Lecture Two

Stories of Complex Sociotechnical Systems: Measurement, Mechanisms, and Meaning
Lipari Summer School, Summer, 2012

Prof. Peter Dodds

Department of Mathematics & Statistics | Center for Complex Systems | Vermont Advanced Computing Center | University of Vermont

Outline

Economics, Schmeconomics

Alan Greenspan (September 18, 2007):

"I've been dealing with these big mathematical models of forecasting the economy ...

If I could figure out a way to determine whether or not people are more fearful or changing to more euphoric,

I don't need any of this other stuff.

I could forecast the economy better than any way I know."

http://wikipedia.org

Economics, Schmeconomics

Greenspan continues:

"The trouble is that we can't figure that out. I've been in the forecasting business for 50 years. I'm no better than I ever was, and nobody else is. Forecasting 50 years ago was as good or as bad as it is today. And the reason is that human nature hasn't changed. We can't improve ourselves."

Jon Stewart:

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

wildbluffmedia.com

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

Economics, Schmeconomics

James K. Galbraith:

NYT But there are at least 15,000 professional economists in this country, and you're saying only two or three of them foresaw the mortgage crisis?
[JKG] Ten or 12 would be closer than two or three.

NYT What does that say about the field of economics, which claims to be a science? [JKG] It's an enormous blot on the reputation of the profession. There are thousands of economists. Most of them teach. And most of them teach a theoretical framework that has been shown to be fundamentally useless.

From the New York Times, 11/02/2008 (⊞)

Collective Cooperation:

- Standard frame:

  Locally selfish behavior
  → collective cooperation.
- Different frame:

  Locally moral/fair behaviour
  → collective bad actions.
- So why do we study frame 1 instead of frame 2?
- Tragedy of the Commons is one example of frame 2.
- Better question:
  Who is it that studies frame 1 over frame 2. . . ?

Homo Economicus

- 'What makes people think like Economists? Evidence on Economic Cognition from the "Survey of Americans and Economists on the Economy" ' [8] Bryan Caplan, Journal of Law and Economics, 2001

People behave like Homo economicus:

1. if they are well educated,
2. if they are male,
3. if their real income rose over the last 5 years,
4. if they expect their real income to rise over the next 5 years,
5. if they have a high degree of job security,
6. but not because of high income nor ideological conservatism.

Wealth distribution in the United States:

Questions used in a recent study by Norton and Ariely: [29]

- What percentage of all wealth is owned by individuals grouped into quintiles?
- How do people believe wealth is distributed?
- How do people believe wealth should be distributed?

Wealth distribution in the United States:

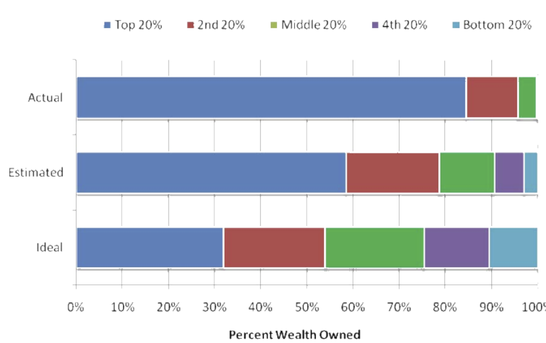


Fig. 2. The actual United States wealth distribution plotted against the estimated and ideal distributions across all respondents. Because of their small percentage share of total wealth, both the "4th 20%" value (0.2%) and the "Bottom 20%" value (0.1%) are not visible in the "Actual" distribution.

Wealth distribution in the United States:

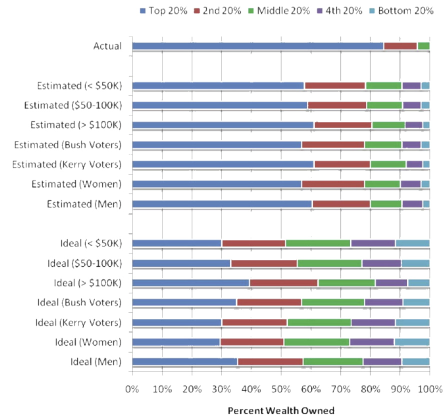


Fig. 3. The actual United States wealth distribution plotted against the estimated and ideal distributions of respondents of different income levels, political affiliations, and genders. Because of their small percentage share of total wealth, both the "4th 20%" value (0.2%) and the "Bottom 20%" value (0.1%) are not visible in the "Actual" distribution.

This is a Collateralized Debt Obligation:

Contagion

A confusion of contagions:

- Was Harry Potter some kind of virus?
- What about Vampires?
- Did Sudoku spread like a disease?
- Language? The alphabet? [17]
- Religion?
- Democracy...?

Contagion

Naturomorphisms

- "The feeling was contagious."
- "The news spread like wildfire."
- "Freedom is the most contagious virus known to man."
  —Hubert H. Humphrey, Johnson's vice president
- "Nothing is so contagious as enthusiasm."
  —Samuel Taylor Coleridge

Social contagion

Eric Hoffer, 1902–1983

There is a grandeur in the uniformity of the mass. When a fashion, a dance, a song, a slogan or a joke sweeps like wildfire from one end of the continent to the other, and a hundred million people roar with laughter, sway their bodies in unison, hum one song or break forth in anger and denunciation, there is the overpowering feeling that in this country we have come nearer the brotherhood of man than ever before.

- Hoffer (⊞) was an interesting fellow...

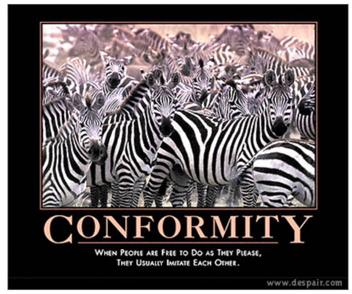
The spread of fanaticism

Hoffer's acclaimed work: "The True Believer: Thoughts On The Nature Of Mass Movements" (1951) [20]

Quotes-aplenty:

- "We can be absolutely certain only about things we do not understand."
- "Mass movements can rise and spread without belief in a God, but never without belief in a devil."
- "Where freedom is real, equality is the passion of the masses. Where equality is real, freedom is the passion of a small minority."

Imitation

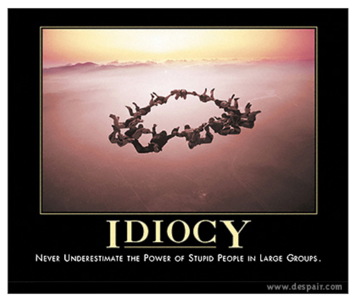


despair.com

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

—Eric Hoffer
"The Passionate State of Mind" [21]

The collective...



despair.com

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

Contagion

Definitions

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

Examples of non-disease spreading:

Interesting infections:

- Spreading of buildings in the US... (⊞)

- Viral get-out-the-vote video. (⊞)

Contagions

Two main classes of contagion

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

Winning: it's not for everyone

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)...

