Social Contagion

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

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















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Social Contagion Models Background Spreading success





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These slides are also brought to you by:

Special Guest Executive Producer: Pratchett



On Instagram at pratchett_the_cat

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200 3 of 110

Outline

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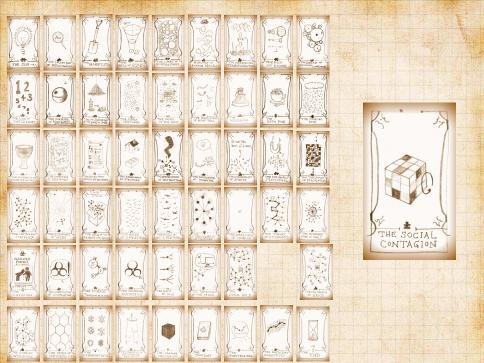
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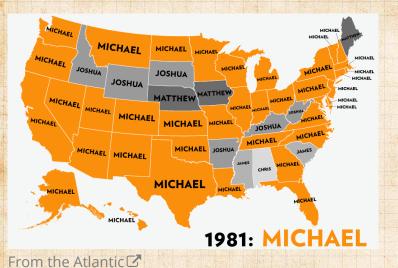


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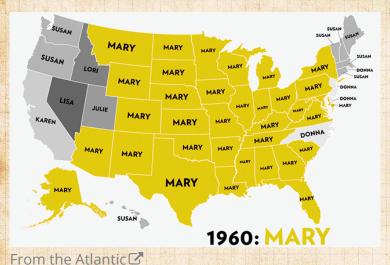


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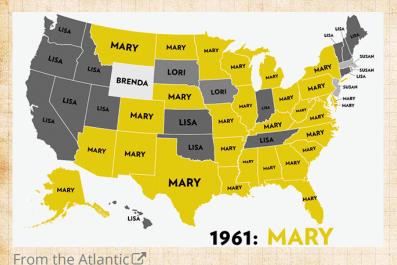


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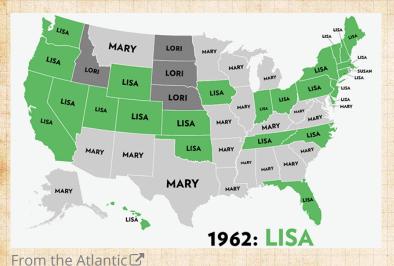
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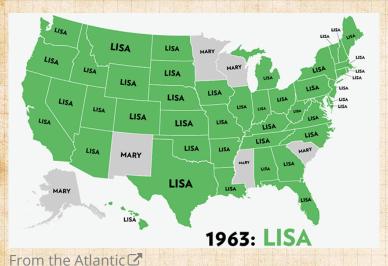


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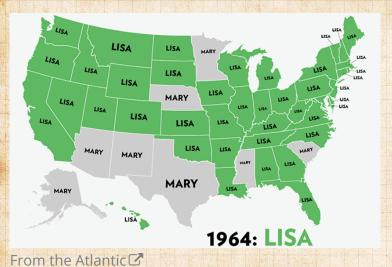


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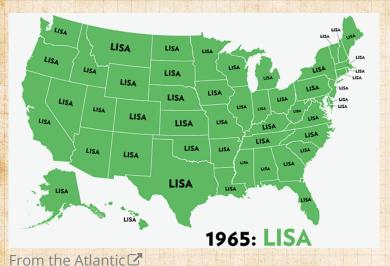


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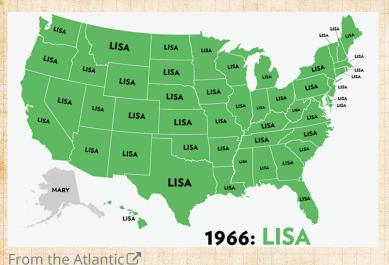


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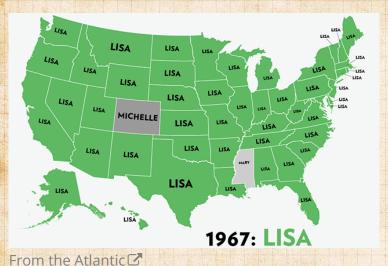
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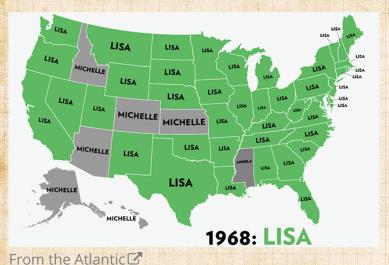


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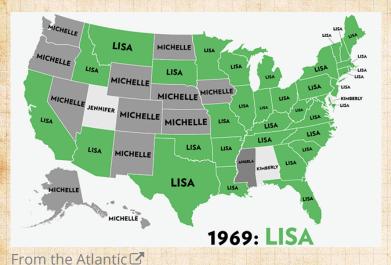
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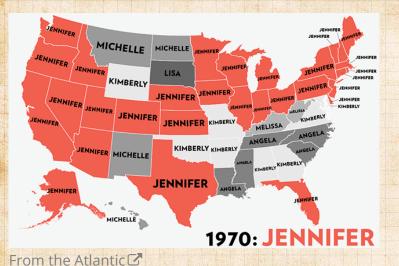




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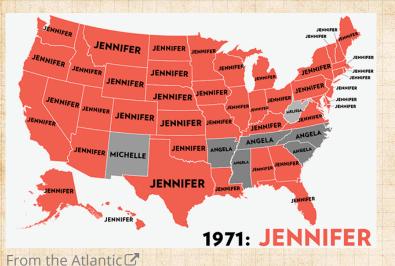




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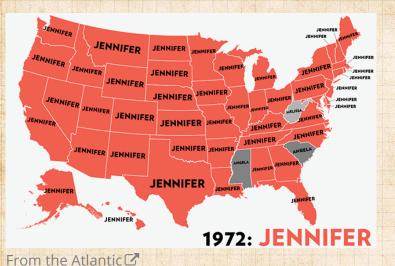


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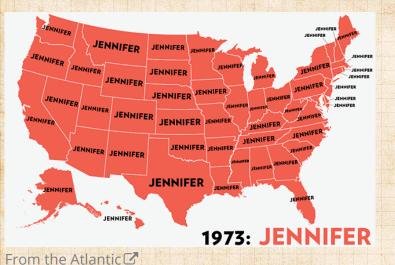


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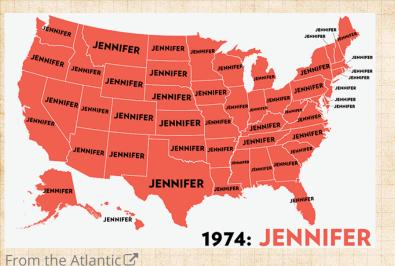


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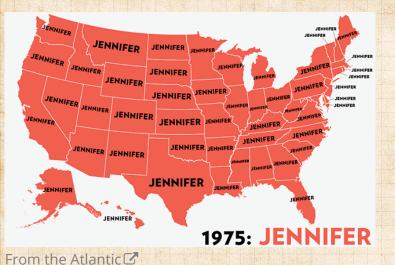
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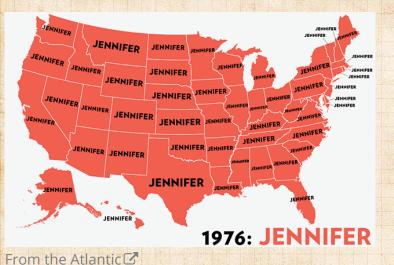


