

# Social Contagion

Principles of Complex Systems | @pocsvox  
 CSYS/MATH 300, Fall, 2017

Prof. Peter Dodds | @peterdodds

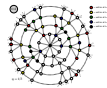
Dept. of Mathematics & Statistics | Vermont Complex Systems Center  
 Vermont Advanced Computing Core | University of Vermont



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Social Contagion Models  
 Background  
 Granovetter's model  
 Network version  
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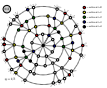
## Outline

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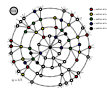
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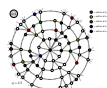
Special Guest Executive Producer: Pratchett



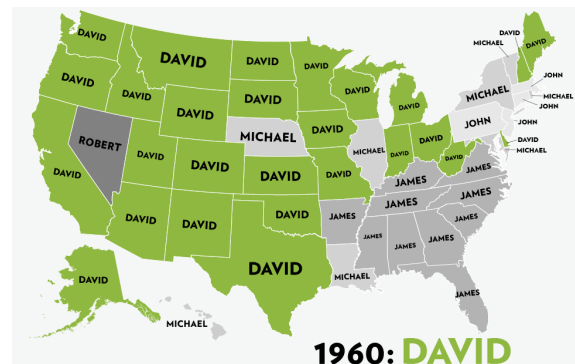
On Instagram at [pratchett\\_the\\_cat](https://www.instagram.com/pratchett_the_cat)

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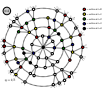
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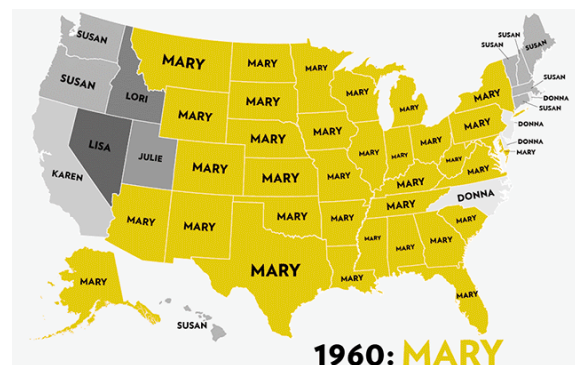
From the Atlantic

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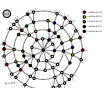
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## Things that spread well:

[buzzfeed.com](http://buzzfeed.com)



Dangerously self aware: 11 Elements that make a perfect viral video.

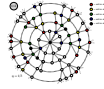
+ News ...

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## Some things really stick:

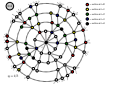


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## LOL + cute + fail + wtf:

# Oopsie!



**BUZZFEED FELL DOWN AND WENT BOOM.**

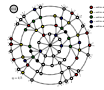
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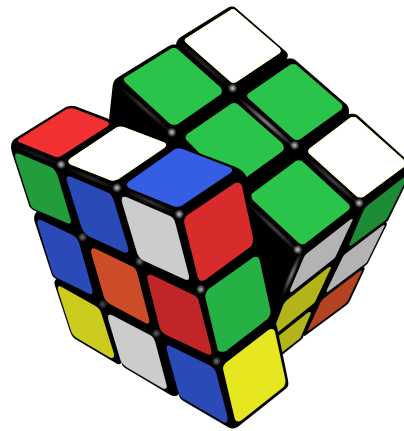
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## wtf + geeky + omg:

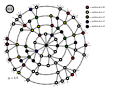


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## The whole lolcats thing:

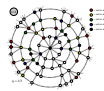


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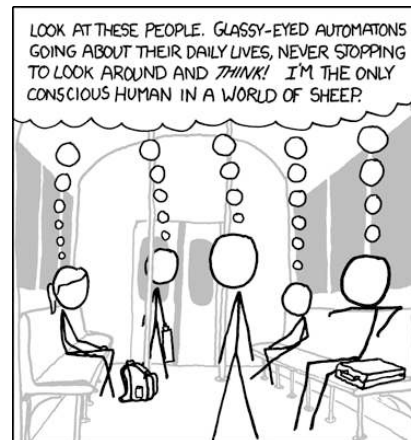
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## Why social contagion works so well:



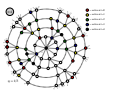
<http://xkcd.com/610/>

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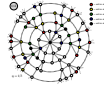
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# Social Contagion



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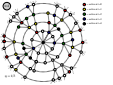
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# Social Contagion

## Examples abound

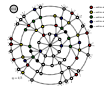
- fashion
- striking
- smoking <sup>[7]</sup>
- residential segregation <sup>[22]</sup>
- iPhones and iThings
- obesity <sup>[6]</sup>
- Harry Potter
- voting
- gossip
- Rubik's cube
- religious beliefs
- school shootings
- leaving lectures

## SIR and SIRS type contagion possible

- Classes of behavior versus specific behavior : **dieting, horror movies, getting married, invading countries, ...**

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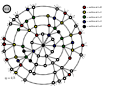
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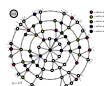
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## Mixed messages: Please copy, but also, don't copy ...

- Cindy Harrell appeared in the (terrifying) music video for Ray Parker Jr.'s Ghostbusters.
- In Stranger Things 2, Steve Harrington reveals his Fabergé secret.

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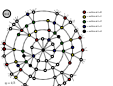
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## Market much?

- Advertisement enjoyed during "Herstory of Dance", Community S4E08, April 2013.

# Framingham heart study:

## Evolving network stories (Christakis and Fowler):

- The spread of quitting smoking <sup>[7]</sup>
- The spread of spreading <sup>[6]</sup>
- Also: happiness <sup>[11]</sup>, loneliness, ...
- The book: Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives

## Controversy:

- Are your friends making you fat? (Clive Thomson, NY Times, September 10, 2009).
- Everything is contagious—Doubts about the social plague stir in the human superorganism (Dave Johns, Slate, April 8, 2010).

