

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

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Contagion models

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?
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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The standard SIR model:

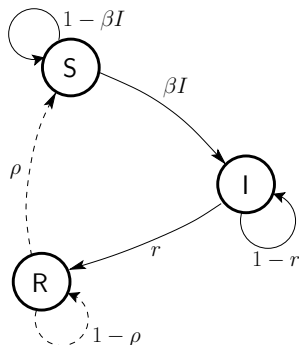
▶ Three states:

- ▶ S = Susceptible
- ▶ I = Infected
- ▶ R = Recovered

▶ $S(t) + I(t) + R(t) = 1$

- ▶ Presumes random interactions

Discrete time example:



Transition Probabilities:

β for being infected given contact with infected

r for recovery

ρ for loss of immunity

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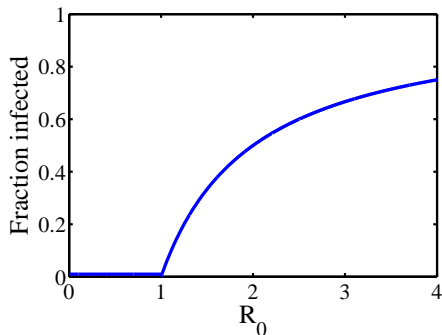
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Independent Interaction models

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.
- ▶ Example:



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

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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 ?

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” \sim 70,000 deaths in US
- ▶ 1968-69 “Hong Kong Flu” \sim 34,000 deaths in US
- ▶ 2003 “SARS Epidemic” \sim 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?**

Power laws distributions are common but not obligatory...

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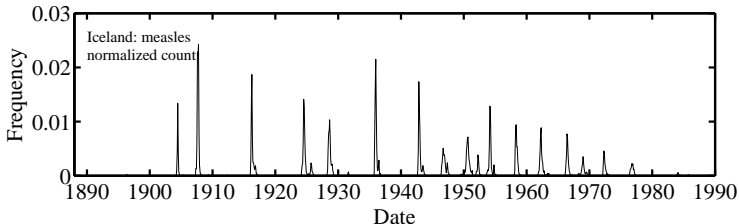
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Feeling icky in Iceland

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



Treat outbreaks separated in time as 'novel' diseases.

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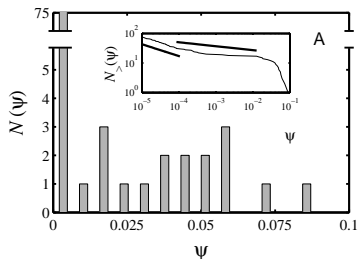
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Insert plots:

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 $2 \leq \gamma < 3$ (finite mean, infinite variance)
- ▶ Distribution is rather **flat**...

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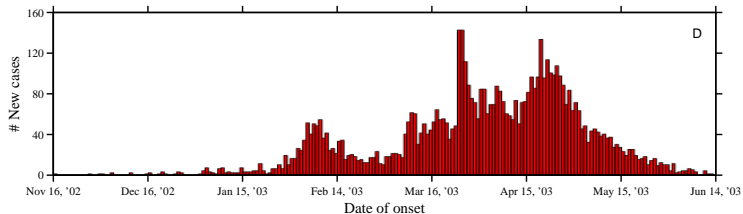
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Resurgence—example of SARS



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

A challenge

So... can a simple model produce

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

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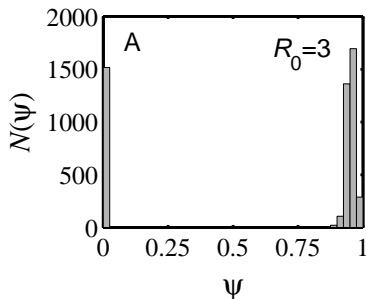
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Size distributions

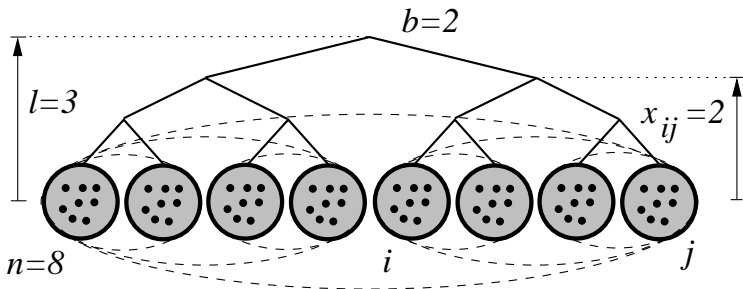


Simple models typically produce **bimodal** or **unimodal** size distributions.

