic threshold: If R₀ > 1, 'epidemic' occurs.
- Example:



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

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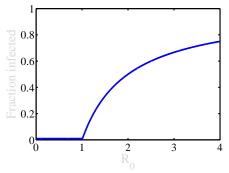
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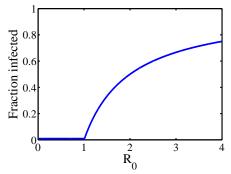
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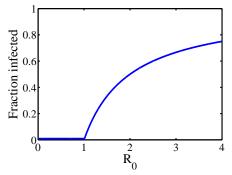
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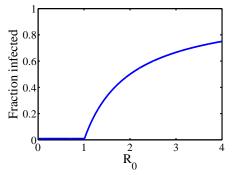
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Disease spreading models

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

 R_0 approximately the same for all of the following:

- > 1918-19 "Spanish Flu" \sim 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

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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?

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Power laws distributions are common but not obligatory...

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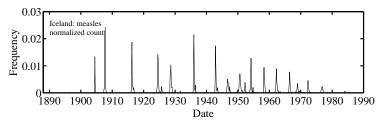
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Feeling icky in Iceland

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



Treat outbreaks separated in time as 'novel' diseases.

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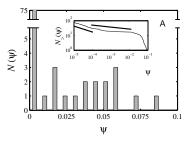
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Measles



Insert plots:

Complementary cumulative frequency distributions:

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

 Ψ = fractional epidemic size

Measured values of γ :

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

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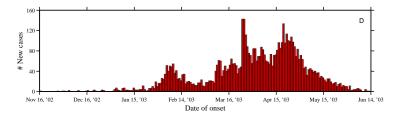
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Resurgence—example of SARS



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

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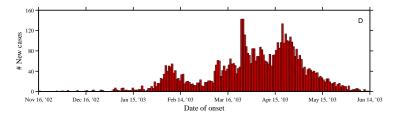
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Resurgence—example of SARS



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A challenge

So... can a simple model produce

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

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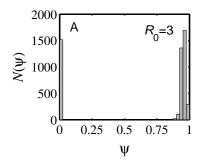
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Simple models typically produce bimodal or unimodal size distributions.

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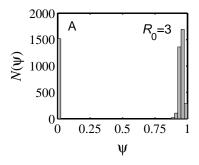
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- This includes network models: random, small-world, scale-free, ...
- Some exceptions:
 - 1. Forest fire models
 - 2. Sophisticated metapopulation models

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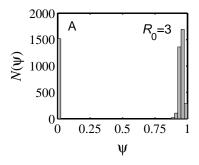
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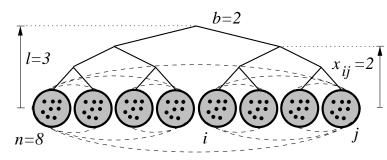
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- Some exceptions:
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A toy agent-based model

Geography: allow people to move between contexts:



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

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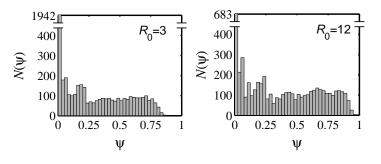
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Example model output: size distributions



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

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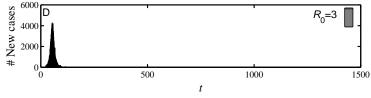
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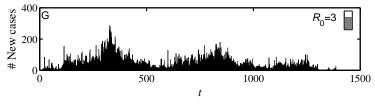
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Standard model:



Standard model with transport: Resurgence



- Disease spread highly sensitive to population structure
- Rare events may matter enormously

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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:

- being polite/rude
- strikes
- innovation
- residential segregation
- ipods
- obesity

SIR and SIRS contagion possible

Classes of behavior versus specific behavior

- Harry Potter
- voting
- gossip
- 🕨 Rubik's cube 🕸
- religious beliefs
- leaving lectures

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Examples abound:

- being polite/rude
- strikes
- innovation
- residential segregation
- ipods
- obesity
- SIR and SIRS contagion possible
 - Classes of behavior versus specific behavior: dieting

- Harry Potter
- voting
- gossip
- 🕨 Rubik's cube 🕸
- religious beliefs
- leaving lectures

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Two focuses for us:

- Widespread media influence
- Word-of-mouth influence

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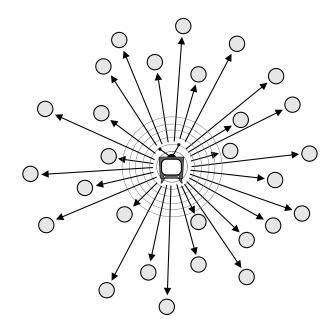
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The hypodermic model of influence:



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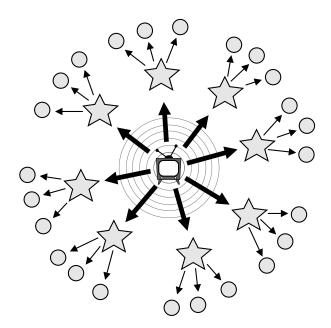
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The two step model of influence:



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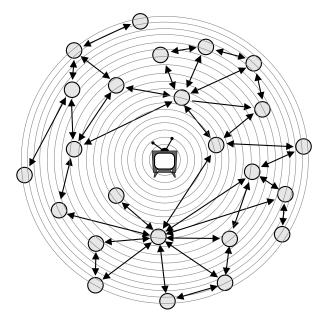
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The general model of influence:



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Why do things spread?

- 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...
- System/group properties harder to understand
- Always good to examine what is said before and after the fact...

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- 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...
- 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

Not the world's greatest painting from the start..

Escalation through theft, vandalism, parody, ...

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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
- 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
- '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
 - Telephones, Facebook, operating systems, ...

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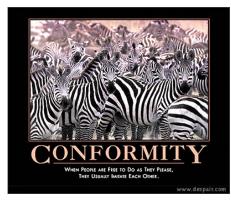
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Imitation



despair.com

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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"^[11]

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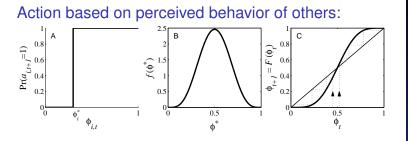
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Granovetter's threshold model:



Two states: S and I.

• ϕ = fraction of contacts 'on' (e.g., rioting)

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

This is a Critical Mass model

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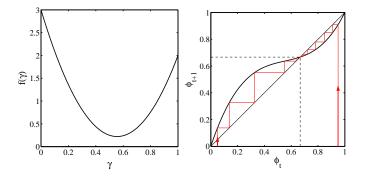
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Social Sciences: Threshold models



Example of single stable state model

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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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Social Sciences—Threshold models

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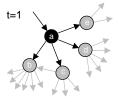
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Threshold model on a network



- All nodes have threshold $\phi = 0.2$.
- "A simple model of global cascades on random networks"

D. J. Watts. Proc. Natl. Acad. Sci., 2002

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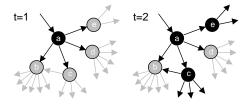
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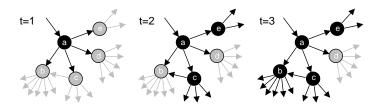
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Snowballing

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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Snowballing

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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
- ▶ Network story: 1 node \rightarrow critical mass \rightarrow everyone.

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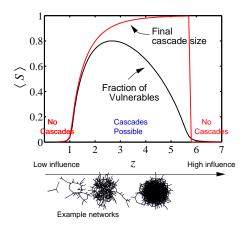
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Cascades on random networks



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

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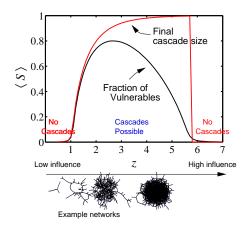
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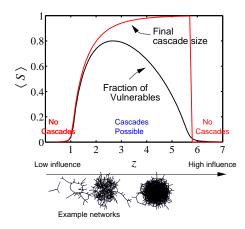
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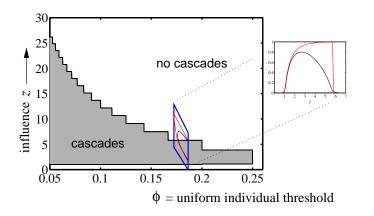
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Cascade window for random networks



- 'Cascade window' widens as threshold \u03c6 decreases.
- Lower thresholds enable spreading.