# Social Contagion

## Two focuses for us

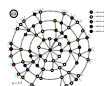
- Widespread media influence
- Word-of-mouth influence

## We need to understand influence

- Who influences whom? Very hard to measure...
- What kinds of influence response functions are there?
- Are some individuals super influencers? Highly popularized by Gladwell <sup>[12]</sup> as 'connectors'
- The infectious idea of opinion leaders (Katz and Lazarsfeld) <sup>[19]</sup>

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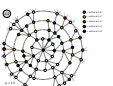
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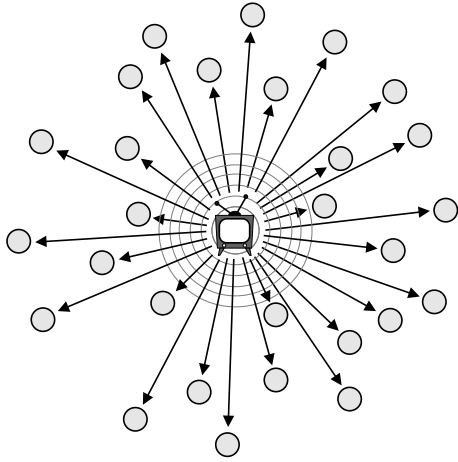
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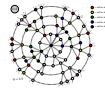
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## The hypodermic model of influence



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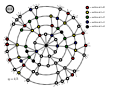
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## Why do things spread socially?

- Because of properties of special individuals?
- Or system level properties?
- Is the match that lights the fire important?
- Yes. But only because we are storytellers: *homo narrativus*.
- We like to think things happened for reasons ...
- Reasons for success are usually ascribed to intrinsic properties (examples next).
- Teleological stories of fame are often easy to generate and believe.
- System/group dynamics harder to understand because most of our stories are built around individuals.
- Always good to examine what is said before and after the fact ...

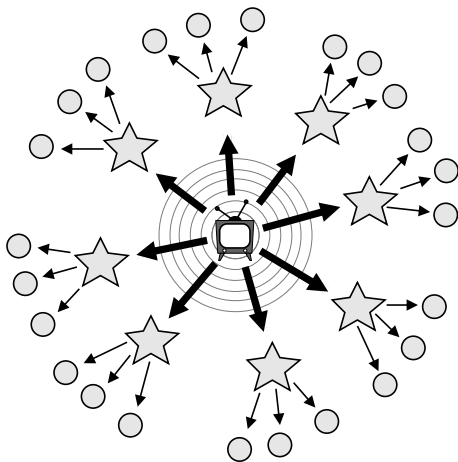
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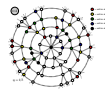
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## The two step model of influence [19]



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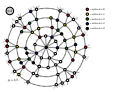
## The Mona Lisa



- "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, ...

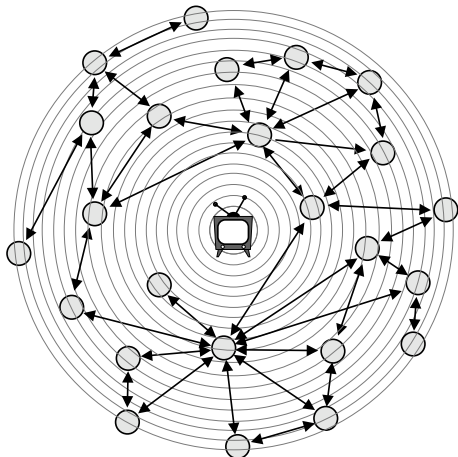
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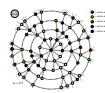
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## The general model of influence: the Social Wild



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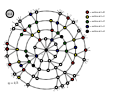
## Tattooed Guy Was Pivotal in Armstrong Case [nytimes]



- "... Leogrande's doping sparked a series of events ..."

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## The completely unpredicted fall of Eastern Europe:



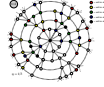
Timunr Kuran: [20, 21] "Now Out of Never: The Element of Surprise in the East European Revolution of 1989"

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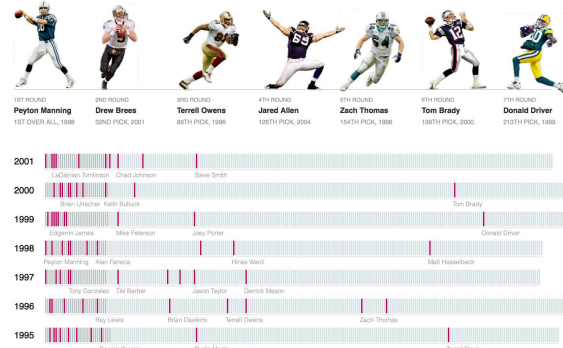
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## Drafting success in the NFL: [↗](#)

### Top Players by Round, 1995-2012



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## The dismal predictive powers of editors...

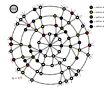


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### Messing with social connections

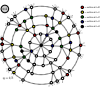
- 📦 Ads based on message content (e.g., Google and email)
- 📦 BzzAgent [↗](#)
  - 📦 Harnessing of BzzAgents to directly market through social ties.
  - 📦 Generally, BzzAgents did not reveal their BzzAgent status and did not want to be paid.
  - 📦 NYT, 2004-12-05: "The Hidden (in Plain Sight) Persuaders" [↗](#)
- 📦 One of Facebook's early advertising attempts: Beacon [↗](#)
- 📦 All of Facebook's advertising attempts.
- 📦 Seriously, Facebook. What could go wrong?

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## From a 2013 Believer Magazine [↗](#) interview with Maurice Sendak [↗](#):

BLVR: Did the success of Where the Wild Things Are ever feel like an albatross?