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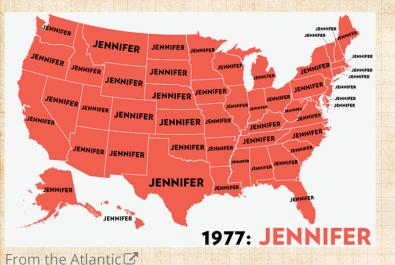


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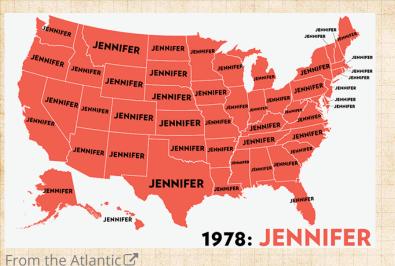


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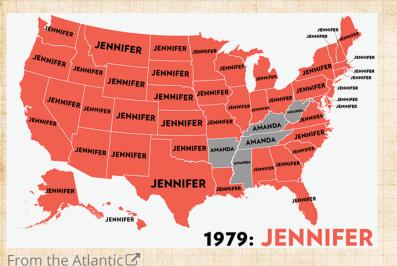


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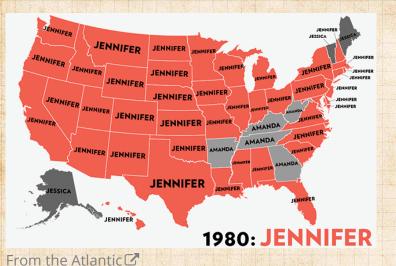


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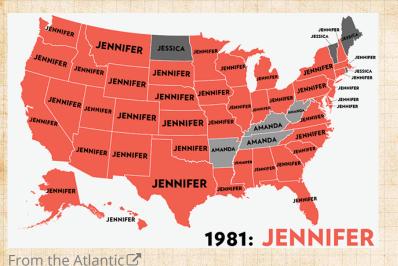


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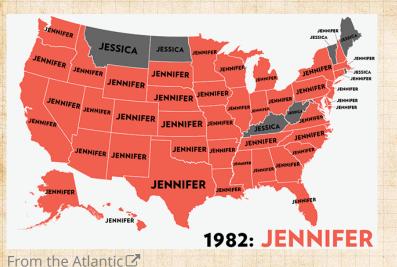
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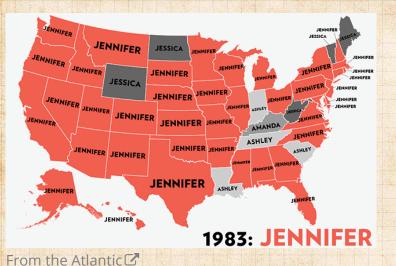


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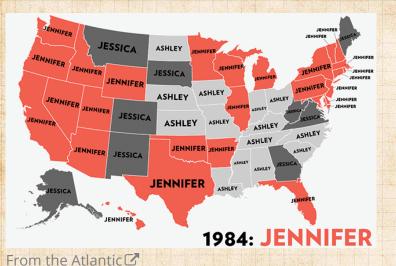


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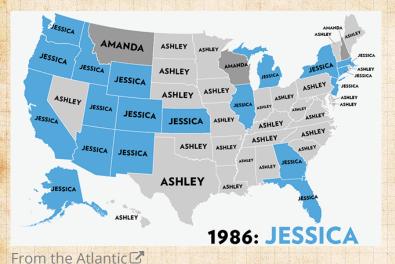


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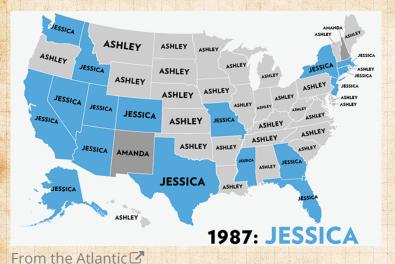


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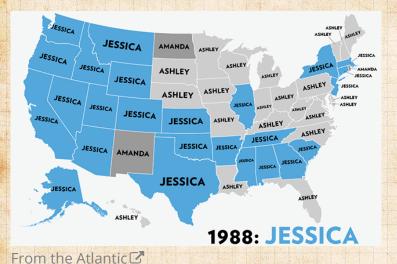


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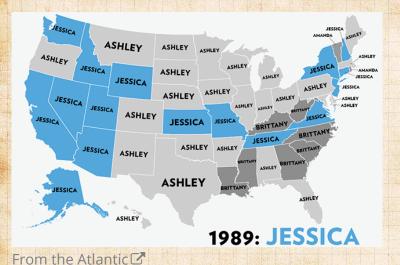


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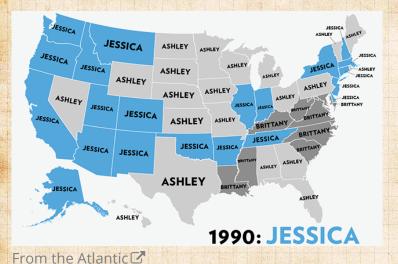


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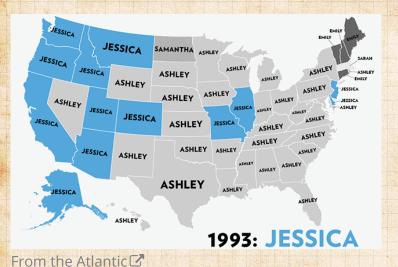


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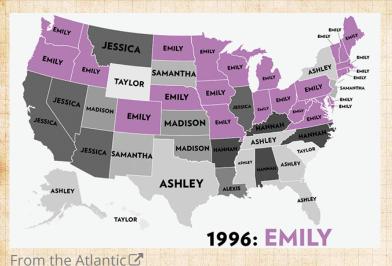
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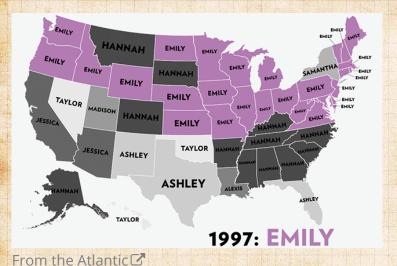


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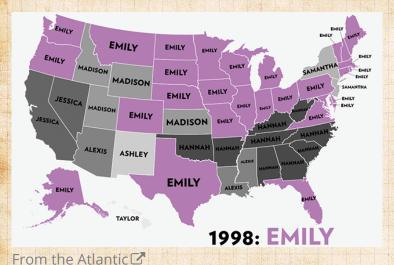


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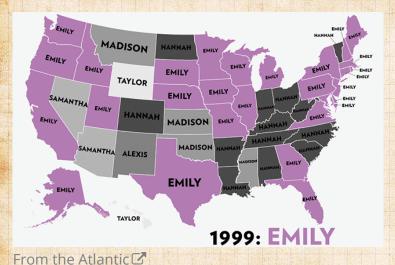
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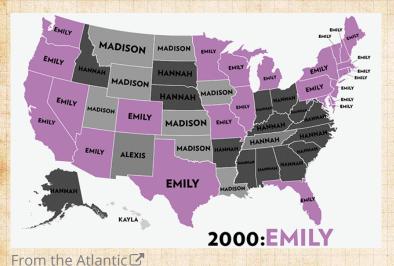


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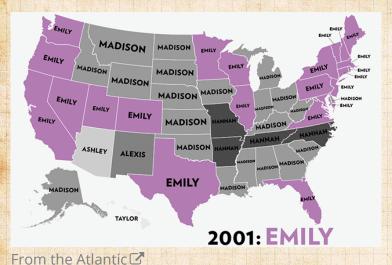


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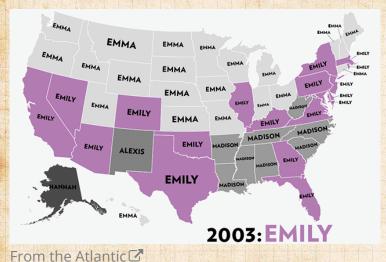
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From the Atlantic



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200 7 of 110

Richard Feynmann on the Social Sciences:

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200 8 of 110

Sheldon Cooper on the Social Sciences:

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References



200 9 of 110

Things that spread well:

buzzfeed.com 🗷:

cute geeky trashy fail omg

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

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Things that spread well:

buzzfeed.com ☑:

cute geeky trashy fail omg

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

+ News ...