- ▶ This **includes** network models: random, small-world, scale-free, ...
- ▶ 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:** $\Pr(d) \propto \exp(-d/\xi)$
- ▶ ξ = typical travel distance

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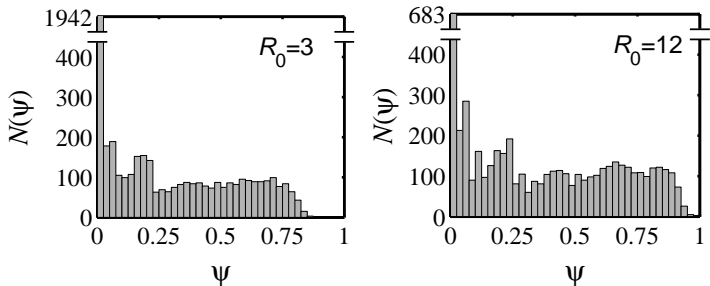
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Example model output: size distributions



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

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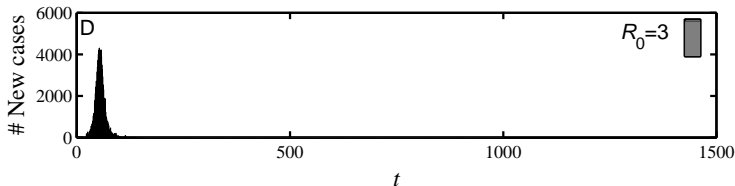
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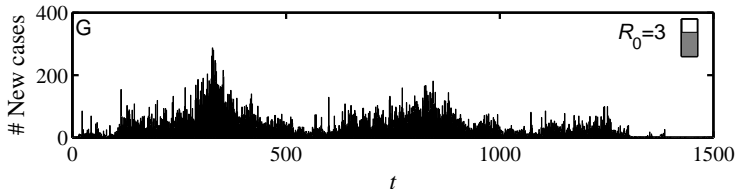
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Standard model:



Standard model with transport: Resurgence



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

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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)

Social Contagion



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Social Contagion

Examples abound:

- ▶ being polite/rude
- ▶ strikes
- ▶ innovation
- ▶ residential segregation
- ▶ ipods
- ▶ obesity
- ▶ Harry Potter
- ▶ voting
- ▶ gossip
- ▶ Rubik's cube 
- ▶ religious beliefs
- ▶ leaving lectures