MS: It's a nice book. It's perfectly nice. I can't complain about it. I remember Herman Melville said, "When I die no one is going to mention Moby-Dick. They're all going to talk about my first book, about \*\*\*\*ing maidens in Tahiti." He was right. No mention of Moby-Dick then. Everyone wanted another Tahitian book, a beach book. But then he kept writing deeper and deeper and then came Moby-Dick and people hated it. The only ones who liked it were Mr. and Mrs. Nathaniel Hawthorne. Moby-Dick didn't get famous until 1930.

📦 Sendak named his dog Herman.

📦 The essential Colbert interview: Pt. 1 [↗](#) and Pt. 2 [↗](#).

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## Getting others to do things for you

A very good book: 'Influence' <sup>[8]</sup> by Robert Cialdini [↗](#)

### Six modes of influence:

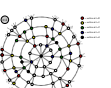
1. **Reciprocation:** *The Old Give and Take... and Take;* e.g., Free samples, Hare Krishnas.
2. **Commitment and Consistency:** *Hobgoblins of the Mind;* e.g., Hazing.
3. **Social Proof:** *Truths Are Us;* e.g., Jonestown [↗](#), Kitty Genovese [↗](#) (contested).
4. **Liking:** *The Friendly Thief;* 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.

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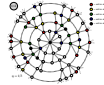
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- Cialdini's modes are heuristics that help up us get through life.
- Useful but can be leveraged...

### Other acts of influence:

- Conspicuous Consumption (Veblen, 1912)
- Conspicuous Destruction (Potlatch)



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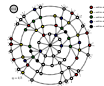
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### Some important models:

- Tipping models—Schelling (1971) [22, 23, 24]
  - Simulation on checker boards
  - Idea of thresholds
  - Polygon-themed online visualization. (Includes optional diversity-seeking proclivity.)
  - Explore the Netlogo online implementation
- Threshold models—Granovetter (1978) [15]
- Herding models—Bikhchandani, Hirschleifer, Welch (1992) [2, 3]
  - Social learning theory, Informational cascades,...



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## Social contagion models

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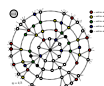
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### Thresholds

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



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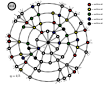
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### Some possible origins of thresholds:

- Inherent, evolution-devised inclination to coordinate, to conform, to imitate. [1]
- 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



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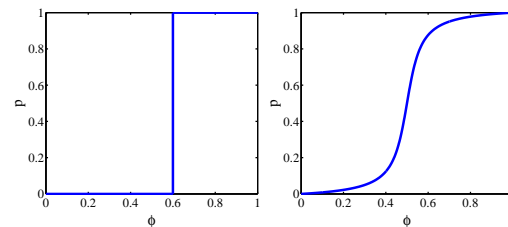
## Threshold models—response functions

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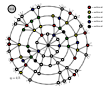
### Social Contagion Models

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- Example threshold influence response functions: **deterministic** and **stochastic**
- $\phi$  = fraction of contacts 'on' (e.g., rioting)
- Two states: S and I.



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## Threshold models

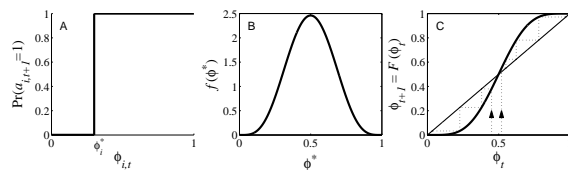
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### Social Contagion Models

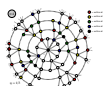
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### Action based on perceived behavior of others:



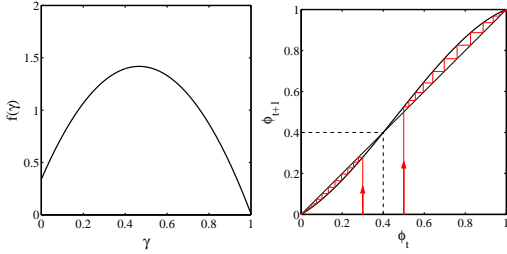
- Two states: S and I.
- $\phi$  = fraction of contacts 'on' (e.g., rioting)
- Discrete time update (strong assumption!)
- This is a **Critical mass model**



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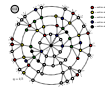
# Threshold models

Another example of critical mass model:



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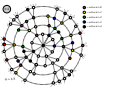
# Threshold models—Nutshell

Implications for collective action theory:

1. Collective uniformity  $\nRightarrow$  individual uniformity
2. Small individual changes  $\Rightarrow$  large global changes
3. The stories/dynamics of complex systems are conceptually inaccessible for individual-centric narratives.
4. System stories live in left null space of our stories—we can't even see them.
5. But we happily impose simplistic, individual-centric stories—we can't help ourselves.

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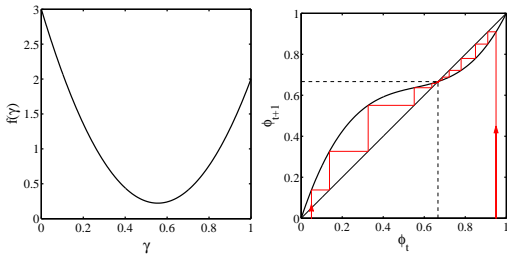
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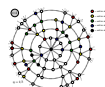
# Threshold models

Example of single stable state model:



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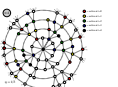
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Many years after Granovetter and Soong's work:

- "A simple model of global cascades on random networks"  
D. J. Watts. Proc. Natl. Acad. Sci., 2002 [26]
- Mean field model  $\rightarrow$  network model
- Individuals now have a limited view of the world