Superstars

Rosen's theory:

- Individual quality q maps to reward $R(q)$
- $R(q)$ is 'convex' ($\mathrm{d}^2 R/\mathrm{d}q^2 > 0$)
- 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'

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
- Success is then purely a social construction

Dominance hierarchies

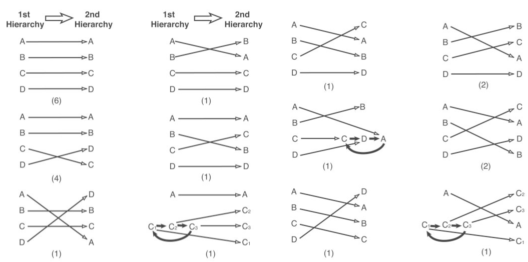
Chase et al. (2002): "Individual differences versus social dynamics in the formation of animal dominance hierarchies" [11]

The aggressive female Metriaclima zebra (⊞):

Pecking orders for fish...

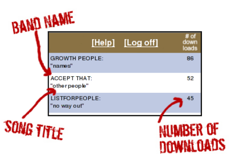
Dominance hierarchies

- Fish forget—changing of dominance hierarchies:



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

Music Lab Experiment



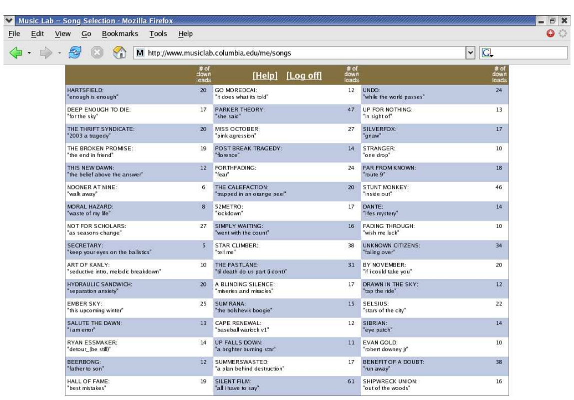
48 songs
30,000 participants

multiple 'worlds'
Inter-world variability

- How probable is a social state?
- Can we estimate variability?

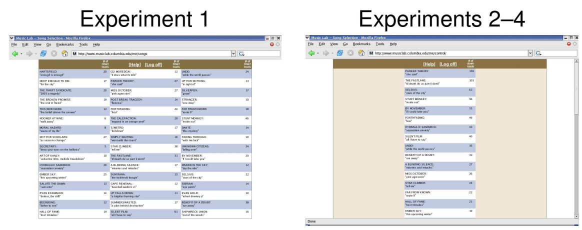
Salganik et al. (2006) "An experimental study of inequality and unpredictability in an artificial cultural market"[33]

Music Lab Experiment

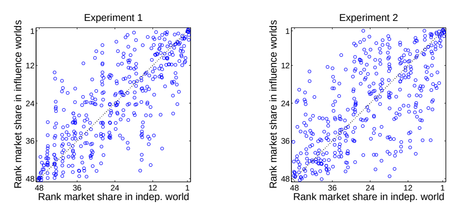


	# of down loads	[Help] [Log off]	# of down loads		# of down loads
HARTSFIELD: "enough is enough"	20	GO MOREDCAI: "it does what its told"	12	UNDO: "while the world passes"	24
DEEP ENOUGH TO DIE: "for the sky"	17	PARKER THEORY: "she said"	47	UP FOR NOTHING: "in sight of"	13
THE THRIFT SYNDICATE: "2003 a tragedy"	20	MISS OCTOBER: "pink 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: "route 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: "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 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 i could take you"	20
HYDRAULIC SANDWICH: "separation anxiety"	20	A BLINDING SILENCE: "miseries and miracles"	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: "i am error"	13	CAPE RENEWAL: "baseball warlock v1"	12	SIBRIAN: "eye patch"	14
RYAN ESSMAKER: "detour_(be 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: "out of the woods"	16

Music Lab Experiment

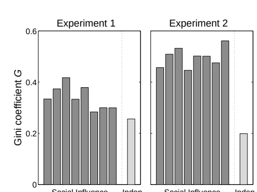


Music Lab Experiment



- Variability in final rank.

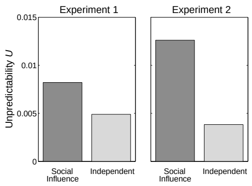
Music Lab Experiment



- Inequality as measured by Gini coefficient:

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

Music Lab Experiment



- Unpredictability

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

Music Lab Experiment

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Sensible result:

- Stronger social signal leads to greater following and greater inequality.

Peculiar result:

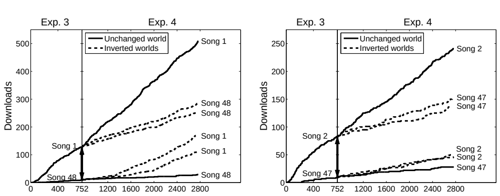
- Stronger social signal leads to greater unpredictability.

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.
- 'Payola' leads to poor system performance.

Music Lab Experiment—Sneakiness

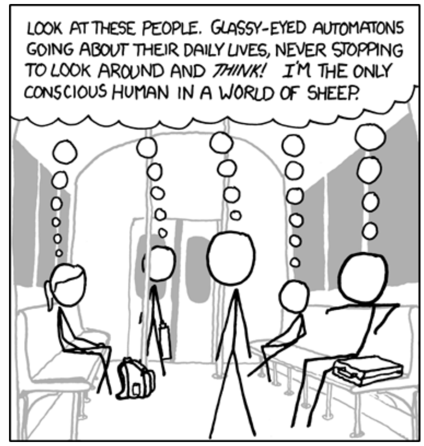
Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References



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

Social Contagion

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References



http://xkcd.com/610/ (⊞)

Social Contagion

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Social Contagion

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Social Contagion

Examples abound

- fashion
- striking
- smoking (⊞) [13]
- residential segregation [34]
- ipods
- obesity (⊞) [12]
- Harry Potter
- voting
- gossip
- Rubik's cube
- religious beliefs
- leaving lectures

SIR and SIRS contagion possible

- Classes of behavior versus specific behavior: dieting

Social Contagion

Two focuses for us:

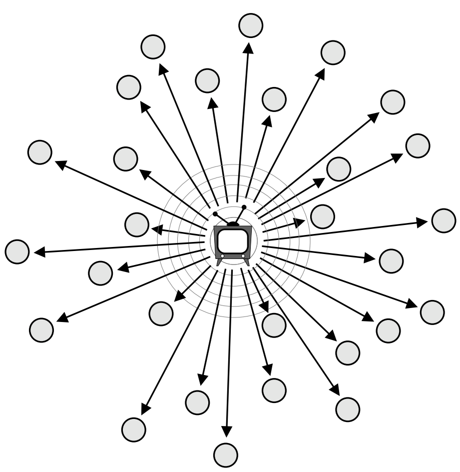
- Widespread media influence
- Word-of-mouth influence