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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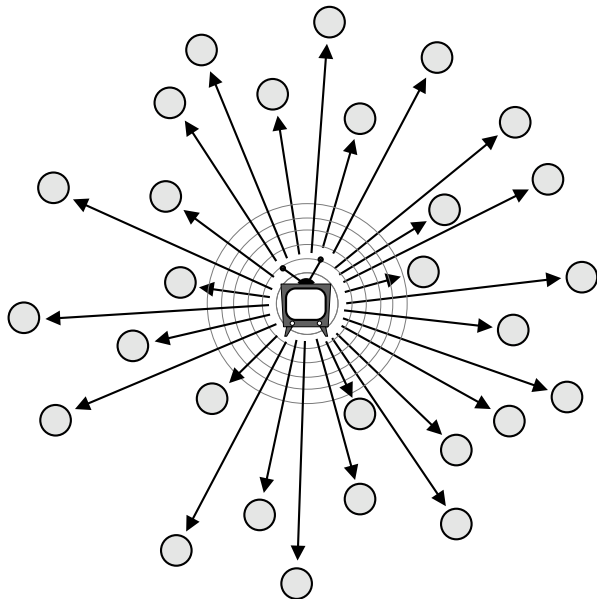
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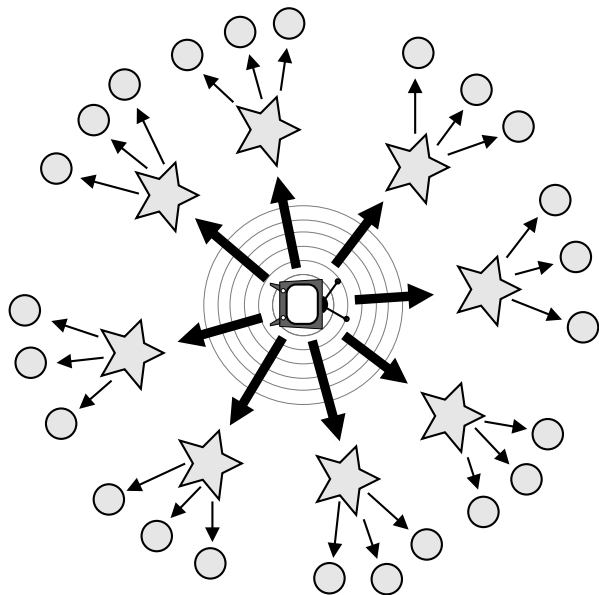
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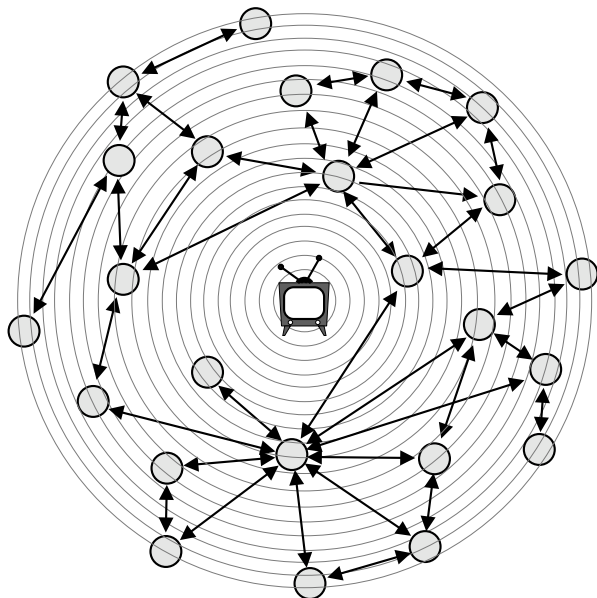
The hypodermic model of influence:



The two step model of influence:



The general model of influence:



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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The Mona Lisa:



- ▶ “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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“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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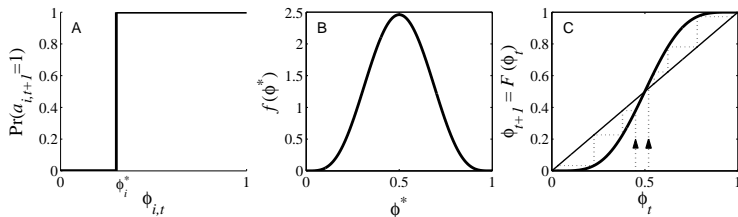
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Granovetter's threshold model:

Action based on perceived behavior of others:



- ▶ Two states: S and I.
- ▶ ϕ = fraction of contacts 'on' (e.g., rioting)

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

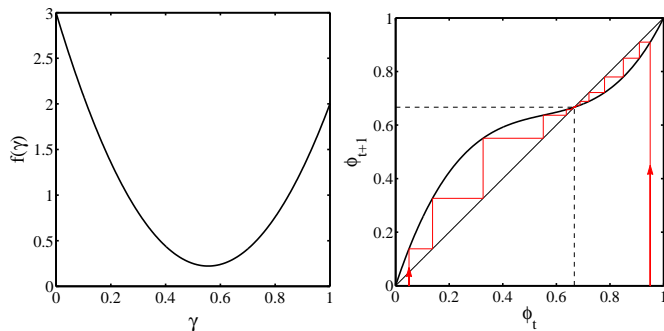
- ▶ This is a **Critical Mass model**

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- ▶ Example of single stable state model

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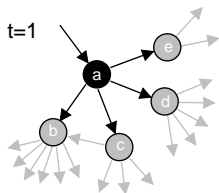
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Implications for collective action theory:

1. Collective uniformity $\not\Rightarrow$ individual uniformity
2. Small individual changes \Rightarrow large global changes

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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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?