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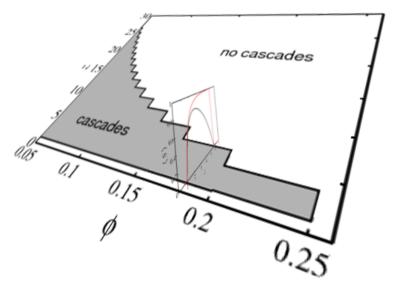
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Cascade window for random networks



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Threshold model completely solved (by 2008):

Cascade condition:^[22]

$$\sum_{k=1}^{\infty} k(k-1)\beta_k P_k/z \ge 1.$$

where β_k = probability a degree *k* node is vulnerable.

- ▶ Final size of spread figured out by Gleeson and Calahane^[9, 8].
- 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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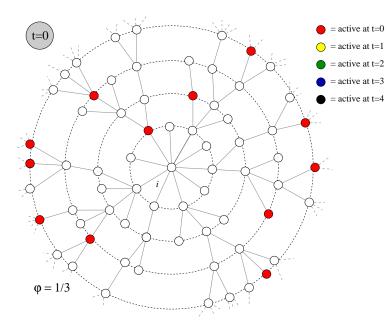
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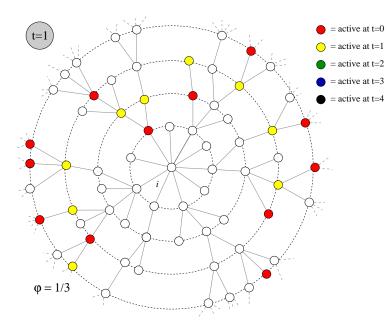
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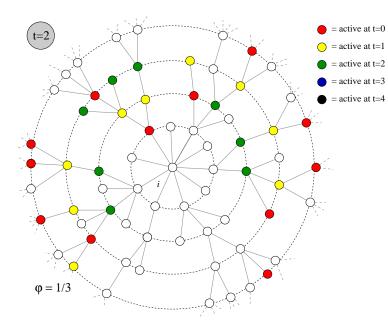
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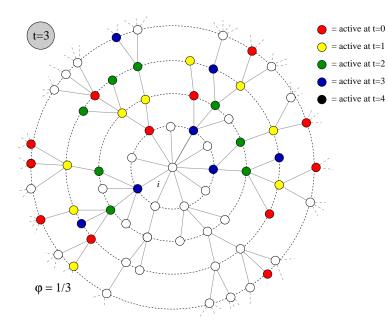
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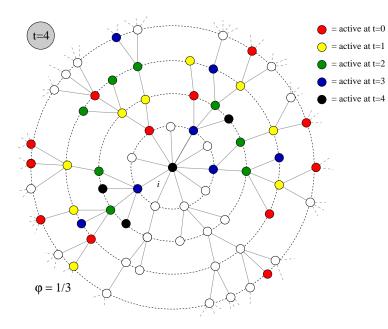
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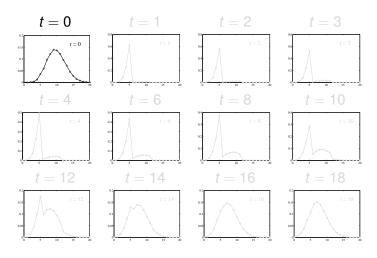
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 $P_{k,t}$ versus k

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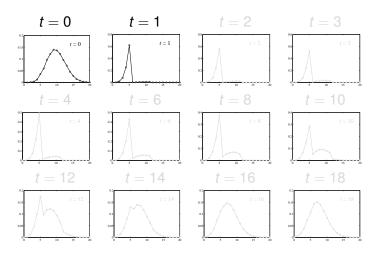
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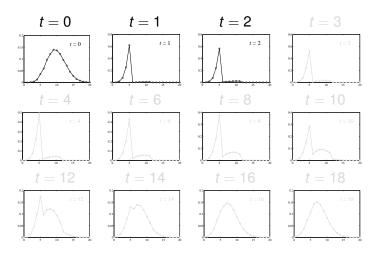
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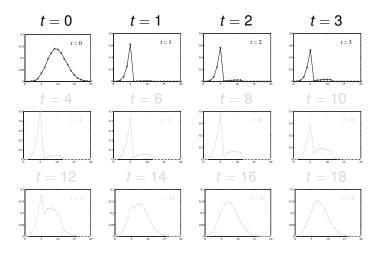
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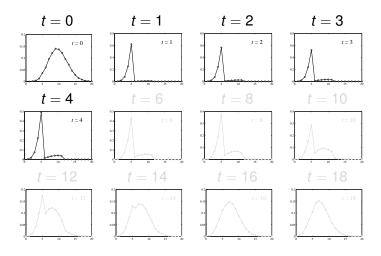
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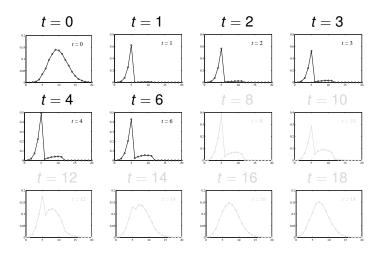
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 $P_{k,t}$ versus k