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200 10 of 110

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Oopsie!

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BUZZFEED FELL DOWN AND WENT BOOM.

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200 11 of 110

The whole lolcats thing:

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Some things really stick:



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200 13 of 110

wtf + geeky + omg:

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DQC 15 of 110

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Why social contagion works so well:

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LOOK AT THESE PEOPLE. GLASSY-EYED AUTOMATONS GOING ABOUT THEIR DAILY LIVES, NEVER STOPPING TO LOOK AROUND AND THINK! I'M THE ONLY CONSCIOUS HUMAN IN A WORLD OF SHEEP.

http://xkcd.com/610/

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200 16 of 110

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References



200 17 of 110

Examples abound



Harry Potter
voting
gossip
Rubik's cube
religious beliefs
school shootings

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References



200 18 of 110

Examples abound



Harry Potter
voting
gossip
Rubik's cube
religious beliefs
school shootings
leaving lectures

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Examples abound



SIR and SIRS type contagion possible

Classes of behavior versus specific behavior

Harry Potter
voting
gossip
Rubik's cube
religious beliefs
school shootings
leaving lectures

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Examples abound



🚳 Harry Potter 🗞 voting 💑 gossip 🚳 Rubik's cube 💐 🚳 religious beliefs \delta school shootings leaving lectures

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SIR and SIRS type contagion possible

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



200 18 of 110

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

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http://www.youtube.com/watch?v=TgDxWNV4wWY?rel=0

Gindy Harrell, and the provide in the (terrifying) music video for Ra Parker Jr.'s the show the C

Steve Harrington



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http://www.youtube.com/watch?v=TgDxWNV4wWY?rel=0

Cindy Harrell appeared I in the (terrifying) music video for Ray Parker Jr.'s Ghostbusters I.



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

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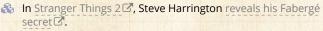
Final size Spreading success

References

http://www.youtube.com/watch?v=TgDxWNV4wWY?rel=0



🗞 Cindy Harrell appeared 🗹 in the (terrifying) music video for Ray Parker Jr.'s Ghostbusters C.





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Market much?

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http://www.youtube.com/watch?v=FEaCflp9gR4?rel=0



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



Evolving network stories (Christakis and Fowler):



The spread of quitting smoking [7] The spread of spreading C^[6]

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Evolving network stories (Christakis and Fowler):

The spread of quitting smoking ^[7]
 The spread of spreading ^[6]
 Also: happiness ^[11], loneliness, ...

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Evolving network stories (Christakis and Fowler):

- The spread of guitting smoking C⁷
 The spread of spreading C⁷⁶
- 🙈 Also: happiness 🖓 [11], loneliness, ...
- The book: Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives

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Evolving network stories (Christakis and Fowler):

- The spread of quitting smoking ^[7]
 The spread of spreading ^[7]
- 🙈 Also: happiness 🖓 [11], loneliness, ...
- The book: Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives 2

Controversy:

Are your friends making you fat? C (Clive Thomspon, NY Times, September 10, 2009).

social plague stir in the human superorganism (Dave Johns, Slate, April 8, 2010). PoCS | @pocsvox Social Contagion

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Evolving network stories (Christakis and Fowler):

- The spread of guitting smoking C^{* [7]}
 The spread of spreading C^{* [6]}
- 🙈 Also: happiness 🖓 [11], loneliness, ...
- The book: Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives

Controversy:

- Are your friends making you fat? C (Clive Thomspon, NY Times, September 10, 2009).

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References



990 21 of 110

Two focuses for us

Widespread media influence Word-of-mouth influence PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



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🚳 Widespread media influence

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References



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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Widespread media influence
 Word-of-mouth influence

 We need to understand influence
 Who influences whom?
 What kinds of influence response functions are there?
 Are some individuals super influencers?
 The infectious idea of opinion leaders (Katz and Lazarsfeld) PoCS | @pocsvox Social Contagion

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



nac 22 of 110

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 Word-of-mouth influence

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



nac 22 of 110

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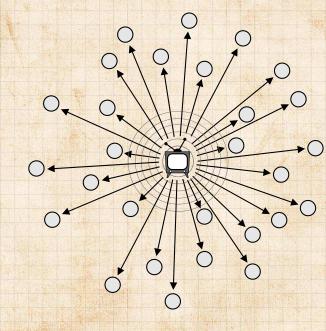
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The hypodermic model of influence

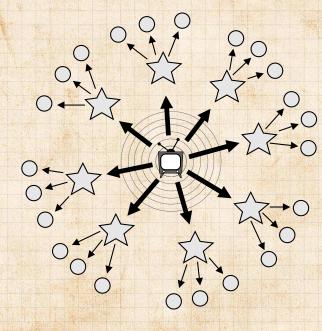


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The two step model of influence [19]



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References



na 24 of 110

The general model of influence: the Social Wild

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References



na 25 of 110

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Talking about the social wild:

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



26 of 110

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:

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

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System/group dynamics harder to understand because most of our stories are built around individuals.

Always good to examine what is said before an after the fact ... PoCS | @pocsvox Social Contagion

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References





27 of 110

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Social Contagion Models Background



27 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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





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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

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 Becoming Mona Lisa: The Making of a Global Icon"—David Sassoon
 Not the world's greatest painting from the start...





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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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References

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8

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References

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References

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Tattooed Guy' Was Pivotal in Armstrong Case [nytimes]



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

..."

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References



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29 of 110

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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References



うへで 30 of 110

The dismal predictive powers of editors...

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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990 31 of 110

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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

References





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20 32 of 110

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

MS: It's a nice book.

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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success

References





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Dac 32 of 110



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References





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References





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200 32 of 110

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References





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2 a a 32 of 110



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References



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References





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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References





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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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References

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nac 32 of 110

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References

WHERE THE WILD THINGS ARE



8

nac 32 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

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where the wild things are



Tory and pictures by majrice senda



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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- 🚳 Sendak named his dog Herman.
- he essential Colbert interview: Pt. 1 🖸 and Pt. 2 🗹.

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

where the wild things are



Drafting success in the NFL:

Top Players by Round, 1995-2012

2ND ROUND

Drew Brees

32ND PICK 2001



1ST OVER ALL 1998

1ST ROUND Peyton Manning





Terrell Owens

89TH PICK, 1996



Jared Allen

126TH PICK 2004



Zach Thomas

154TH PICK, 1996



6TH ROUND

Tom Brady



199TH PICK 2000

7TH ROUND Donald Driver 213TH PICK, 1999 References



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Models Background Final size Spreading success

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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 Fidden In Paragent

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References



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References



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References



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References



20 0 34 of 110

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References



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Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



うへで 34 of 110

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Getting others to do things for you A very good book: 'Influence' [8] by Robert Cialdini Six modes of influence:

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Six modes of influence:

- 1. Reciprocation: The Old Give and Take... and Take; e.g., Free samples, Hare Krishnas.
 - Commitment and Consistency: Hobgoblins of the Mind; e.e., Hazing
- 3. Social Proof: Truths Are Us;

Kitty Genovese C (contested), Liking: The Friendly Thief; e.g., Se

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Spreading success Groups



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 e.g., Milgram's obedience to authority experiment.