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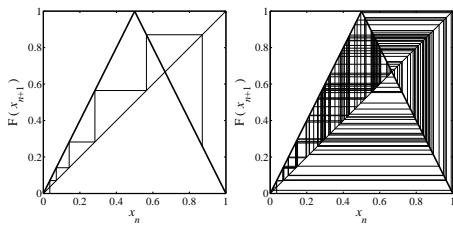
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We'll also explore:

- "Seed size strongly affects cascades on random networks"<sup>[14]</sup>  
Gleeson and Cahalane, Phys. Rev. E, 2007.
- "Direct, physically motivated derivation of the contagion condition for spreading processes on generalized random networks"<sup>[10]</sup> Dodds, Harris, and Payne, Phys. Rev. E, 2011
- "Influentials, Networks, and Public Opinion Formation"<sup>[27]</sup>  
Watts and Dodds, J. Cons. Res., 2007.
- "Threshold models of Social Influence"<sup>[28]</sup>  
Watts and Dodds, The Oxford Handbook of Analytical Sociology, 2009.

# Threshold models

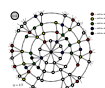
Chaotic behavior possible [17, 16, 9, 18]



- Period doubling arises as map amplitude  $r$  is increased.
- Synchronous update assumption is crucial

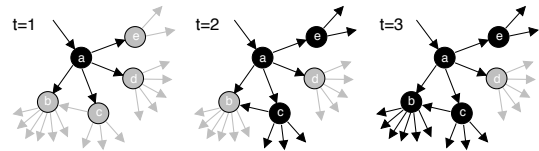
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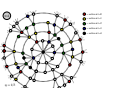
# Threshold model on a network



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

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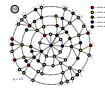
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## Threshold model on a network

- 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  $\phi_i$ .
- 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).

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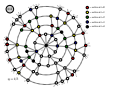
## Snowballing

### 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 neighbors becomes active.

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## Snowballing

### First study random networks:

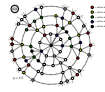
- Start with  $N$  nodes with a degree distribution  $P_k$
- Nodes are randomly connected (carefully so)
- Aim: Figure out when activation will propagate
- Determine a **cascade condition**

### 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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## The most gullible

### Vulnerables:

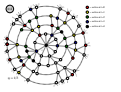
- We call individuals who can be activated by just one contact being active **vulnerables**
- The vulnerability condition for node  $i$ :

$$1/k_i \geq \phi_i$$

- Which means # contacts  $k_i \leq \lfloor 1/\phi_i \rfloor$
- For global cascades on random networks, must have a **global cluster of vulnerables** [26]
- Cluster of vulnerables = critical mass**
- Network story: 1 node  $\rightarrow$  critical mass  $\rightarrow$  everyone.

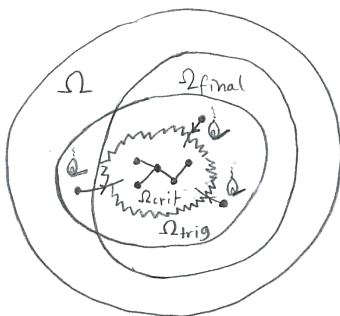
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## Example random network structure:

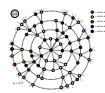


- $\Omega_{crit} = \Omega_{vuln} =$  critical mass = global vulnerable component
- $\Omega_{trig} =$  triggering component
- $\Omega_{final} =$  potential extent of spread
- $\Omega =$  entire network

$$\Omega_{crit} \subset \Omega_{trig}; \Omega_{crit} \subset \Omega_{final}; \text{ and } \Omega_{trig}, \Omega_{final} \subset \Omega.$$

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## 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:

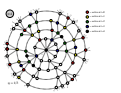
$$\sum_{k=0}^{\infty} kP_k = \langle k \rangle$$

- So

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

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# Cascade condition

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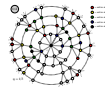
## Next: Vulnerability of linked node

Linked node is **vulnerable** with probability

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

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

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# Cascade condition

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## Two special cases:

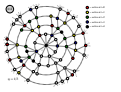
(1) Simple disease-like spreading succeeds:  $\beta_k = \beta$

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

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

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

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# Cascade condition

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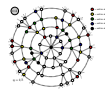
## Putting things together:

Expected number of active edges produced by an active edge:

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

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

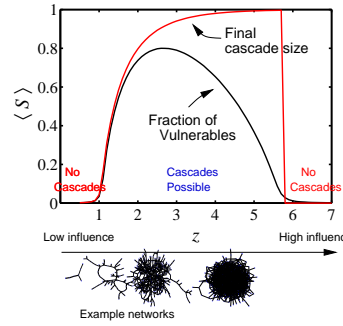
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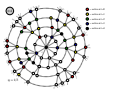
# Cascades on random networks

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

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# Cascade condition

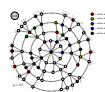
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So... for random networks with fixed degree distributions, cascades take off when:

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

- $\beta_k$  = probability a degree  $k$  node is vulnerable.
- $P_k$  = probability a node has degree  $k$ .

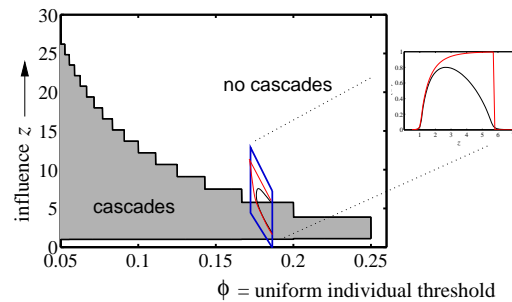
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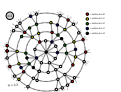
# Cascade window for random networks

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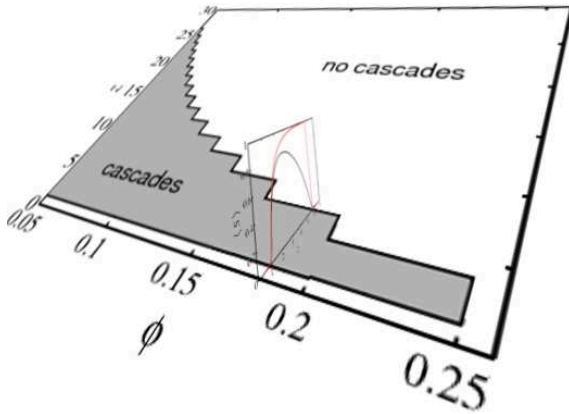
- 'Cascade window' widens as threshold  $\phi$  decreases.
- Lower thresholds enable spreading.