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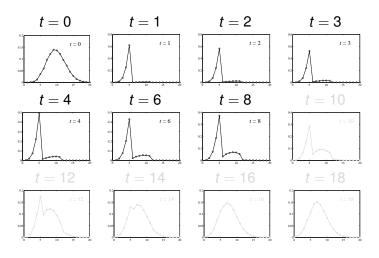
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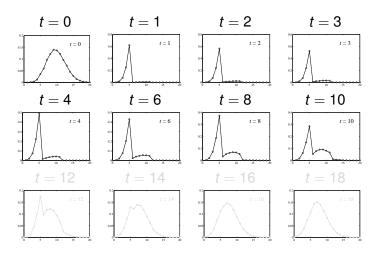
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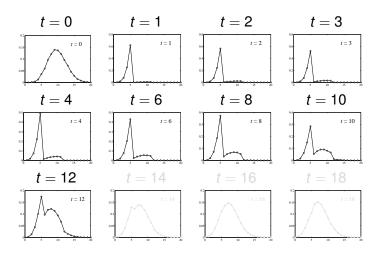
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 $P_{k,t}$ versus k

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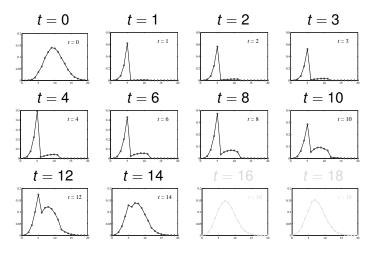
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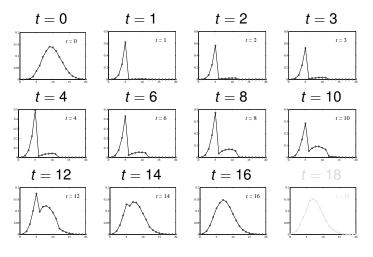
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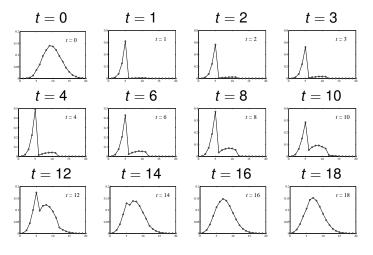
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The power of groups...



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."

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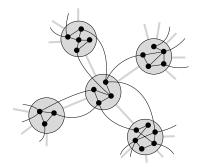
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despair.com

Group structure—Ramified random networks



p = intergroup connection probability q = intragroup connection probability.

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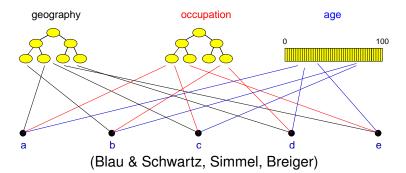
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Generalized affiliation model



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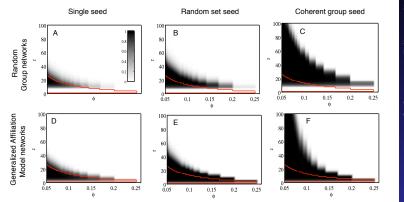
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Cascade windows for group-based networks



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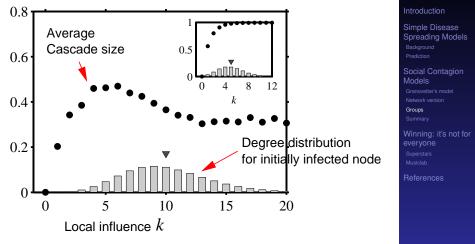
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Assortativity in group-based networks

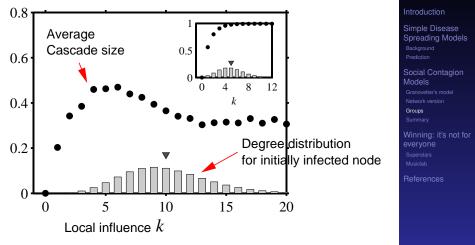


- The most connected nodes aren't always the most 'influential.'
- Degree assortativity is the reason.