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 experiment.
- 6. Scarcity: The Rule of the Few; e.g., Prohibition.

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References



200 36 of 110

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

through life.

🚳 Cialdini's modes are heuristics that help up us get

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References



200 36 of 110

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🚳 Cialdini's modes are heuristics that help up us get

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



200 36 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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References

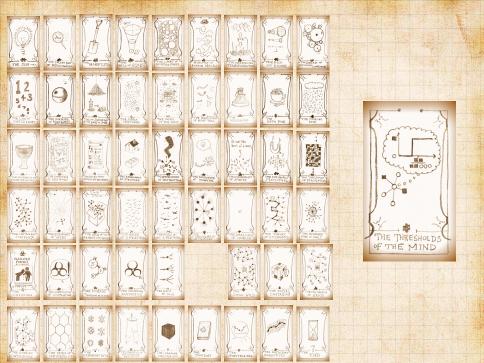
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Some important models:

Tipping models—Schelling (1971)^[22, 23, 24]

Simulation on checker boards Idea of thresholds Folgeon the new online visualia

Explore the

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success

Groups

References



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



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References



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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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 no matter.

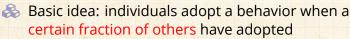
Assumption: level of influence per person is uniform PoCS | @pocsvox Social Contagion

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Social contagion models

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Some possible origins of thresholds:

Inherent, evolution-devised inclination to coordinate, to conform, to imitate. Lack of information: impute the worth of a go or behavior based on degree of adoption (soo proof) Economics: Network effects or network PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version

Spreading success Groups

References



200 40 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



200 40 of 110

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Neural reboot (NR):

Shareworthy interlude

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References



https://www.youtube.com/watch?v=LL2GQrvbb1k?rel=0

200 41 of 110

Outline

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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

References

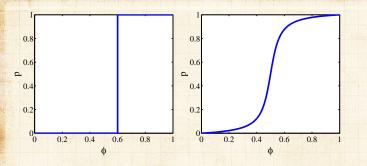


200 42 of 110

Social Contagion Models

Granovetter's model

Threshold models—response functions



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References

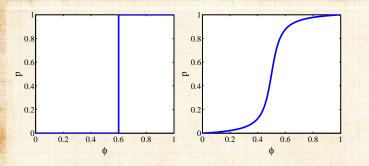
Example threshold influence response functions: deterministic and stochastic

 ϕ = fraction of contacts 'on' (e.g. Two states: S and I.



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Threshold models—response functions



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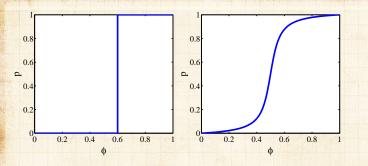
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Threshold models—response functions



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Social Contagion Models Background Gracoetter's model Network version Final size Spreading success Groups

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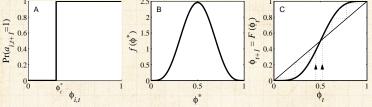


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Action based on perceived behavior of others:



🚳 Two states: S and I.

- $\Leftrightarrow \phi$ = fraction of contacts 'on' (e.g., rioting)
 - Discrete time update (strong assumption!) This is a Critical mass model



200 44 of 110

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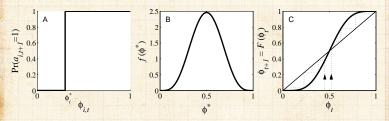
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Granovetter's model

Spreading success

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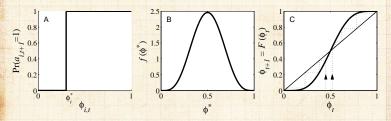
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Granovetter's model

Spreading success

References

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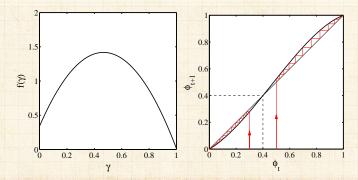


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Another example of critical mass model:



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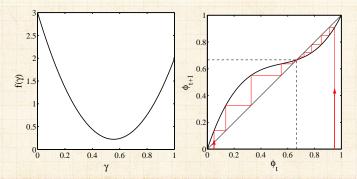
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References



[8]

Example of single stable state model:



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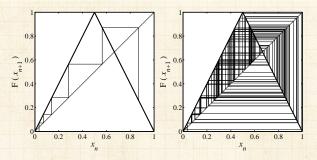
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References



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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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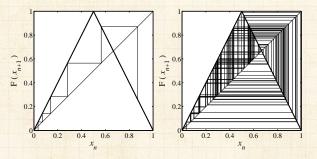
Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



200 47 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

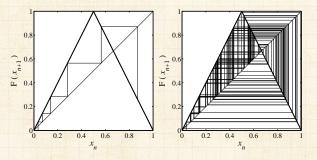
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200 47 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

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うへで 47 of 110

Implications for collective action theory:
 Collective uniformity ⇒ individual uniformity
 Small individual changes ⇒ large global changes
 The stories/dynamics of complex systems are conceptually inaccessible for individual-centri narratives.

 System stories live in left null space of ou stories—we can't even see them.

 But we happily impose simplistic, individual-centric stories—we can PoCS | @pocsvox Social Contagion

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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Outline

Social Contagion Models

Network version

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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

References



200 49 of 110

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 ightarrow network model Individuals now have a limited view of the wor

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Final size Spreading success Groups



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Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References





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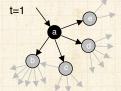
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Social Contagion Models Background

Granovetter's model

Network version Final size Spreading success Groups

References



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



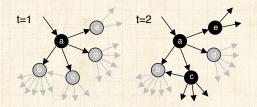
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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

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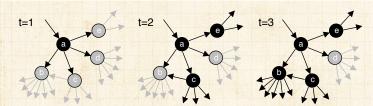
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う Q @ 51 of 110



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8

Interactions between individuals now represented by a network.

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



- Interactions between individuals now represented by a network.
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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

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weight. Each individual *i* has a fixed threshold φ_i . Individuals repeatedly poll contacts on networ Synchronous, discrete time updating. Individual *i* becomes active when fraction of active contacts $\frac{\varphi_i}{2} \ge \phi_i$. Individuals remain active when switched (no recovery = SI model). PoCS | @pocsvox Social Contagion

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Spreading success Groups

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Individuals repeatedly poll contacts on network Synchronous, discrete time updating. Individual *i* becomes active when fraction of active contacts $\frac{10}{12} \ge \phi_2$. Individuals remain active when switched (no recovery = SI model) PoCS | @pocsvox Social Contagion

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Individual *i* becomes active when fraction of active contacts $\frac{1}{2} \ge \phi_i$. Individuals remain active when switched (no recovery = SI model). PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Soreading success

References



- Interactions between individuals now represented by a network.
- line work is sparse.
- \bigotimes Individual *i* has k_i contacts.
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References



First study random networks:

Start with N nodes with a degree distribution Nodes are randomly connected (carefully so) Aim: Figure out when activation will propagate Determine a cascade condition PoCS | @pocsvox Social Contagion

Social Contagion Models Background

Network version Final size Spreading success Groups

References



nac 53 of 110

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Social Contagion Models Background Granovetter's model Network version Einal size

Final size Spreading success Groups

References



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- \Im Start with N nodes with a degree distribution P_k
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- Social Contagion Models Background Granovetter's model Network version
- Final size Spreading success Groups

References



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Final size Spreading success Groups

References



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Social Contagion Models Background Granovetter's model <u>Network version</u> Final size

Spreading success Groups

References



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The Cascade Condition:

- 1. 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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Example random network structure:

final

 $\Re \Omega_{\rm crit} = \Omega_{\rm vuln} =$ critical mass = global vulnerable component $\bigotimes \Omega_{\text{trig}} =$ triggering component $\bigotimes \Omega_{\text{final}} =$ potential extent of spread 3 $\Omega = entire$ network

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References



8

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



Follow active links

An active link is a link connected to an activated node.