We need to understand influence:

- Who influences whom? Very hard to measure...
- What kinds of influence response functions are there?
  (see Romero et al. [31], Ugander et al. [39])
- Are some individuals super influencers?
  Highly popularized by Gladwell [16] as 'connectors'
- The infectious idea of opinion leaders (Katz and Lazarsfeld) [22]

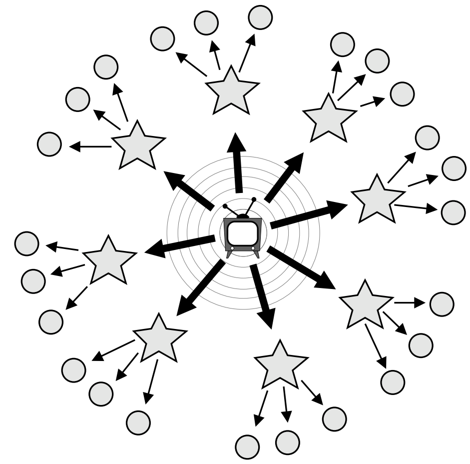
Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

The hypodermic model of influence



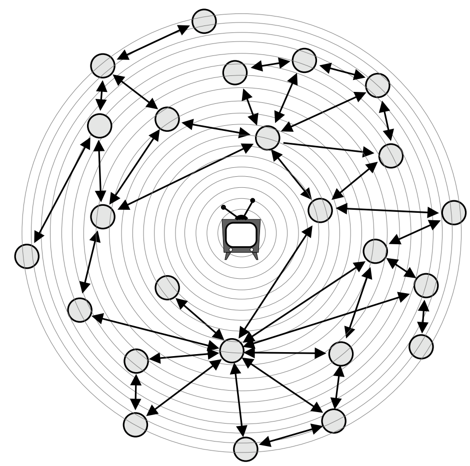
Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

The two step model of influence [22]



Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

The general model of influence



Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Social Contagion

Why do things spread?

- Because of special individuals?
- Or system level properties?
- Is the match that lights the fire important?
- Yes. But only because we are narrative-making machines...
- We like to think things happened for reasons...
- Reasons for success are usually ascribed to intrinsic properties (e.g., Mona Lisa)
- System/group properties harder to understand—-no natural frame/metaphor
- Always good to examine what is said before and after the fact...

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

From Pratchett's "Lords and Ladies":

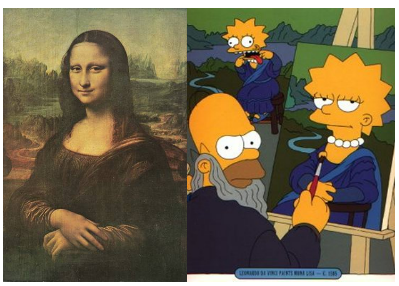
Granny Weatherwax (⊞) on trying to borrow the mind of a swarm of bees—

"But a swarm, a mind made up of thousands of mobile parts, was beyond her. It was the toughest test of all. She'd tried over and over again to ride on one, to see the world through ten thousand pairs of multifaceted eyes all at once, and all she'd ever got was a migraine and an inclination to make love to flowers."

(p. 42). Harper Collins, Inc. Kindle Edition.

The Mona Lisa

Complex Sociotechnical Systems



- "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, ...

The completely unpredicted fall of Eastern Europe

Complex Sociotechnical Systems

Timur Kuran:[26, 27] "Now Out of Never: The Element of Surprise in the East European Revolution of 1989"

The dismal predictive powers of editors...

Complex Sociotechnical Systems

Getting others to do things for you

Complex Sociotechnical Systems

From 'Influence'[14] by Robert Cialdini (⊞)

Six modes of influence:

1. Reciprocation: *The Old Give and Take... and Take*; e.g., Free samples, Hare Krishnas.
2. Commitment and Consistency: *Hobgoblins of the Mind*; e.g., Hazing.
3. Social Proof: *Truths Are Us*; e.g., Jonestown (⊞), Kitty Genovese (⊞) (contested).
4. Liking: *The Friendly Thief*; e.g., Separation into groups is enough to cause problems.
5. Authority: *Directed Deference*; e.g., Milgram's obedience to authority experiment. (⊞)
6. Scarcity: *The Rule of the Few*; e.g., Prohibition.

Social Contagion

Complex Sociotechnical Systems

- Cialdini's modes are heuristics that help up us get through life.
- Very useful but can be leveraged...

Messing with social connections

- Ads based on message content (e.g., Google and email)
- BzzAgent (⊞)
- Facebook's advertising: Beacon (⊞)

Thomas Schelling (⊞) (Economist/Nobelist):

[youtube] (⊞)

- Tipping models—Schelling (1971) [34, 35, 36]
  - Simulation on checker boards
  - Idea of thresholds
- Threshold models—Granovetter (1978) [19]
- Herding models—Bikhchandani, Hirschleifer, Welch (1992) [4, 5]
  - Social learning theory, Informational cascades,...

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Social contagion models

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 can vary
- Assumption: order of others' adoption does not matter... (unrealistic).
- Assumption: level of influence per person is uniform (unrealistic).

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

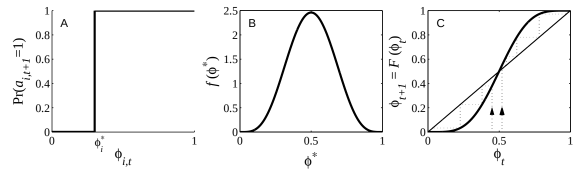
Social Contagion

Some possible origins of thresholds:

- Inherent, evolution-devised inclination to coordinate, to conform, to imitate. [3]
- Lack of information: impute the worth of a good or behavior based on degree of adoption (social proof)
- Economics: Network effects or network externalities
  - Externalities = Effects on others not directly involved in a transaction
  - Examples: telephones, fax machine, Facebook, operating systems
  - An individual's utility increases with the adoption level among peers and the population in general

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Action based on perceived behavior of others:



- Two states: Susceptible and Infected.
- ϕ = fraction of contacts 'on' (e.g., rioting)
- Discrete time update (strong assumption!)
- This is a Critical mass model
- Many other kinds of dynamics are possible.