The most gullible

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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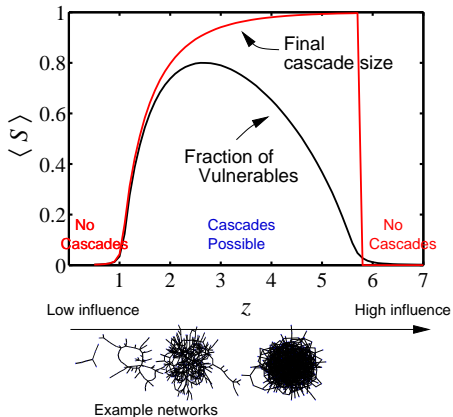
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Cascades on random networks



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

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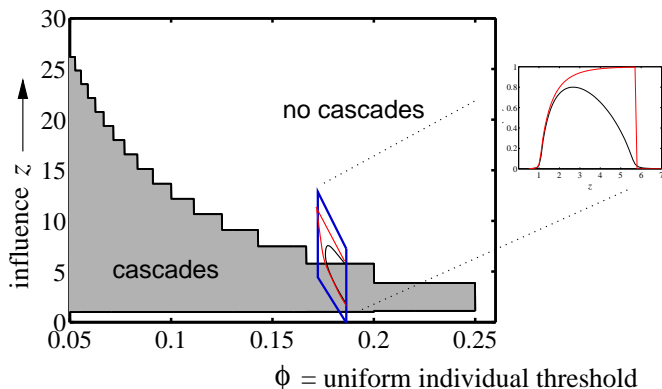
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Cascade window for random networks



- ▶ 'Cascade window' widens as threshold ϕ decreases.
- ▶ Lower thresholds enable spreading.

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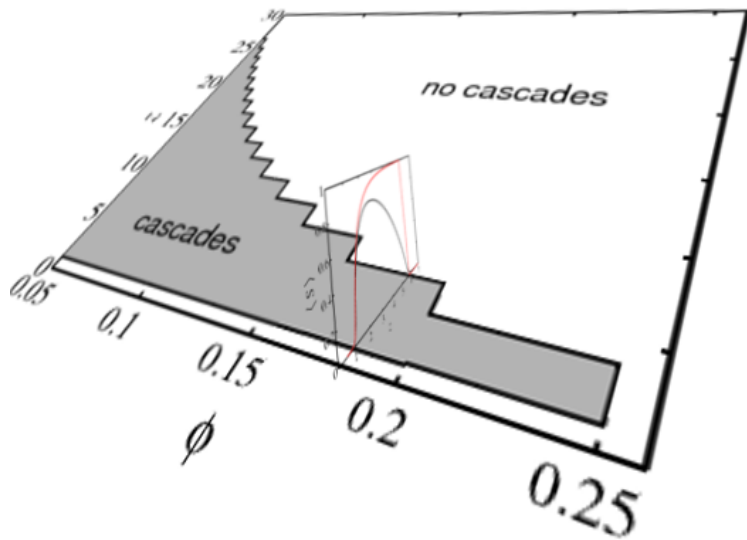
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Analytic work