If an infected link leads to at least 1 more infecte link, then activation spreads.

We need to understand which nodes can be activated when only one of their neigbors becomes active. PoCS | @pocsvox Social Contagion

Social Contagion Models Background

Network version Final size Spreading success Groups

References



200 55 of 110

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Final size Spreading success Groups

References



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Social Contagion Models Background Granovetter's model <u>Network version</u> Final size

Spreading success Groups

References



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Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References



ク へ 55 of 110

UVN S

Vulnerables:

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Network version Final size Spreading success Groups

References



200 56 of 110

Vulnerables:

We call individuals who can be activated by just one contact being active vulnerables

Which means # contacts $k_i \leq \lfloor 1/\phi_i \rfloor$ For global cascades on random networks, mu have a global cluster of vulnerables Cluster of vulnerables = critical mass Network story: 1 node \rightarrow critical mass \rightarrow everyone. PoCS | @pocsvox Social Contagion

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Final size Spreading success Groups

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200 56 of 110

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Final size Spreading success Groups

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



200 56 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



200 56 of 110

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Spreading succes Groups

References



うへで 56 of 110

Back to following a link:

A randomly chosen link, traversed in a random direction, leads to a degree k node with probability $\propto k R_k$.

Follows from there being *k* ways to connect to a node with degree *k*.

Normalization:

P(linked node has degree k

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Network version Final size Spreading success Groups

References



DQ @ 57 of 110

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Network version Final size Spreading success Groups

References



Dac 57 of 110

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



う Q C 57 of 110

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

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



うへで 57 of 110

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So

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

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

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Social Contagion Models Background Granovetter's model Network version Final size

Spreading succes Groups

References



うへで 57 of 110

Next: Vulnerability of linked node

Linked node is vulnerable with probability

If linked node is vulnerable, it produces outgoing active links

active links.

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Social Contagion Models Background

Network version Final size Spreading success Groups

References



200 58 of 110

Next: Vulnerability of linked node Linked node is vulnerable with probability

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

If linked node is vulnerable, it produces / outgoing active links If linked node is not vulnerable, it produces active links. PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



う Q (~ 58 of 110

Next: Vulnerability of linked node Linked node is vulnerable with probability

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

Solution If linked node is vulnerable, it produces k - 1 new outgoing active links

If linked node is not vulnerable, it produces n active links. PoCS | @pocsvox Social Contagion

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Spreading success Groups





Next: Vulnerability of linked node Linked node is vulnerable with probability

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

- Solution 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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Social Contagion Models Background Granovetter's model Network version Einal size

Spreading success Groups

References



うへで 58 of 110

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Putting things together:

Expected number of active edges produced by an active edge:

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



DQC 59 of 110

Putting things together:

Expected number of active edges produced by an active edge:

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

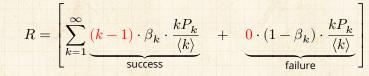
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Putting things together:

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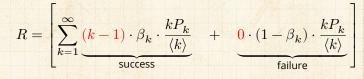
References



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Putting things together:

Expected number of active edges produced by an active edge:



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

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Social Contagion Models Background Granovetter's model <u>Network version</u> Final size Spreading success

References



うへで 59 of 110

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

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

 $\beta_k = \text{probability a degree } k \text{ node is vulnerable.}$ $P_k = \text{probability a node has degree } k.$

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References



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Two special cases:

Simple disease-like spreading succeeds:

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

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Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

References



200 61 of 110

Two special cases:

 \mathfrak{R} (1) Simple disease-like spreading succeeds: $\beta_k = \beta$

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Context

References



200 61 of 110

Two special cases:

 \mathfrak{R} (1) Simple disease-like spreading succeeds: $\beta_k = \beta$

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

Social Contagion Models Background Granovetter's model <u>Network version</u> Final size Spreading success Conuer

References



200 61 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



う Q (~ 61 of 110

Two special cases:

 \mathfrak{R} (1) Simple disease-like spreading succeeds: $\beta_k = \beta$

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

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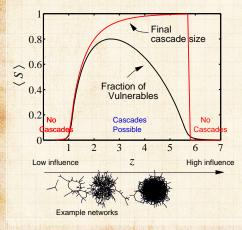
$$1\cdot \sum_{k=1}^{\infty} (k-1)\cdot \frac{kP_k}{\langle k\rangle} > 1.$$

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Cascades on random networks



Cascades occur only if size of max vulnerable cluster > 0.

> robust-yetfragile flagile facilitates spreading.

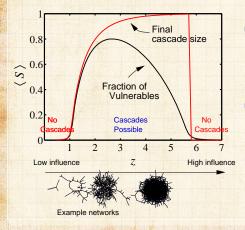
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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups



Cascades on random networks



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

> facilitates spreading.

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Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

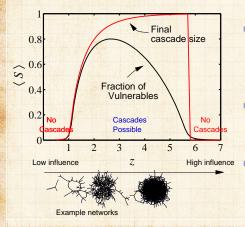
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20 62 of 110

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Cascades on random networks



Cascades occur only if size of max vulnerable cluster > 0. System may be 8 'robust-yetfragile'. 'Ignorance' facilitates spreading.

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success

Groups

References

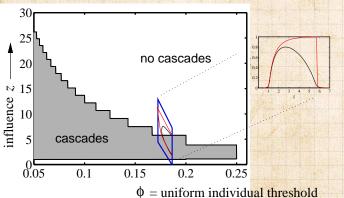


200 62 of 110

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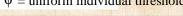
Cascade window for random networks

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References



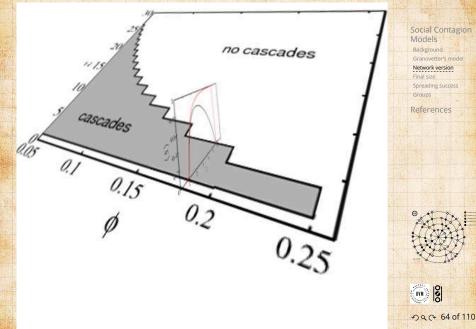
 Cascade window' widens as threshold φ decreases.
 Lower thresholds enable spreading.



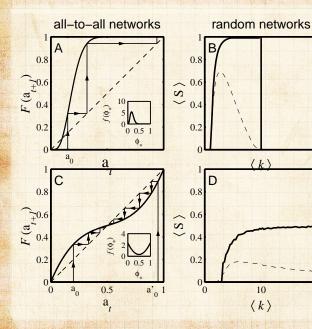
(i)

Cascade window for random networks

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All-to-all versus random networks



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



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20 65 of 110

For our simple model of a uniform threshold:

Low (a) No cascades in poorly connected networks. No global clusters of any kind. High (a) Giant component exists but not enoug vulnerables.

exists. Cascades are possible in "Cascade window PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model

Network version Final size Spreading success Groups

References



200 66 of 110

For our simple model of a uniform threshold:

- Low (k): No cascades in poorly connected networks. No global clusters of any kind.
 - High (*) Giant component exists but not enouvely vulnerables.