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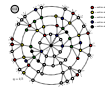
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## Cascade window for random networks



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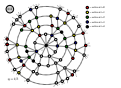
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## Threshold contagion on random networks

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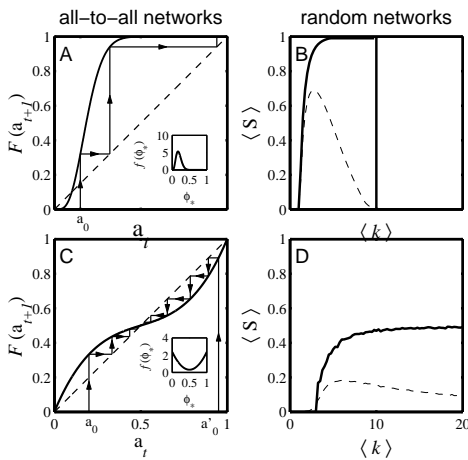
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- Next: Find expected fractional size of spread.
- Not obvious even for uniform threshold problem.
- Difficulty is in figuring out if and when nodes that need  $\geq 2$  hits switch on.
- Problem beautifully solved for infinite seed case by Gleeson and Cahalane: "Seed size strongly affects cascades on random networks," Phys. Rev. E, 2007. [14]
- Developed further by Gleeson in "Cascades on correlated and modular random networks," Phys. Rev. E, 2008. [13]



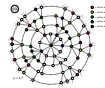
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## All-to-all versus random networks



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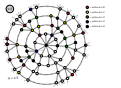
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## Determining expected size of spread:

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- Randomly turn on a fraction  $\phi_0$  of nodes at time  $t = 0$
- Capitalize on local branching network structure of random networks (again)
- Now think about what must happen for a specific node  $i$  to become active at time  $t$ :
  - $t = 0$ :  $i$  is one of the seeds (prob =  $\phi_0$ )
  - $t = 1$ :  $i$  was not a seed but enough of  $i$ 's friends switched on at time  $t = 0$  so that  $i$ 's threshold is now exceeded.
  - $t = 2$ : enough of  $i$ 's friends and friends-of-friends switched on at time  $t = 0$  so that  $i$ 's threshold is now exceeded.
  - $t = n$ : enough nodes within  $n$  hops of  $i$  switched on at  $t = 0$  and their effects have propagated to reach  $i$ .



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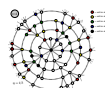
## Cascade window—summary

For our simple model of a uniform threshold:

1. Low  $\langle k \rangle$ : No cascades in poorly connected networks. No global clusters of any kind.
2. High  $\langle k \rangle$ : Giant component exists but not enough vulnerables.
3. Intermediate  $\langle k \rangle$ : Global cluster of vulnerables exists. Cascades are possible in "Cascade window."

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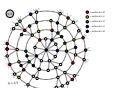
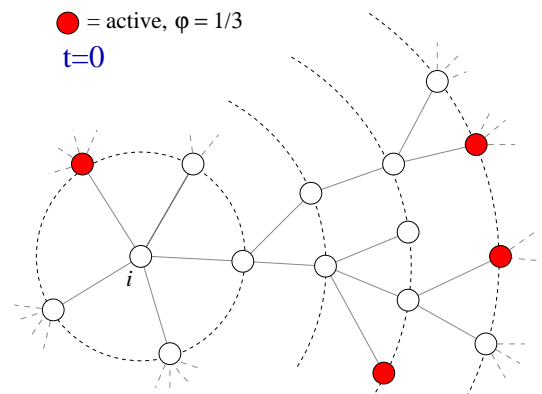


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## Expected size of spread

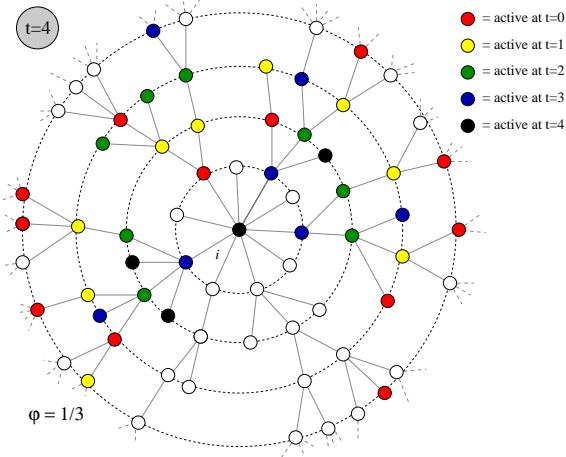
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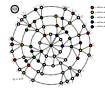
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## Expected size of spread



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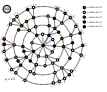
## Expected size of spread