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

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

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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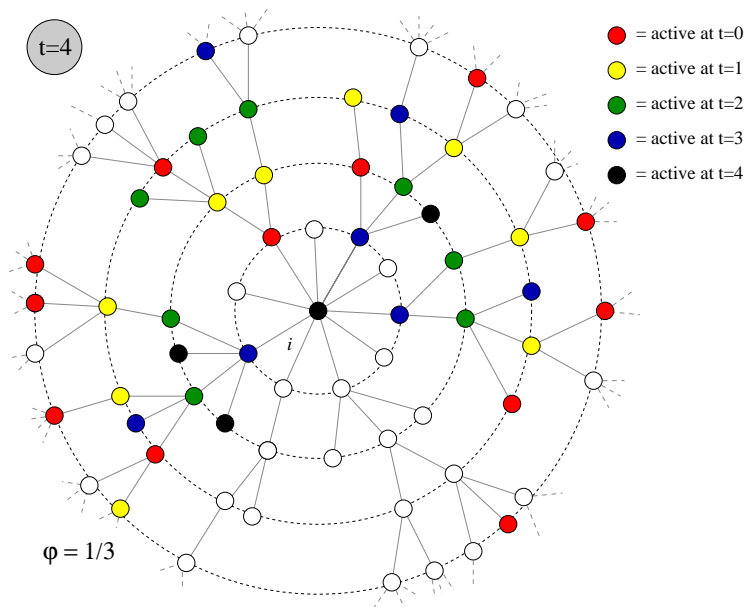
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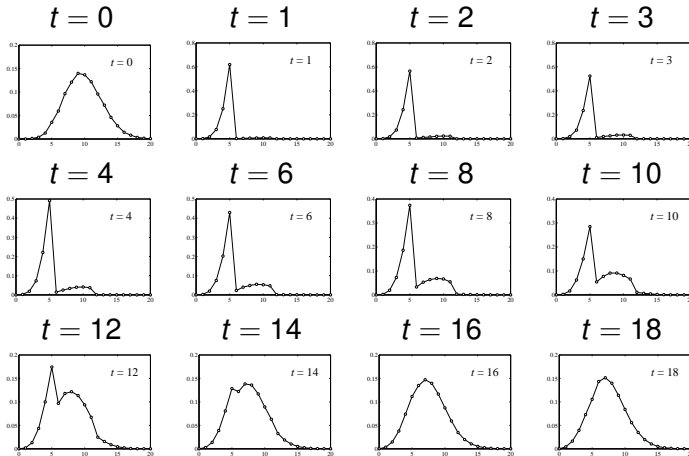
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Expected size of spread



Early adopters—degree distributions



$P_{k,t}$ versus k

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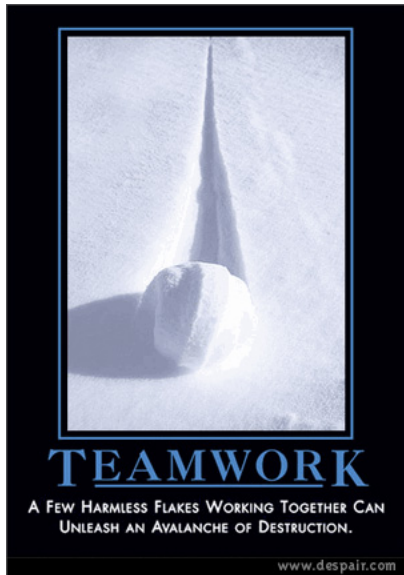
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The power of groups...



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“A few harmless flakes working together can unleash an avalanche of destruction.”

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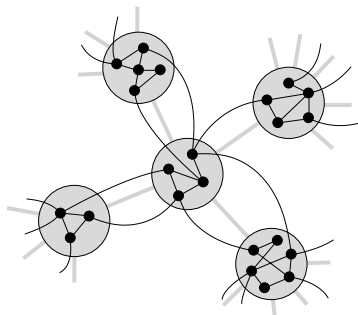
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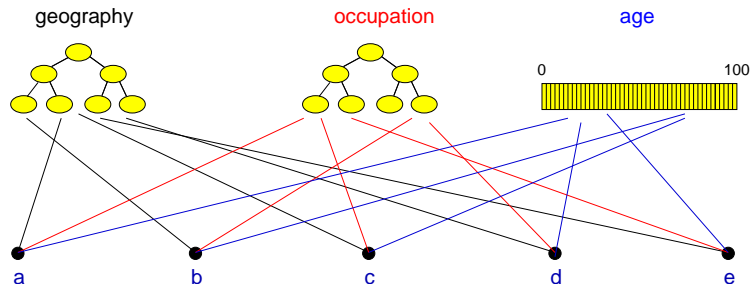
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Group structure—Ramified random networks



p = intergroup connection probability
 q = intragroup connection probability.