 Intermediate (k): Global cluster of vulnerables exists.

 Cascades are possible in "Cascade window."

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Social Contagion Models Background Granovetter's model Network version

Final size Spreading success Groups

References



200 66 of 110

For our simple model of a uniform threshold:

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Social Contagion Models Background Granovetter's model Network version

Spreading success Groups

References



200 66 of 110

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Cascades are possible in "Cascade window."

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Social Contagion Models Background Granovetter's model Network version Final size

Spreading succes Groups





Outline

Social Contagion Models

Final size

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Final size Spreading success Groups

References



200 67 of 110

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References

Next: Find expected fractional size of spread.

correlated and modular random networks," Ph Rev. E, 2008.



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References

Next: Find expected fractional size of spread. 🚳 Not obvious even for uniform threshold problem.

200 68 of 110

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References



20 68 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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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 switche on at t = 0 and their effects have propagated to reach i. PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



200 69 of 110

Determining expected size of spread:

- Randomly turn on a fraction ϕ_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*:
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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References





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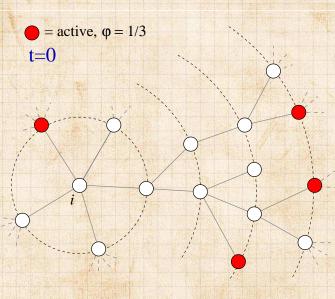
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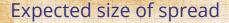
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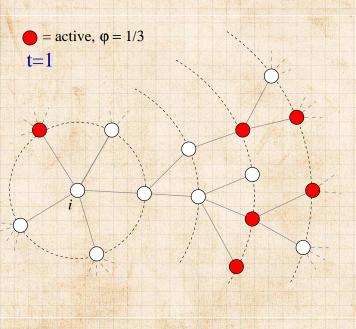
Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References

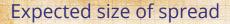


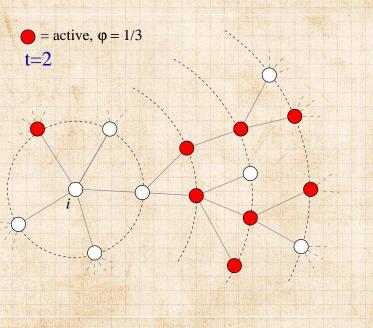




Social Contagion Models Background Granovetter's model Network version Final size Spreading success





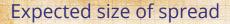


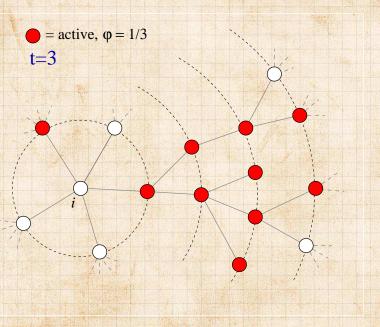
Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References





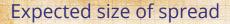


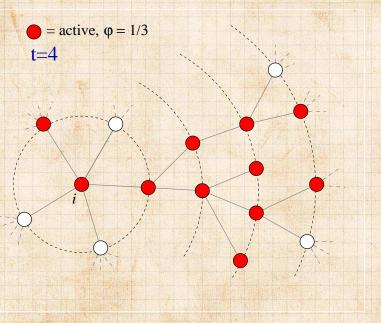
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Spreading success Groups

References





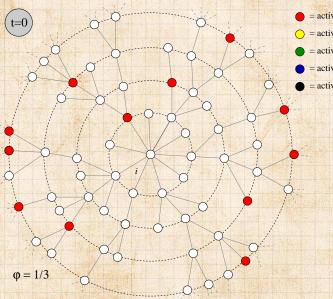


Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References





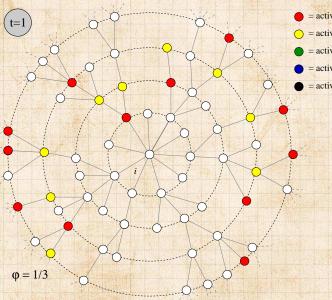
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References





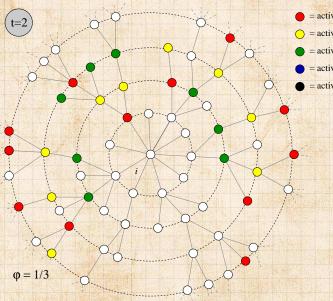
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References





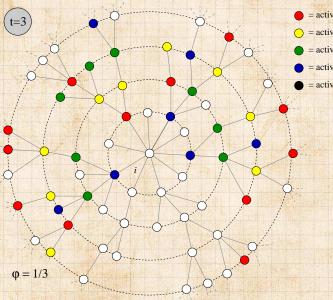
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References





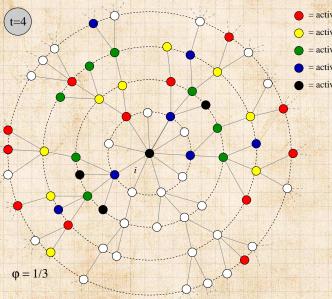
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References





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References



Notes:

Calculations are possible if nodes do not become inactive (strong restriction).

Not just for threshold model—works for a wid 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 PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Conuer

References



200 72 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



Dac 72 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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200 72 of 110

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



うくら 72 of 110

Pleasantness:

Taking off from a single seed story is about expansion away from a node. PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References



na 73 of 110

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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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



- Notation: $\phi_{k,t} = \mathbf{Pr}(a \text{ degree } k \text{ node is active at time } t).$
 - Notation: $B_{kj} = \mathbf{Pr}$ (a degree k node becomes active if *j* neighbors are active).
 - Our starting point: $\phi_{k,0} = \phi_0$.
 - $(f_1)\phi_0'(1-\phi_0)^{k-\tau} = \mathbf{Pr} (j \text{ of a degree } k \text{ node's neighbors}$ were seeded at time t = 0.
 - Probability a degree k node was a seed at t = 0 is (as above).
 - Probability a degree k node was not a seed at t = 0
 - Combining everything, we have

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



- Notation: $\phi_{k,t} = \mathbf{Pr}(a \text{ degree } k \text{ node is active at time } t).$
- Solution: $B_{kj} = \Pr$ (a degree k node becomes active if *j* neighbors are active).

 \bigotimes Our starting point: $\phi_{k,0} = \phi_0$.

 $(f_{1})\phi_{0}^{2}(1 - \phi_{0})^{k-t} = \mathbf{Pr} (j \text{ of a degree } k \text{ node's neighbolic were seeded at time } t = 0).$ Probability a degree k node was a seed at t = 0 is ϕ_{0} (as above). Probability a degree k node was not a seed at t = 0 is $(1 - \phi_{0})$. PoCS | @pocsvox Social Contagion

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 - Probability a degree k node was a seed at t = 0 is (as above).
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 $({}^k_j)\phi_0^j(1-\phi_0)^{k-j} = \Pr(j \text{ of a degree } k \text{ node's neighbors were seeded at time } t=0).$

Probability a degree k node was a seed at t = 0 is ϕ_0 (as above).

Probability a degree k node was not a seed at t = 0

Combining everything, we have

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- $\frac{1}{2}$ Notation:
 - $\phi_{k,t} = \Pr(a \text{ degree } k \text{ node is active at time } t).$
- Solution: $B_{kj} = \Pr$ (a degree k node becomes active if *j* neighbors are active).
- Solution of the starting point: $\phi_{k,0} = \phi_0$.
- $({}^k_j)\phi_0^j(1-\phi_0)^{k-j} = \Pr(j \text{ of a degree } k \text{ node's neighbors were seeded at time } t=0).$
- Probability a degree k node was a seed at t = 0 is ϕ_0 (as above).