Implications for collective action theory:

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

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Threshold model on a network

Many years after Granovetter and Soong's work:

"A simple model of global cascades on random networks"
D. J. Watts. Proc. Natl. Acad. Sci., 2002 [40]

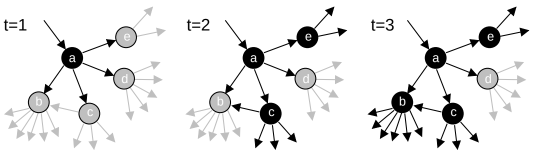
- Mean field model $\rightarrow$ network model
- Individuals now have a limited view of the world

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Threshold model on a network

- Interactions between individuals now represented by a network
- Network is sparse
- Individual i has k_i contacts
- Influence on each link is reciprocal and of unit weight
- Each individual i has a fixed threshold ϕ_i
- Individuals repeatedly poll contacts on network
- Synchronous, discrete time updating
- Individual i becomes active when fraction of active contacts $\frac{a_i}{k_i} \geq \phi_i$
- Individuals remain active when switched (no recovery = SI model)

Threshold model on a network



- All nodes have threshold $\phi = 0.2$.

Snowballing

The Cascade Condition:

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

First study random networks:

- Start with N nodes with a degree distribution p_k
- Nodes are randomly connected (carefully so)
- Aim: Figure out when activation will propagate
- Determine a cascade condition

Snowballing

Follow active links

- An active link is a link connected to an activated node.
- If an infected link leads to at least 1 more infected link, then activation spreads.
- We need to understand which nodes can be activated when only one of their neigbors becomes active.

The most gullible

Vulnerables:

- We call individuals who can be activated by just one contact being active vulnerables
- The vulnerability condition for node i:

$$1/k_i \geq \phi_i$$

- Which means # contacts $k_i \leq \lfloor 1/\phi_i \rfloor$
- For global cascades on random networks, must have a *global cluster of vulnerables* [40]
- Cluster of vulnerables = critical mass
- Network story: 1 node $\rightarrow$ critical mass $\rightarrow$ everyone.

Cascade condition

Back to following a link:

- A randomly chosen link, traversed in a random direction, leads to a degree k node with probability $\propto kP_k$.
- Follows from there being k ways to connect to a node with degree k.
- Normalization:

$$\sum_{k=0}^{\infty} kP_k = \langle k \rangle$$

- So

$$P(\text{linked node has degree } k) = \frac{kP_k}{\langle k \rangle}$$

Cascade condition

Next: Vulnerability of linked node

- Linked node is vulnerable with probability

$$\beta_k = \int_{\phi'_*=0}^{1/k} f(\phi'_*)\mathrm{d}\phi'_*$$

- If linked node is vulnerable, it produces $k-1$ new outgoing active links
- If linked node is not vulnerable, it produces no active links.

Cascade condition

Putting things together:

- Expected number of active edges produced by an active edge:

$$R = \underbrace{\sum_{k=1}^{\infty} (k-1) \cdot \beta_k \cdot \frac{kP_k}{\langle k \rangle}}_{\text{success}} + \underbrace{0 \cdot (1-\beta_k) \cdot \frac{kP_k}{\langle k \rangle}}_{\text{failure}}$$

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

Cascade condition

So... for random networks with fixed degree distributions, cacades take off when:

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

- β_k = probability a degree k node is vulnerable.
- P_k = probability a node has degree k.

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Cascade condition

Two special cases:

- (1) Simple disease-like spreading succeeds: $\beta_k = \beta$

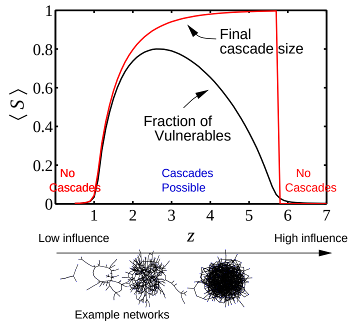
$$\beta \cdot \sum_{k=1}^{\infty} (k-1) \cdot \frac{kP_k}{\langle k \rangle} \geq 1.$$

- (2) Giant component exists: $\beta = 1$

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

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

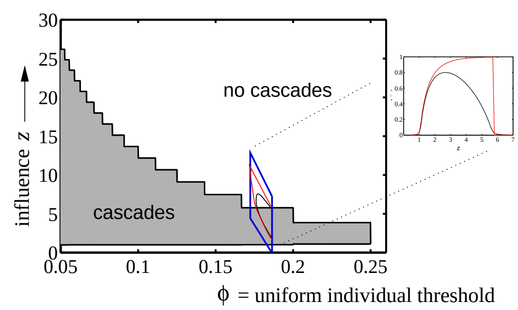
Cascades on random networks



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

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

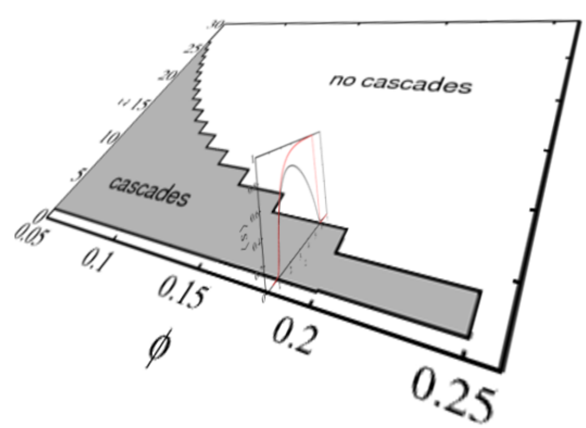
Cascade window for random networks



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

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

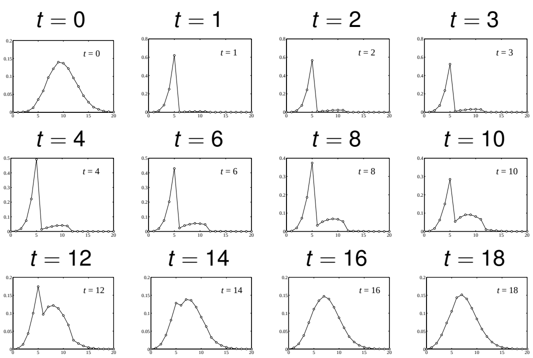
Cascade window for random networks



A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

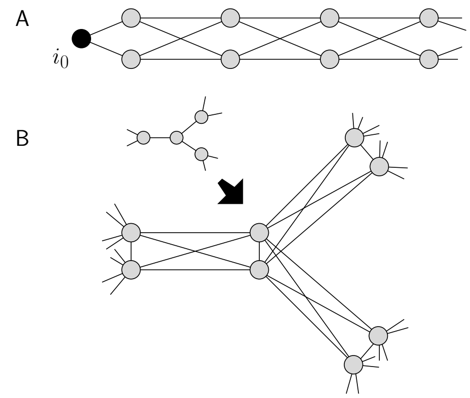
Early adopters are not well connected:

- Degree distributions of nodes adopting at time t:



$P_{k,t}$ versus k

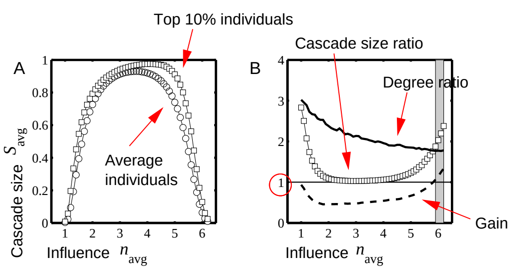
Special subnetworks can act as triggers



- $\phi = 1/3$ for all nodes

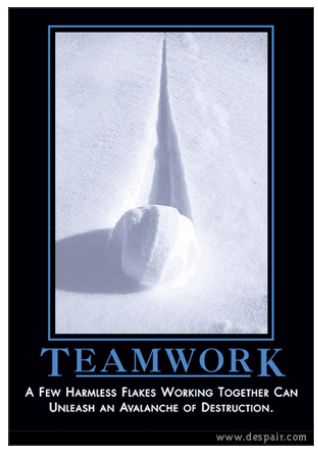
The multiplier effect:

"Influentials, Networks, and Public Opinion Formation" [41]
Journal of Consumer Research, Watts and Dodds, 2007.



- Fairly uniform levels of individual influence.
- Multiplier effect is mostly below 1.

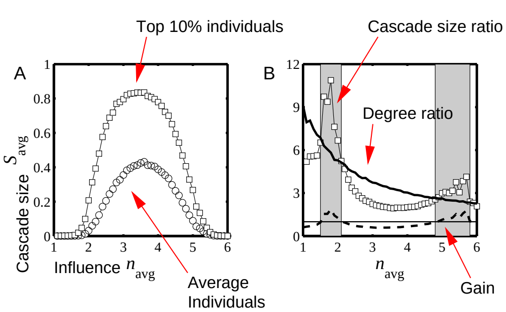
The power of groups...



despair.com

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

The multiplier effect:

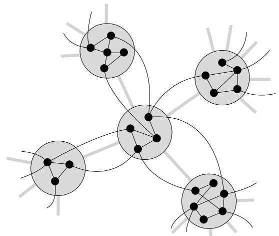


- Skewed influence distribution example.

Incorporating social context:

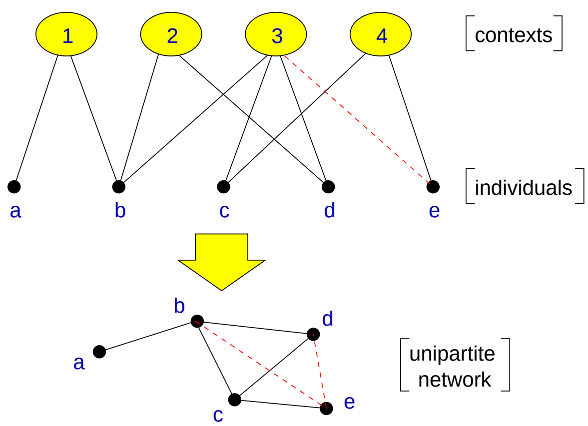
- Assumption of sparse interactions is good
- Degree distribution is (generally) key to a network's function
- Still, random networks don't represent all networks
- Major element missing: group structure
- "Threshold Models of Social Influence" [42]
  Watts and Dodds, 2009.
  Oxford Handbook of Analytic Sociology.
  Eds. Hedström and Bearman.

Group structure—Ramified random networks

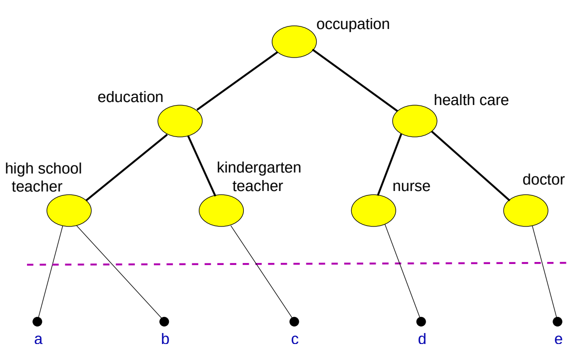


p = intergroup connection probability
q = intragroup connection probability.

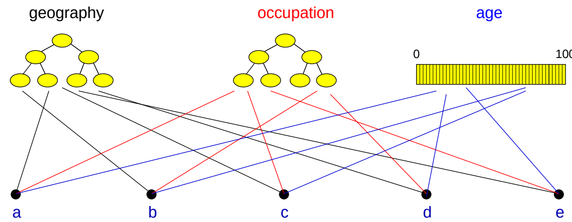
Bipartite networks



Context distance



Generalized affiliation model

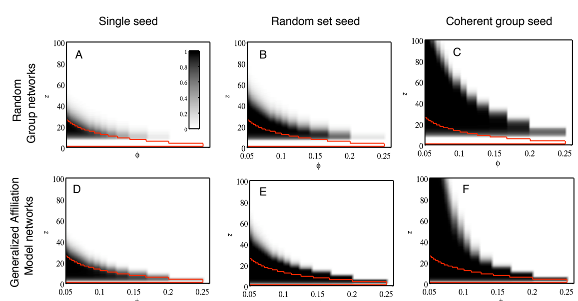


(Blau & Schwartz, Simmel, Breiger)

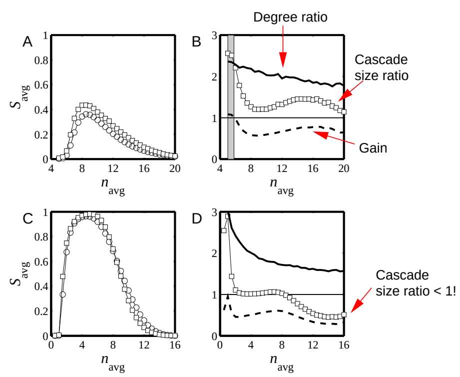
Generalized affiliation model networks with triadic closure

- Connect nodes with probability $\propto \exp^{-\alpha d}$ where
  α = homophily parameter
  and
  d = distance between nodes (height of lowest common ancestor)
- τ_1 = intergroup probability of friend-of-friend connection
- τ_2 = intragroup probability of friend-of-friend connection

Cascade windows for group-based networks

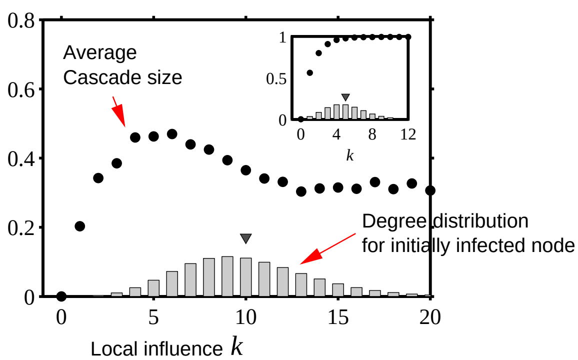


Multiplier effect for group-based networks:



- Multiplier almost always below 1.