Generalized affiliation model



(Blau & Schwartz, Simmel, Breiger)

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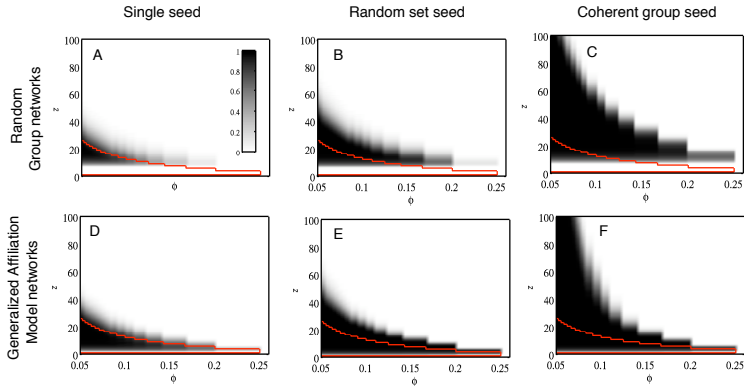
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Cascade windows for group-based networks



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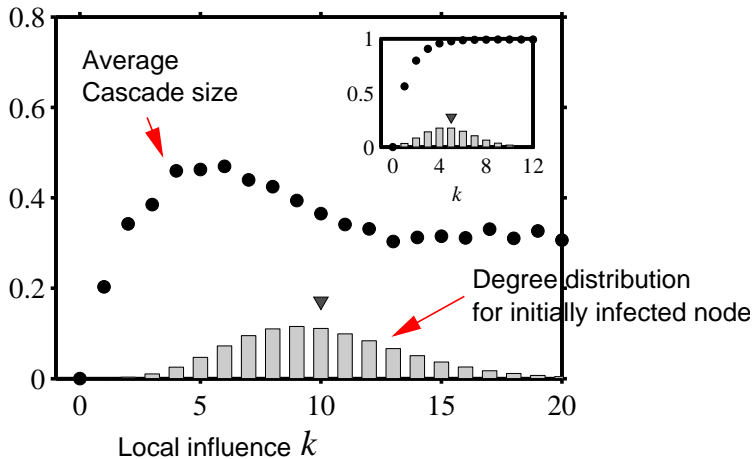
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Assortativity in group-based networks



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

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Summary:

- ▶ '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.
(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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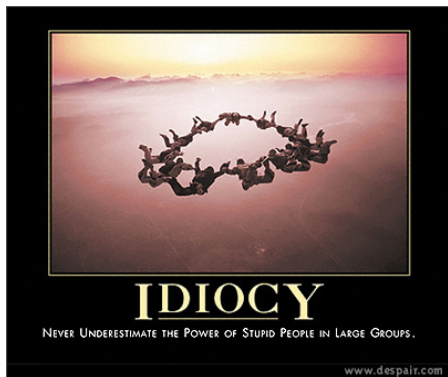
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The collective...



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“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 (≈ 200)
- ▶ 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' ($d^2 R/dq^2 > 0$)
- ▶ 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**”

- ▶ 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**

Dominance hierarchies

Chase et al. (2002): “Individual differences versus social dynamics in the formation of animal dominance hierarchies”

The aggressive female Metriaclima zebra (田):



Pecking orders for fish...

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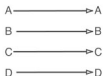
References

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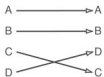
Dominance hierarchies

► Fish forget—changing of dominance hierarchies:

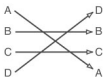
1st Hierarchy \rightleftharpoons 2nd Hierarchy



(6)



(4)

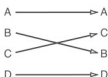


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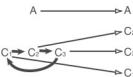
1st Hierarchy \rightleftharpoons 2nd Hierarchy



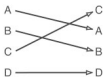
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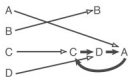
(1)



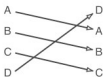
(1)



(1)



(1)



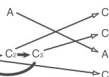
(1)



(2)



(2)



(1)