Robability a degree k node was not a seed at t = 0 is $(1 - \phi_0)$.

Combining everything, we have

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- Representation of the second second

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Combining everything, we have:

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

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



We already know $\theta_0 = \phi_0$. Story analogous to t = 1 case. For node *i*:

Average over all nodes to obtain expression for a

io we need to compute θ_t ..

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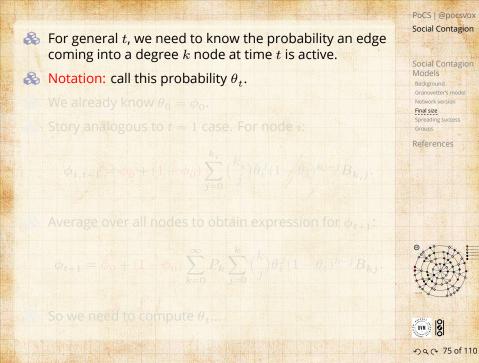
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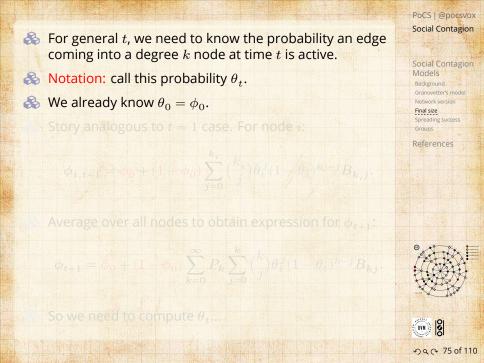
Final size Spreading success Groups

References



のQ ~ 75 of 110





- For general t, we need to know the probability an edge coming into a degree k node at time t is active.
- \mathfrak{S} Notation: call this probability θ_t .
- \bigotimes We already know $\theta_0 = \phi_0$.

Story analogous to t = 1 case. For node *i*:

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

Average over all nodes to obtain expression for ϕ_{t}

So we need to compute θ_t .

200 75 of 110

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Final size

 \mathbb{R} Notation: call this probability θ_t .

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Story analogous to t = 1 case. For node *i*:

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Average over all nodes to obtain expression for ϕ_{t+1} :

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



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

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So we need to compute θ_t ...

200 75 of 110

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 \mathfrak{S} So we need to compute θ_t ... massive excitement...

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



200 75 of 110

First connect θ_0 to θ_1 :

 $\theta_1 = \phi_0 +$

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

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

See this all generalizes to give $heta_{t+1}$ in terms of heta

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



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See this all generalizes to give θ_{t+1} in terms of θ_t ...

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Two pieces: edges first, and then nodes 1. $\theta_{t+1} = \underbrace{\phi_0}_{\text{exogenous}}$

$$+(1-\phi_0)\sum_{k=1}^{\infty}\frac{kP_k}{\langle k\rangle}\sum_{j=0}^{k-1}{\binom{k-1}{j}\theta_t^{\ j}(1-\theta_t)^{k-1-j}B_k}$$

social effects

with $\theta_0 = \phi_0$. 2. $\phi_{t+1} =$

$$\underbrace{\phi_0}_{\text{exogenous}} + (1 - \phi_0) \underbrace{\sum_{k=0}^{\infty} P_k \sum_{j=0}^k {k \choose j} \theta_t^{j} (1 - \theta_t)^{k-j} B_{kj}}_{(1 - \theta_t)^{k-j} (1 - \theta_t)^{k-j} (1 - \theta_t)^{k-j} B_{kj}}$$

social effects

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References

DQ ~ 77 of 110

Iterative map for θ_t is key:

 $\theta_{t+1} = \underbrace{\phi_0}_{\text{exogenous}}$

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

social effects

 $= G(\boldsymbol{\theta}_t; \boldsymbol{\phi}_0)$

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Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References



DQ @ 78 of 110

Retrieve cascade condition for spreading from a single seed in limit $\phi_0 \rightarrow 0$.

First: if self-starters are present, some activation assured:

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

meaning $B_{k0} > 0$ for at least one value of $k \ge 1$. If $\theta = 0$ is a fixed point of G (i.e., $G(0; \phi_0) = 0$) the spreading occurs if

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

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups



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 $\theta = 0$, ther cascades are also always possible.

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Social Contagion Models Background Granovetter's model Network version Final size

Spreading succes Groups

References



200 80 of 110

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 \clubsuit 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 fo $\theta_0 > \theta_*$, spreading takes off. Tricky point: G depends on ϕ_0 , so as we change ϕ_0 , we also change G. A version of a critical mass model again. PoCS | @pocsvox Social Contagion

Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups

References



200 80 of 110

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Tricky point: *G* depends on ϕ_0 , so as we change ϕ_0 , we also change *G*.

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References



200 80 of 110

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:

- So Cascade condition is more complicated for $\phi_0 > 0$.
- Solution 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 ϕ_0 , so as we change ϕ_0 , we also change G.

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Social Contagion Models Background Granovetter's model Network version Final size Spreading success Groups





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- lacktrian A version of a critical mass model again.

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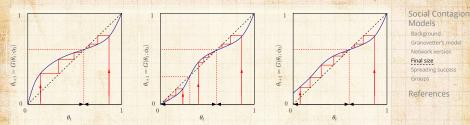


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Final size



Given $\theta_0(=\phi_0)$, θ_∞ will be the nearest stable fixed point, either above or below.

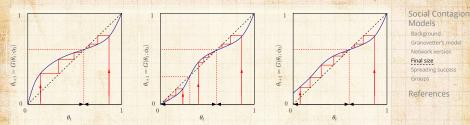


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Final size



Given $\theta_0 (= \phi_0)$, θ_∞ will be the nearest stable fixed point, either above or below.

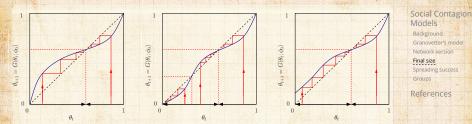
A n.b., adjacent fixed points must have opposite stability types.



29 C 81 of 110

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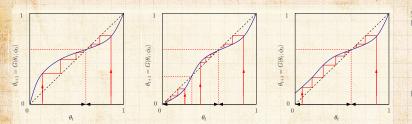
Final size



- Given $\theta_0 (= \phi_0)$, θ_∞ will be the nearest stable fixed 3 point, either above or below.
- A n.b., adjacent fixed points must have opposite stability types.
- \mathbb{R} Important: Actual form of G depends on ϕ_0 .



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- Siven $\theta_0(=\phi_0)$, θ_∞ will be the nearest stable fixed point, either above or below.
- n.b., adjacent fixed points must have opposite stability types.
- \Im Important: Actual form of G depends on ϕ_0 .
- So choice of ϕ_0 dictates both *G* and starting point—can't start anywhere for a given *G*.