Assortativity in group-based networks



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

Social contagion

Summary

- 'Influential vulnerables' are key to spread.
- Early adopters are mostly vulnerables.
- Vulnerable nodes important but not necessary.
- Vulnerable groups may greatly facilitate spread.
- Seems that cascade condition is a global one.
- Most extreme/unexpected cascades occur in highly connected networks.
- 'Influentials' are posterior constructs.
- Many potential 'influentials' exist.

Social contagion

Implications

- Focus on the influential vulnerables.
- Create entities that can be transmitted successfully through many individuals rather than broadcast from one 'influential.'
- Only simple ideas can spread by word-of-mouth.
  (Idea of opinion leaders spreads well...)
- Want enough individuals who will adopt and display.
- Displaying can be passive = free (yo-yo's, fashion), or active = harder to achieve (political messages).
- Entities can be novel or designed to combine with others, e.g. block another one.

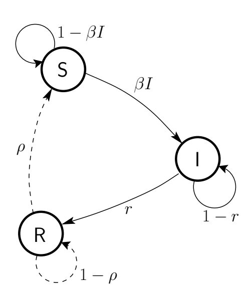
Mathematical Epidemiology

The standard SIR model [28]

- = basic model of disease contagion
- Three states:
  1. S = Susceptible
  2. I = Infective/Infectious
  3. R = Recovered or Removed or Refractory
- $S(t) + I(t) + R(t) = 1$
- Presumes random interactions (mass-action principle)
- Interactions are independent (no memory)
- Discrete and continuous time versions

Mathematical Epidemiology

Discrete time automata example:



Transition Probabilities:

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

Mathematical Epidemiology

Original models attributed to

- 1920's: Reed and Frost
- 1920's/1930's: Kermack and McKendrick [23, 25, 24]
- Coupled differential equations with a mass-action principle

Independent Interaction models

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Differential equations for continuous model

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

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

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

β, r, and ρ are now rates.

Reproduction Number R_0:

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

Reproduction Number R_0

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Discrete version:

- Set up: One Infective in a randomly mixing population of Susceptibles
- At time $t = 0$, single infective random bumps into a Susceptible
- Probability of transmission = β
- At time $t = 1$, single Infective remains infected with probability $1 - r$
- At time $t = k$, single Infective remains infected with probability $(1 - r)^k$

Reproduction Number R_0

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Discrete version:

- Expected number infected by original Infective:

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

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

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

For S_0 initial infectives ($1 - S_0 = R_0$ immune):

$$R_0 = S_0\beta/r$$

Independent Interaction models

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

For the continuous version

- Second equation:

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

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

- Number of infectives grows initially if

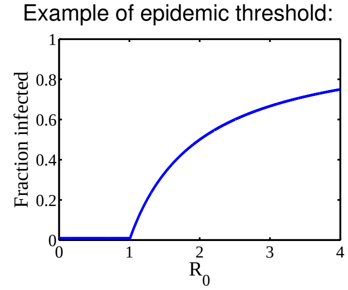
$$\beta S(0) - r > 0 : \beta S(0) > r : \beta S(0)/r > 1$$

- Same story as for discrete model.

Independent Interaction models

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Example of epidemic threshold:



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

Independent Interaction models

Many variants of the SIR model:

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

Disease spreading models

For novel diseases:

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

R_0 approximately same for all of the following:

- 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

Size distributions

Size distributions are important elsewhere:

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

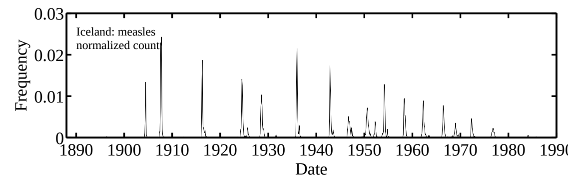
Power laws distributions are common but not obligatory...

Really, what about epidemics?

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

Feeling Ill in Iceland

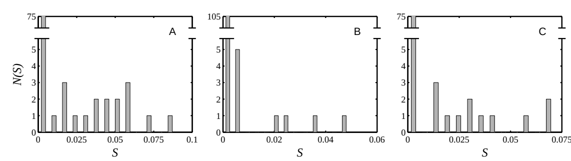
Caseload recorded monthly for range of diseases in Iceland, 1888-1990



- Treat outbreaks separated in time as 'novel' diseases.

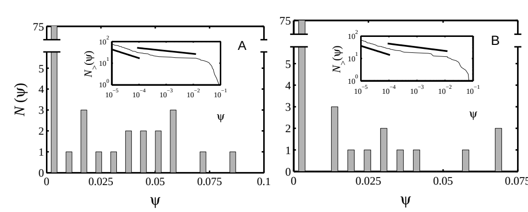
Really not so good at all in Iceland

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



Spike near $S = 0$, relatively flat otherwise.

Measles & Pertussis



Insert plots:
Complementary cumulative frequency distributions:

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

Limited scaling with a possible break.

Power law distributions

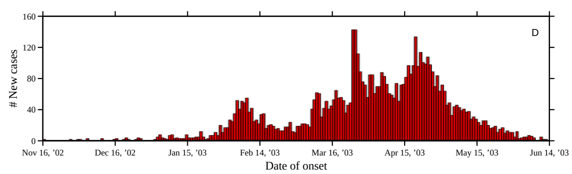
Measured values of γ:

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

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

Complex Sociotechnical Systems

Resurgence—example of SARS



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

Complex Sociotechnical Systems

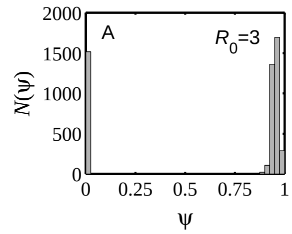
The challenge

So... can a simple model produce

1. broad epidemic distributions
   and
2. resurgence ?

Complex Sociotechnical Systems

Size distributions



Simple models typically produce bimodal or unimodal size distributions.

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

Complex Sociotechnical Systems

Burning through the population

Forest fire models:[30]

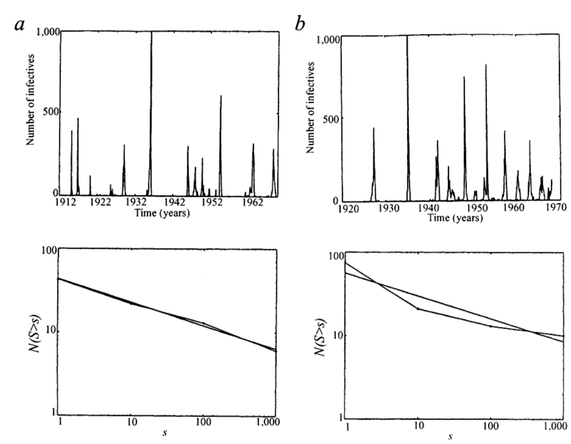
- Rhodes & Anderson, 1996
- The physicist's approach:
  "if it works for magnets, it'll work for people..."