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

Music Lab Experiment



48 songs

30,000 participants

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

	[Help]	[Log off]	# of down loads
GROWTH PEOPLE: "named"			86
ACCEPT THAT: "other people"			52
LISTFORPEOPLE: "no way out"			45

multiple 'worlds'
Inter-world variability

Music Lab Experiment

Contagion



	# of down loads	[Help] [Log off]	# of down loads	# of down loads	
HARTSFIELD: "enough is enough"	20	GO MOREDCAL: "It does what its told"	12	UNDO: "while the world passes"	24
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 aggression"	27	SILVERFOX: "gnaw"	17
THE BROKEN PROMISE: "the end in friend"	19	POST BREAK TRAGEDY: "flower"	14	STRANGER: "one drop"	30
THIS NEW DAWN: "the belief above the answer"	12	FORTHFADING: "fear"	24	FAR FROM KNOWN: "route 9"	18
WOONER AT NINE: "walk away"	6	THE CALEFACTION: "trapped in an orange peef"	20	STUNT MONKEY: "inside out"	46
MORAL HAZARD: "waste of my life"	8	52METRO: "lockdown"	17	DANTE: "life's mystery"	14
NOT FOR SCHOLARS: "as seasons change"	27	SIMPLY WAITING: "went with the count"	16	FADING THROUGH: "wish me luck"	30
SECRETARY: "keep your eyes on the ballistic"	5	STAR CLIMBER: "tell me"	38	UNKNOWN CITIZENS: "falling over"	34
ART OF KANLY: "reductive into, medic breakdown"	10	THE FASTLANE: "if death do us part i dont"	31	BY NOVEMBER: "if i could take you"	20
HYDRAULIC SANDWICH: "separation anxiety"	20	A BLINDING SILENCE: "misery and mtraces"	17	DRAWN IN THE SKY: "tap the ride"	12
EMBER SKY: "this upcoming winter"	25	SUMRANA: "the bolshhevik boogie"	15	SELSIUS: "stars of the city"	22
SALUTE THE DAWN: "i am em"	13	CAPE RENAISSANCE: "baseball warlock v1"	12	SIBIRIAN: "eye patch"	14
RYAN ESSMAKER: "detour, the still"	14	UP FALLS DOWN: "a brighter burning star"	11	EVAN COLD: "inbet downey jr"	30
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: "out of the woods"	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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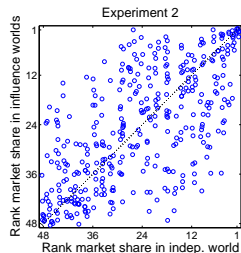
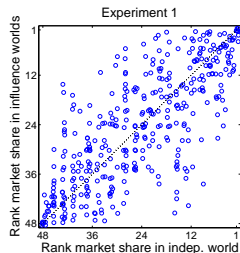
Experiment 1

Rank	Artist	Album	Year	Genre
1	WIRETAPERS	Through a Veil	12	Rock
2	DEEP DISCO	Through a Veil	12	Rock
3	DEEP DISCO	Through a Veil	12	Rock
4	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
5	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
6	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
7	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
8	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
9	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
10	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
11	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
12	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
13	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
14	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
15	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
16	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
17	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
18	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
19	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
20	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
21	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
22	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
23	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
24	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
25	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
26	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
27	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
28	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
29	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
30	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
31	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
32	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
33	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
34	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
35	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
36	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
37	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
38	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
39	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
40	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
41	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
42	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
43	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
44	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
45	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
46	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
47	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
48	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
49	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock
50	THE SHERIFF'S DAUGHTER	Through a Veil	12	Rock