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Assortativity in group-based networks



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

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Frame 54/80

Summary:

- Influential 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.
- Influentials' are posterior constructs.

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Implications:

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

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(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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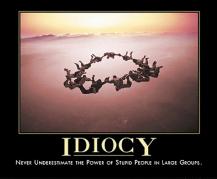
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The collective...



www.despair.com

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

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Where do superstars come from?

Rosen (1981): "The Economics of Superstars" Examples:

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

Highly skewed distributions again...

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Where do superstars come from?

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- Soloists in Classical Music
- Economic Textbooks (the usual myopic example)
- Highly skewed distributions again...

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Rosen's theory:

- Individual quality q maps to reward R(q)
- *R*(*q*) is 'convex' (d²*R*/d*q*² > 0)
- Two reasons:
 - 1. Imperfect substitution:
 - 2. Technology:

No social element—success follows 'inherent quality'

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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"

Assumes extreme case of equal 'inherent quality'

- Argues desire for coordination in knowledge and culture leads to differential success
- 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 <u>Metriaclima zebra</u> (\boxplus) :



Pecking orders for fish...

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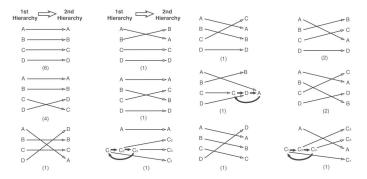
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Dominance hierarchies

Fish forget—changing of dominance hierarchies:



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

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BAND NAME TECHNING REGISTER CONTRIBUTION CONTRIBUTION

48 songs 30,000 participants

multiple 'worlds' Inter-world variability

- How probable is the world?
- Can we estimate variability?
- Superstars dominate but are unpredictable. Why?

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multiple 'worlds'

Inter-world variability

48 songs 30,000 participants

- How probable is the world?
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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 tagedy"	20	MISS OCTOBER: "pink agression"	27	SILVERFOX: "gnaw"	17
THE BROKEN PROMISE: "the end in friend"	19	POST BREAK TRAGEDY: "florence"	14	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	S2METRO: "lockdown"	17	DANTE: "lifes 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 ballstics"	\$	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 bolshevik boogie"	15	SELSIUS: "stars of the city"	22
SALUTE THE DAWN: "Lam emor"	13	CAPE RENEWAL: "baseball warlock v1"	12	SIBRIAN: "eye patch"	14
RYAN ESSMAKER: "detout_ibe 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 i 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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Experiment 1

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Experiments 2-4

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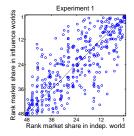
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Variability in final rank.

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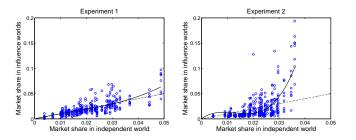
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Variability in final number of downloads.

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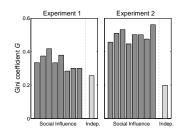
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Inequality as measured by Gini coefficient:

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

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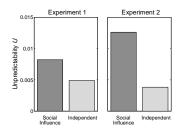
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Unpredictability

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

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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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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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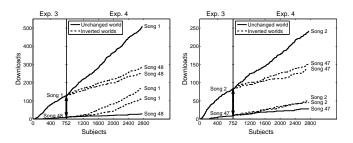
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Music Lab Experiment—Sneakiness



Inversion of download count

- The 'pretend rich' get richer ...
- but at a slower rate

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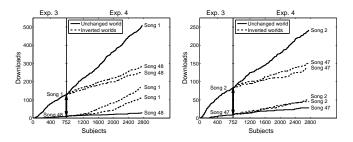
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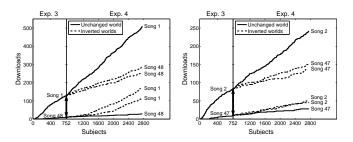
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