A bit of a stretch:

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

Complex Sociotechnical Systems

Size distributions



From Rhodes and Anderson, 1996.

Sophisticated metapopulation models

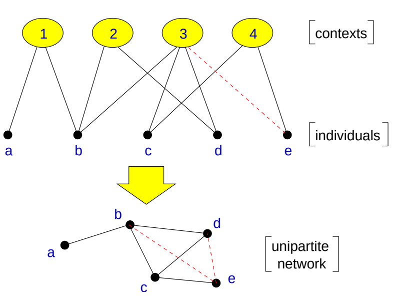
- Community based mixing: Longini (two scales).
- Eubank et al.'s EpiSims/TRANSIMS—city simulations.
- Spreading through countries—Airlines: Germann et al., Corlizza et al.
- Vital work but perhaps hard to generalize from...
- : Create a simple model involving multiscale travel
- Multiscale models suggested by others but not formalized (Bailey, Cliff and Haggett, Ferguson et al.)

Size distributions

- Very big question: What is N?
- Should we model SARS in Hong Kong as spreading in a neighborhood, in Hong Kong, Asia, or the world?
- For simple models, we need to know the final size beforehand...

Improving simple models

Contexts and Identities—Bipartite networks



- boards of directors
- movies
- transportation modes (subway)

Improving simple models

Idea for social networks: incorporate identity.

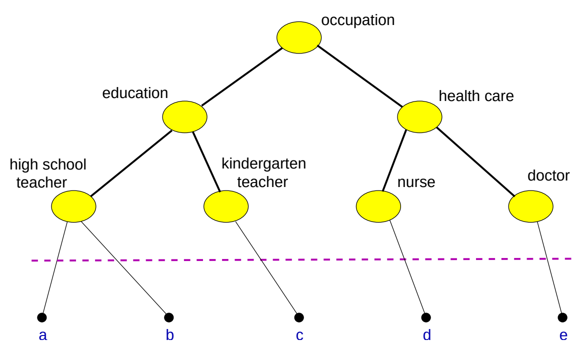
Identity is formed from attributes such as:

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

Groups are crucial...

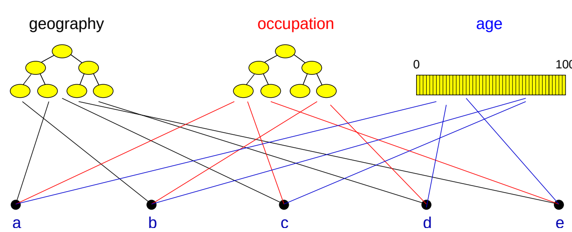
- formed by people with at least one similar attribute
- Attributes ⇔ Contexts ⇔ Interactions ⇔ Networks. [43]

Infer interactions/network from identities



Distance makes sense in identity/context space.

Generalized context space



(Blau & Schwartz [6], Simmel [37], Breiger [7])

A toy agent-based model

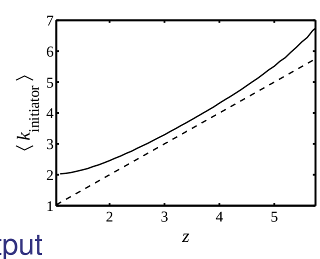
Geography—allow people to move between contexts:

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

A toy agent-based model

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Schematic:



Model output

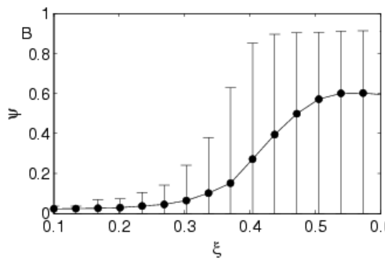
Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

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

Model output

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Varying ξ:

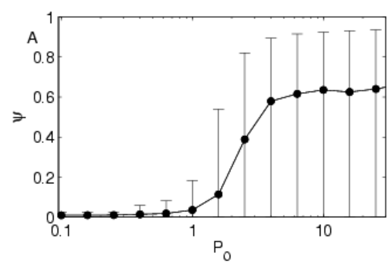


- Transition in expected final size based on typical movement distance (sensible)

Model output

Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

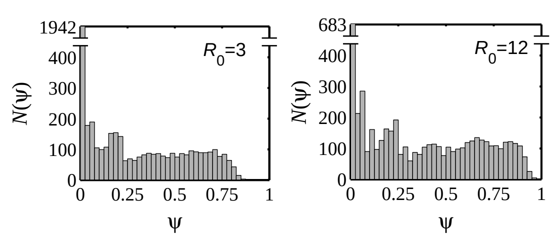
Varying P_0:



- Transition in expected final size based on typical number of infectives leaving first group (also sensible)
- Travel advisories: ξ has larger effect than P_0.

Example model output: size distributions

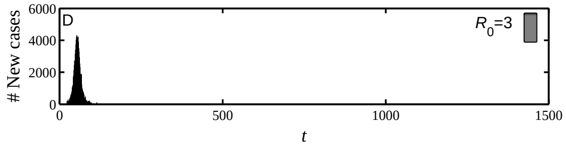
Complex Sociotechnical Systems
A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References



- 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

Model output—resurgence

Standard model:

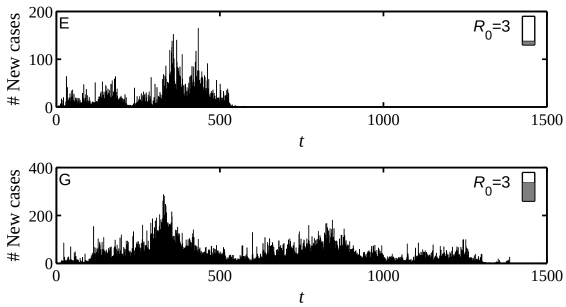


Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

Model output—resurgence

Standard model with transport:



The upshot

Simple multiscale population structure
+
stochasticity

leads to

resurgence
+
broad epidemic size distributions

Conclusions

- For this model, epidemic size is highly unpredictable
- Model is more complicated than SIR but still simple
- We haven't even included normal social responses such as travel bans and self-quarantine.
- The reproduction number R_0 is not terribly useful.
- R_0, however measured, is not informative about
  1. how likely the observed epidemic size was,
  2. and how likely future epidemics will be.
- Problem: R_0 summarises one epidemic after the fact and enfolds movement, the price of bananas, everything.