Experiments 2-4

Rank	Artist	Album	Year	Genre
1	WIRETAPERS	Through a Veil	12	Rock
2	WIRETAPERS	Through a Veil	12	Rock
3	WIRETAPERS	Through a Veil	12	Rock
4	WIRETAPERS	Through a Veil	12	Rock
5	WIRETAPERS	Through a Veil	12	Rock
6	WIRETAPERS	Through a Veil	12	Rock
7	WIRETAPERS	Through a Veil	12	Rock
8	WIRETAPERS	Through a Veil	12	Rock
9	WIRETAPERS	Through a Veil	12	Rock
10	WIRETAPERS	Through a Veil	12	Rock
11	WIRETAPERS	Through a Veil	12	Rock
12	WIRETAPERS	Through a Veil	12	Rock
13	WIRETAPERS	Through a Veil	12	Rock
14	WIRETAPERS	Through a Veil	12	Rock
15	WIRETAPERS	Through a Veil	12	Rock
16	WIRETAPERS	Through a Veil	12	Rock
17	WIRETAPERS	Through a Veil	12	Rock
18	WIRETAPERS	Through a Veil	12	Rock
19	WIRETAPERS	Through a Veil	12	Rock
20	WIRETAPERS	Through a Veil	12	Rock
21	WIRETAPERS	Through a Veil	12	Rock
22	WIRETAPERS	Through a Veil	12	Rock
23	WIRETAPERS	Through a Veil	12	Rock
24	WIRETAPERS	Through a Veil	12	Rock
25	WIRETAPERS	Through a Veil	12	Rock
26	WIRETAPERS	Through a Veil	12	Rock
27	WIRETAPERS	Through a Veil	12	Rock
28	WIRETAPERS	Through a Veil	12	Rock
29	WIRETAPERS	Through a Veil	12	Rock
30	WIRETAPERS	Through a Veil	12	Rock
31	WIRETAPERS	Through a Veil	12	Rock
32	WIRETAPERS	Through a Veil	12	Rock
33	WIRETAPERS	Through a Veil	12	Rock
34	WIRETAPERS	Through a Veil	12	Rock
35	WIRETAPERS	Through a Veil	12	Rock
36	WIRETAPERS	Through a Veil	12	Rock
37	WIRETAPERS	Through a Veil	12	Rock
38	WIRETAPERS	Through a Veil	12	Rock
39	WIRETAPERS	Through a Veil	12	Rock
40	WIRETAPERS	Through a Veil	12	Rock
41	WIRETAPERS	Through a Veil	12	Rock
42	WIRETAPERS	Through a Veil	12	Rock
43	WIRETAPERS	Through a Veil	12	Rock
44	WIRETAPERS	Through a Veil	12	Rock
45	WIRETAPERS	Through a Veil	12	Rock
46	WIRETAPERS	Through a Veil	12	Rock
47	WIRETAPERS	Through a Veil	12	Rock
48	WIRETAPERS	Through a Veil	12	Rock
49	WIRETAPERS	Through a Veil	12	Rock
50	WIRETAPERS	Through a Veil	12	Rock

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- ▶ Variability in final rank.

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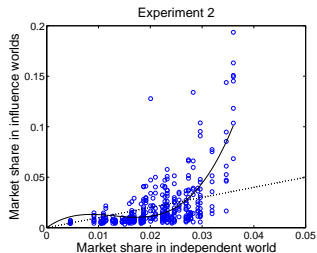
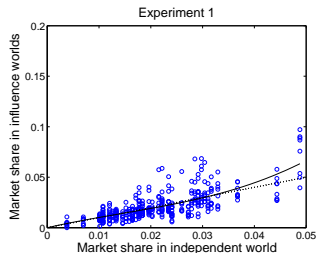
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- ▶ Variability in final number of downloads.

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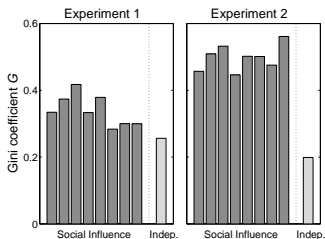
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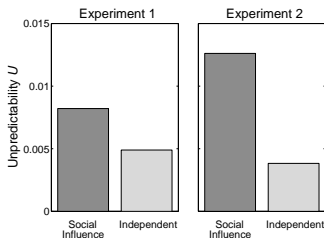
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- ▶ Inequality as measured by Gini coefficient:

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



► Unpredictability

$$U = \frac{1}{N_s \binom{N_w}{2}} \sum_{i=1}^{N_s} \sum_{j=1}^{N_w} \sum_{k=j+1}^{N_w} |m_{i,j} - m_{i,k}|$$

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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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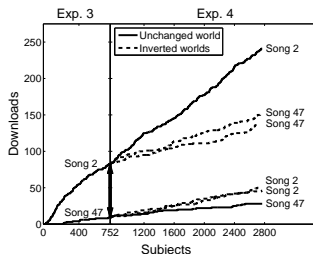
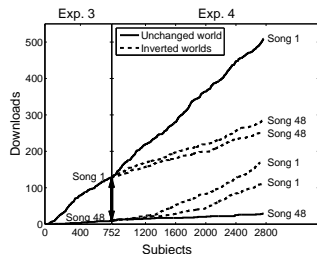
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Music Lab Experiment—Sneakiness



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

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