- Notation:**  $\phi_{k,t} = \Pr$ (a degree  $k$  node is active at time  $t$ ).
- Notation:**  $B_{kj} = \Pr$ (a degree  $k$  node becomes active if  $j$  neighbors are active).
- Our starting point:  $\phi_{k,0} = \phi_0$ .
- $\binom{k}{j} \phi_0^j (1 - \phi_0)^{k-j} = \Pr$ ( $j$  of a degree  $k$  node's neighbors were seeded at time  $t = 0$ ).
- Probability a degree  $k$  node was a seed at  $t = 0$  is  $\phi_0$  (as above).
- Probability a degree  $k$  node was not a seed at  $t = 0$  is  $(1 - \phi_0)$ .
- Combining everything, we have:

$$\phi_{k,1} = \phi_0 + (1 - \phi_0) \sum_{j=0}^k \binom{k}{j} \phi_0^j (1 - \phi_0)^{k-j} B_{kj}$$

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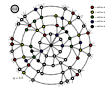
## Expected size of spread

### Notes:

- Calculations are possible if nodes do not become inactive (strong restriction).
- Not just for threshold model—works for a wide range of contagion processes.
- We can analytically determine the entire time evolution, not just the final size.
- We can in fact determine  $\Pr$ (node of degree  $k$  switching on at time  $t$ ).
- Asynchronous updating can be handled too.

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- For general  $t$ , we need to know the probability an edge coming into a degree  $k$  node at time  $t$  is active.
- Notation:** call this probability  $\theta_t$ .
- We already know  $\theta_0 = \phi_0$ .
- Story analogous to  $t = 1$  case. For node  $i$ :

$$\phi_{i,t+1} = \phi_0 + (1 - \phi_0) \sum_{j=0}^{k_i} \binom{k_i}{j} \theta_t^j (1 - \theta_t)^{k_i-j} B_{k_i j}$$

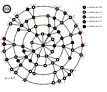
- Average over all nodes to obtain expression for  $\phi_{t+1}$ :

$$\phi_{t+1} = \phi_0 + (1 - \phi_0) \sum_{k=1}^{\infty} P_k \sum_{j=0}^k \binom{k}{j} \theta_t^j (1 - \theta_t)^{k-j} B_{kj}$$

- So we need to compute  $\theta_t$ ... massive excitement...

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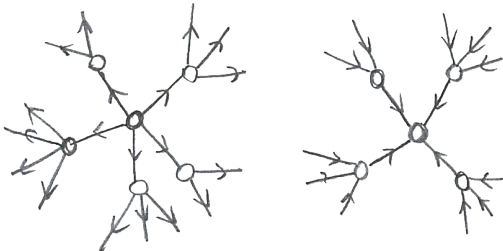


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## Expected size of spread

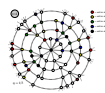
### Pleasantness:

- Taking off from a single seed story is about **expansion** away from a node.
- Extent of spreading story is about **contraction** at a node.



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## Expected size of spread

### First connect $\theta_0$ to $\theta_1$ :

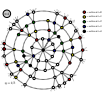
$$\theta_1 = \phi_0 +$$

$$(1 - \phi_0) \sum_{k=1}^{\infty} \frac{k P_k}{\langle k \rangle} \sum_{j=0}^{k-1} \binom{k-1}{j} \theta_0^j (1 - \theta_0)^{k-1-j} B_{kj}$$

- $\frac{k P_k}{\langle k \rangle} = R_k = \Pr$ (edge connects to a degree  $k$  node).
- $\sum_{j=0}^{k-1}$  piece gives  $\Pr$ (degree node  $k$  activates) of its neighbors  $k - 1$  incoming neighbors are active.
- $\phi_0$  and  $(1 - \phi_0)$  terms account for state of node at time  $t = 0$ .
- See this all generalizes to give  $\theta_{t+1}$  in terms of  $\theta_t$ ...

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## Expected size of spread

Two pieces: edges first, and then nodes

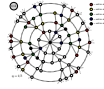
$$1. \theta_{t+1} = \underbrace{\phi_0}_{\text{exogenous}} + (1 - \phi_0) \underbrace{\sum_{k=1}^{\infty} \frac{k P_k}{\langle k \rangle} \sum_{j=0}^{k-1} \binom{k-1}{j} \theta_t^j (1 - \theta_t)^{k-1-j} B_{kj}}_{\text{social effects}}$$

with  $\theta_0 = \phi_0$ .

$$2. \phi_{t+1} = \underbrace{\phi_0}_{\text{exogenous}} + (1 - \phi_0) \underbrace{\sum_{k=0}^{\infty} P_k \sum_{j=0}^k \binom{k}{j} \theta_t^j (1 - \theta_t)^{k-j} B_{kj}}_{\text{social effects}}$$

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## Expected size of spread:

In words:

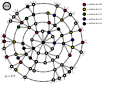
- If  $G(0; \phi_0) > 0$ , spreading must occur because some nodes turn on for free.
- If  $G$  has an **unstable fixed point** at  $\theta = 0$ , then cascades are also always possible.

Non-vanishing seed case:

- Cascade condition is more complicated for  $\phi_0 > 0$ .
- If  $G$  has a **stable fixed point** at  $\theta = 0$ , and an **unstable fixed point** for some  $0 < \theta_* < 1$ , then for  $\theta_0 > \theta_*$ , spreading takes off.
- Tricky point:  $G$  depends on  $\phi_0$ , so as we change  $\phi_0$ , we also change  $G$ .
- A version of a critical mass model again.

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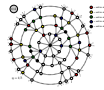
## Expected size of spread

Iterative map for  $\theta_t$  is key:

$$\theta_{t+1} = \underbrace{\phi_0}_{\text{exogenous}} + (1 - \phi_0) \underbrace{\sum_{k=1}^{\infty} \frac{k P_k}{\langle k \rangle} \sum_{j=0}^{k-1} \binom{k-1}{j} \theta_t^j (1 - \theta_t)^{k-1-j} B_{kj}}_{\text{social effects}} = G(\theta_t; \phi_0)$$

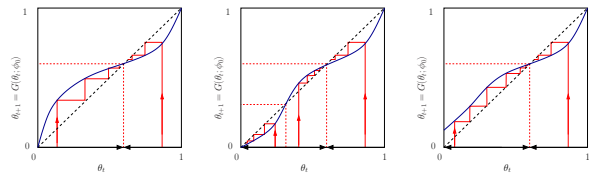
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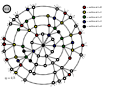
## General fixed point story:



- Given  $\theta_0 (= \phi_0)$ ,  $\theta_\infty$  will be the nearest stable fixed point, either above or below.
- n.b., adjacent fixed points must have opposite stability types.
- Important:** Actual form of  $G$  depends on  $\phi_0$ .
- So choice of  $\phi_0$  dictates both  $G$  and starting point—can't start anywhere for a given  $G$ .