Conclusions

- Disease spread highly sensitive to population structure
- Rare events may matter enormously (e.g., an infected individual taking an international flight)
- More support for controlling population movement (e.g., travel advisories, quarantine)

Conclusions

What to do:

- Need to separate movement from disease
- R_0 needs a friend or two.
- Need $R_0 > 1$ and $P_0 > 1$ and ξ sufficiently large for disease to have a chance of spreading

More wondering:

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

Simple disease spreading models

Valiant attempts to use SIR and co. elsewhere:

- Adoption of ideas/beliefs (Goffman & Newell, 1964) [18]
- Spread of rumors (Daley & Kendall, 1965) [15]
- Diffusion of innovations (Bass, 1969) [2]
- Spread of fanatical behavior (Castillo-Chávez & Song, 2003)
- Spread of Feynmann diagrams (Bettencourt et al., 2006)

References I

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[1] M. Adler.
Stardom and talent.
American Economic Review, pages 208–212, 1985. pdf (⊞)

[2] F. Bass.
A new product growth model for consumer durables.
Manage. Sci., 15:215–227, 1969. pdf (⊞)

[3] A. Bentley, M. Earls, and M. J. O'Brien.
I'll Have What She's Having: Mapping Social Behavior.
MIT Press, Cambridge, MA, 2011.

[4] S. Bikhchandani, D. Hirshleifer, and I. Welch.
A theory of fads, fashion, custom, and cultural change as informational cascades.
J. Polit. Econ., 100:992–1026, 1992.

References II

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[5] S. Bikhchandani, D. Hirshleifer, and I. Welch.
Learning from the behavior of others: Conformity, fads, and informational cascades.
J. Econ. Perspect., 12(3):151–170, 1998. pdf (⊞)

[6] P. M. Blau and J. E. Schwartz.
Crosscutting Social Circles.
Academic Press, Orlando, FL, 1984.

[7] R. L. Breiger.
The duality of persons and groups.
Social Forces, 53(2):181–190, 1974. pdf (⊞)

References III

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[8] B. Caplan.
What makes people think like economists? evidence on economic cognition from the "survey of americans and economists on the economy".
Journal of Law and Economics, 44:395–426, 2001. pdf (⊞)

[9] J. M. Carlson and J. Doyle.
Highly optimized tolerance: A mechanism for power laws in designed systems.
Phys. Rev. E, 60(2):1412–1427, 1999. pdf (⊞)

[10] J. M. Carlson and J. Doyle.
Highly optimized tolerance: Robustness and design in complex systems.
Phys. Rev. Lett., 84(11):2529–2532, 2000. pdf (⊞)

References IV

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[11] I. D. Chase, C. Tovey, D. Spangler-Martin, and M. Manfredonia.
Individual differences versus social dynamics in the formation of animal dominance hierarchies.
Proc. Natl. Acad. Sci., 99(8):5744–5749, 2002. pdf (⊞)

[12] N. A. Christakis and J. H. Fowler.
The spread of obesity in a large social network over 32 years.
New England Journal of Medicine, 357:370–379, 2007. pdf (⊞)

[13] N. A. Christakis and J. H. Fowler.
The collective dynamics of smoking in a large social network.
New England Journal of Medicine, 358:2249–2258, 2008. pdf (⊞)

References V

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[14] R. B. Cialdini.
Influence: Science and Practice.
Allyn and Bacon, Boston, MA, 4th edition, 2000.

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

[16] M. Gladwell.
The Tipping Point.
Little, Brown and Company, New York, 2000.

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

References VI

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

[19] M. Granovetter.
Threshold models of collective behavior.
Am. J. Sociol., 83(6):1420–1443, 1978. pdf (⊞)

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

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

References VII

[22] E. Katz and P. F. Lazarsfeld.
Personal Influence.
The Free Press, New York, 1955.

[23] W. O. Kermack and A. G. McKendrick.
A contribution to the mathematical theory of epidemics.
Proc. R. Soc. Lond. A, 115:700–721, 1927. pdf (⊞)

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

References VIII

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

[26] T. Kuran.
Now out of never: The element of surprise in the east european revolution of 1989.
World Politics, 44:7–48, 1991. pdf (⊞)

[27] T. Kuran.
Private Truths, Public Lies: The Social Consequences of Preference Falsification.
Harvard University Press, Cambridge, MA, Reprint edition, 1997.

References IX

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

[29] M. I. Norton and D. Ariely.
Building a better America—One wealth quintile at a time.
Perspectives on Psychological Science, 6:9–12, 2011. pdf (⊞)

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

References X

[31] D. M. Romero, B. Meeder, and J. Kleinberg.
Differences in the mechanics of information diffusion across topics: Idioms, political hashtags, and complex contagion on Twitter.
In Proceedings of World Wide Web Conference, 2011. pdf (⊞)

[32] S. Rosen.
The economics of superstars.
Am. Econ. Rev., 71:845–858, 1981. pdf (⊞)

[33] M. J. Salganik, P. S. Dodds, and D. J. Watts.
An experimental study of inequality and unpredictability in an artificial cultural market.
Science, 311:854–856, 2006. pdf (⊞)

References XI

[34] T. C. Schelling.
Dynamic models of segregation.
J. Math. Sociol., 1:143–186, 1971. pdf (⊞)

[35] T. C. Schelling.
Hockey helmets, concealed weapons, and daylight saving: A study of binary choices with externalities.
J. Conflict Resolut., 17:381–428, 1973. pdf (⊞)

[36] T. C. Schelling.
Micromotives and Macrobehavior.
Norton, New York, 1978.

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

References XII

[38] D. Sornette.
Critical Phenomena in Natural Sciences.
Springer-Verlag, Berlin, 2nd edition, 2003.

[39] J. Ugander, L. Backstrom, C. Marlow, and J. Kleinberg.
Structural diversity in social contagion.
Proc. Natl. Acad. Sci., 109:5962–5966, 2012. pdf (⊞)

[40] D. J. Watts.
A simple model of global cascades on random networks.
Proc. Natl. Acad. Sci., 99(9):5766–5771, 2002. pdf (⊞)

References XIII

Complex Sociotechnical Systems

A Very Dismal Science
Contagion
Winning: it's not for everyone
Social Contagion Models
Granovetter's model
Network version
Groups
Simple disease spreading models
References

[41] D. J. Watts and P. S. Dodds.
Influentials, networks, and public opinion formation.
Journal of Consumer Research, 34:441–458, 2007. pdf (⊞)

[42] D. J. Watts and P. S. Dodds.
Threshold models of social influence.
In P. Hedström and P. Bearman, editors, The Oxford Handbook of Analytical Sociology, chapter 20, pages 475–497. Oxford University Press, Oxford, UK, 2009. pdf (⊞)

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