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## Expected size of spread:

- Retrieve cascade condition for spreading from a single seed in limit  $\phi_0 \rightarrow 0$ .
- Depends on map  $\theta_{t+1} = G(\theta_t; \phi_0)$ .
- First: if self-starters are present, some activation is assured:

$$G(0; \phi_0) = \sum_{k=1}^{\infty} \frac{k P_k}{\langle k \rangle} \bullet B_{k0} > 0.$$

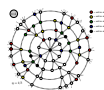
meaning  $B_{k0} > 0$  for at least one value of  $k \geq 1$ .

- If  $\theta = 0$  is a fixed point of  $G$  (i.e.,  $G(0; \phi_0) = 0$ ) then spreading occurs if

$$G'(0; \phi_0) = \sum_{k=0}^{\infty} \frac{k P_k}{\langle k \rangle} \bullet (k - 1) \bullet B_{k1} > 1.$$

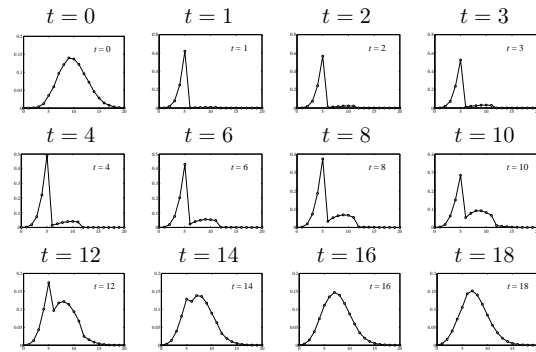
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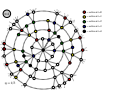
## Early adopters—degree distributions



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

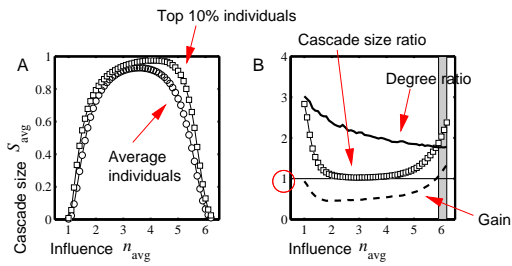
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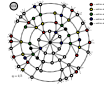
## The multiplier effect:



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

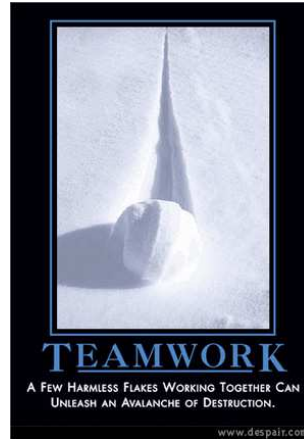
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## The power of groups...

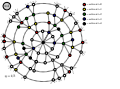


despair.com

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

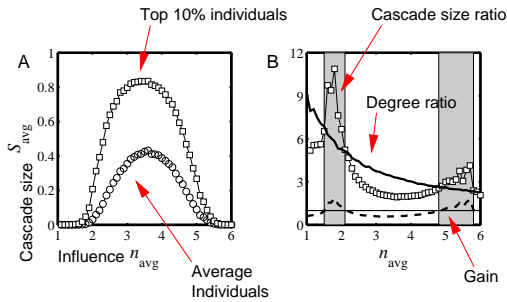
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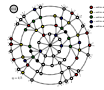
## The multiplier effect:



- Skewed influence distribution example.

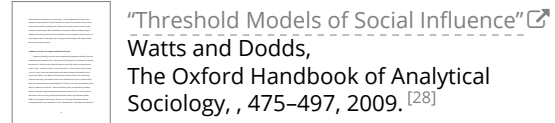
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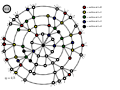
## Extensions



- 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**

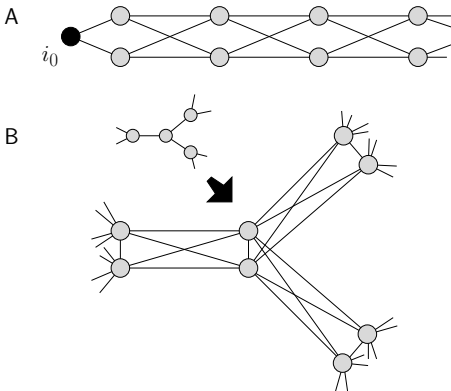
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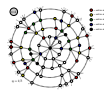
## Special subnetworks can act as triggers



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

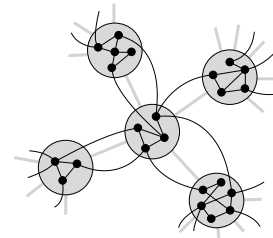
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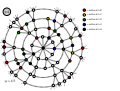
## Group structure—Ramified random networks



$p$  = intergroup connection probability  
 $q$  = intragroup connection probability.

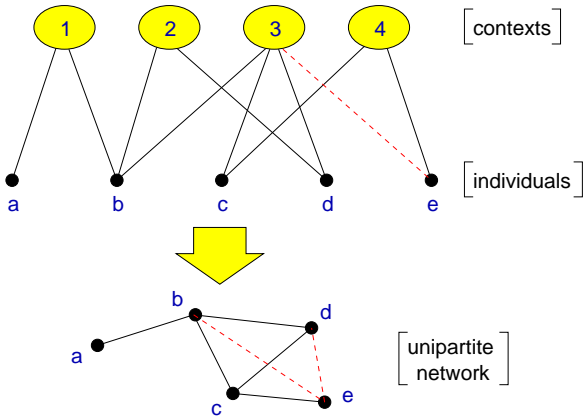
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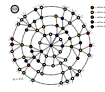
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## Bipartite networks



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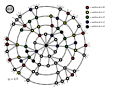
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## Generalized affiliation model networks with triadic closure

- Connect nodes with probability  $\propto \exp^{-\alpha d}$  where
  - $\alpha$  = homophily parameter
  - and  $d$  = distance between nodes (height of lowest common ancestor)
- $\tau_1$  = intergroup probability of friend-of-friend connection
- $\tau_2$  = intragroup probability of friend-of-friend connection

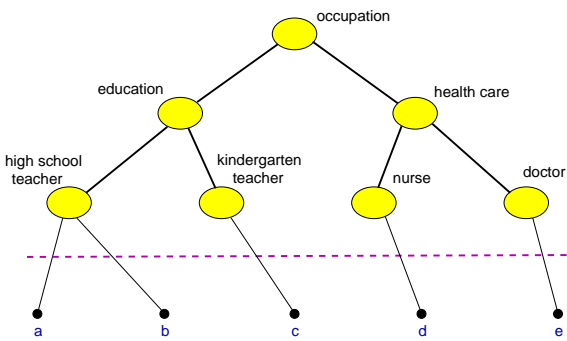
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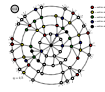
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## Context distance



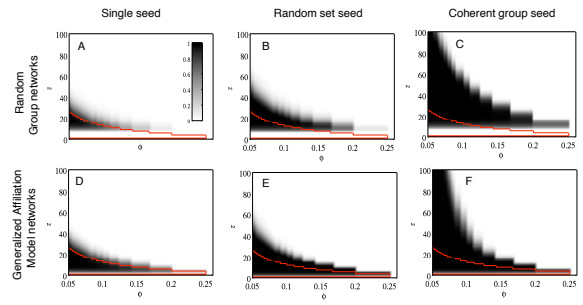
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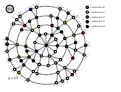
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## Cascade windows for group-based networks



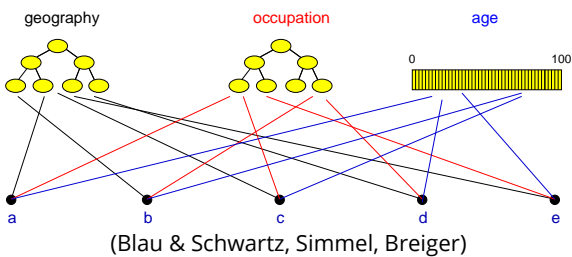
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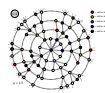
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## Generalized affiliation model



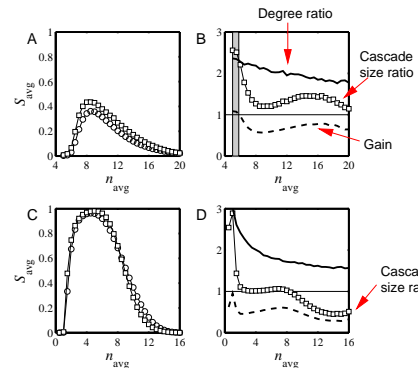
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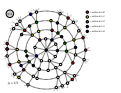
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## Multiplier effect for group-based networks:



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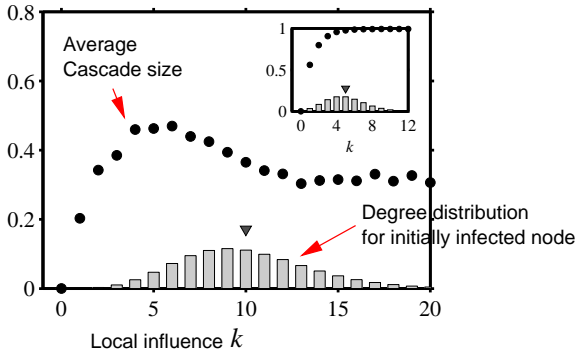
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- Multiplier almost always below 1.

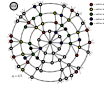
## Assortativity in group-based networks



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

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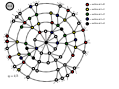
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- [3] S. Bikhchandani, D. Hirshleifer, and I. Welch. Learning from the behavior of others: Conformity, fads, and informational cascades. J. Econ. Perspect., 12(3):151–170, 1998. [pdf](#)

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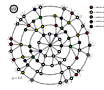
## Social contagion

### Summary

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

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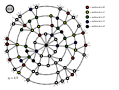
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- [6] N. A. Christakis and J. H. Fowler. The spread of obesity in a large social network over 32 years. New England Journal of Medicine, 357:370–379, 2007. [pdf](#)

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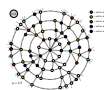
## Social contagion

### 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.

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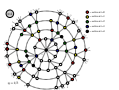
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- [8] R. B. Cialdini. Influence: Science and Practice. Allyn and Bacon, Boston, MA, 4th edition, 2000.
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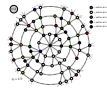
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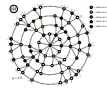
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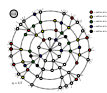
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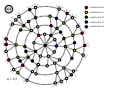
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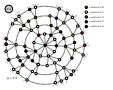
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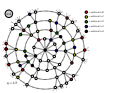
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