Outline

Social Contagion Models

Spreading success

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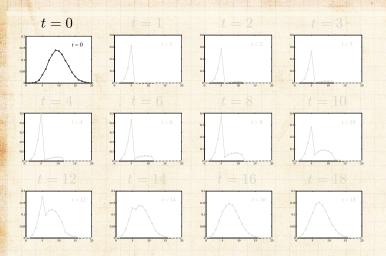
Social Contagion Models Background Granovetter's model Network version Final size

Spreading success Groups

References



2 0 82 of 110



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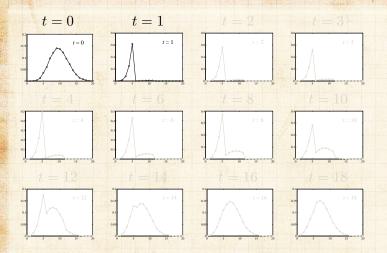
Social Contagion Models Background Granovetter's model Network version Final size Spreading success

References



DQC 83 of 110

 $P_{k,t}$ versus k



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References



20 83 of 110

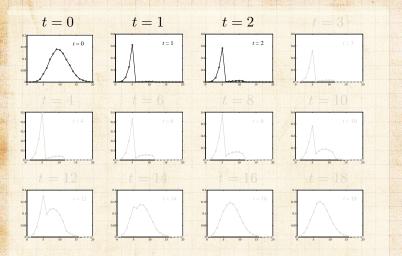
 $P_{k,t}$ versus k

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Social Contagion

Models Background

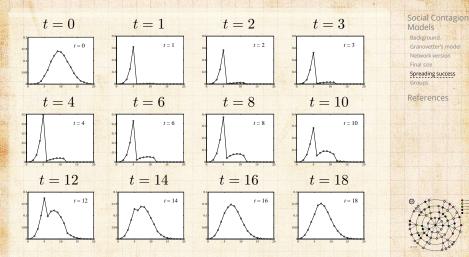
Network version Final size Spreading success Groups References



 $P_{k,t}$ versus k

20 0 83 of 110

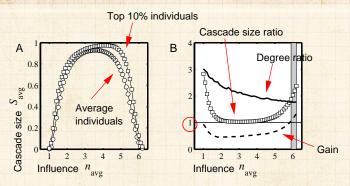
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 $P_{k,t}$ versus k

20 83 of 110

The multiplier effect:



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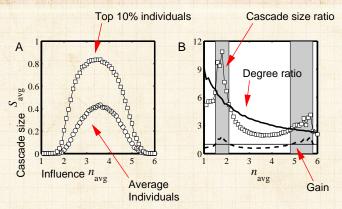
References

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



The multiplier effect:

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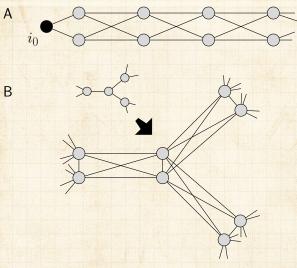
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References

Skewed influence distribution example.



Special subnetworks can act as triggers



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Spreading success Groups

References



200 86 of 110

Outline

Social Contagion Models

Groups

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Social Contagion Models Background Granovetters model Network version Final size Spreading success Groups

References



20 87 of 110

The power of groups...



A FEW HARMLESS FLAKES WORKING TOGETHER CAN UNLEASH AN AVALANCHE OF DESTRUCTION.

www.despair.com

"A few harmless flakes working together can unleash an avalanche of destruction." PoCS | @pocsvox Social Contagion

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200 88 of 110

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"Threshold Models of Social Influence" Watts and Dodds, The Oxford Handbook of Analytical Sociology, , 475–497, 2009. ^[28] Models Background Granovetter's mod Network version Final size Spreading success Groups

References

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



200 89 of 110

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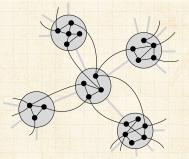
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Group structure—Ramified random networks

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References



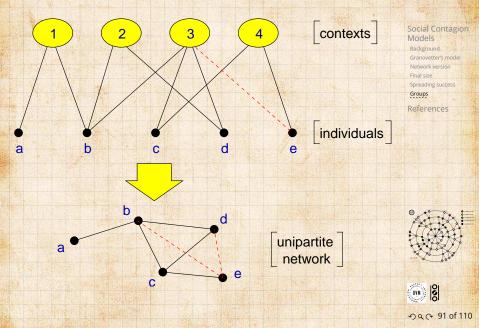
p = intergroup connection probability q = intragroup connection probability.



200 90 of 110

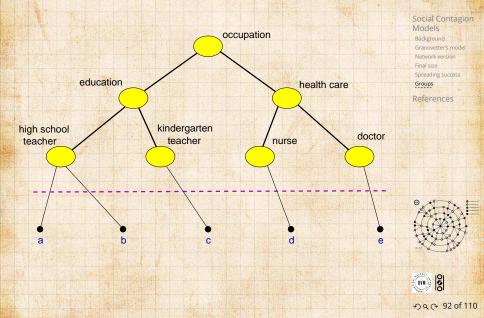
Bipartite networks

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Context distance

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Generalized affiliation model

b

geography

a



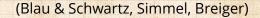


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200 93 of 110

Generalized affiliation model networks with triadic closure

Source the connect of the connect o

 τ_1 = intergroup probability of friend-of-frienc connection

 $\tau_2 = \text{Intragroup probability of mend-of-mend connection}$

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References



200 94 of 110

Generalized affiliation model networks with triadic closure

- Source the probability $\propto \exp^{-\alpha d}$ where
 - α = homophily parameter and
 - *d* = distance between nodes (height of lowest common ancestor)
- $rac{1}{\tau_1}$ = intergroup probability of friend-of-friend connection
 - au_2 = intragroup probability of friend-of-friend connection

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Generalized affiliation model networks with triadic closure

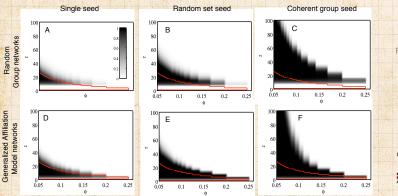
- Solution Connect nodes with probability $\propto \exp^{-\alpha d}$ where
 - α = homophily parameter and
 - *d* = distance between nodes (height of lowest common ancestor)
- $rac{1}{\tau_1}$ = intergroup probability of friend-of-friend connection
- $rac{1}{2}$ = intragroup probability of friend-of-friend connection

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Cascade windows for group-based networks

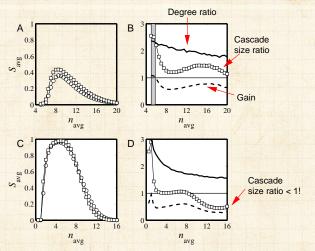


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Multiplier effect for group-based networks:

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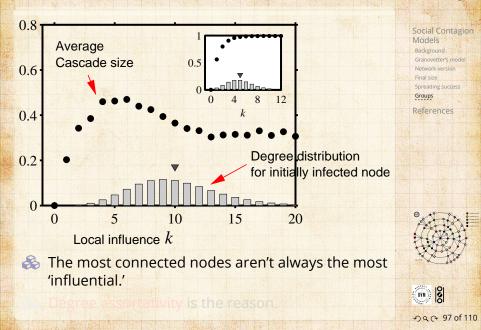
🚳 Multiplier almost always below 1.

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200 96 of 110

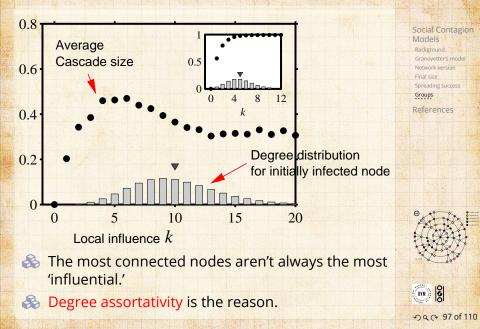
Assortativity in group-based networks



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Assortativity in group-based networks



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Summary linfluential vulnerables' are key to spread.

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References



200 98 of 110

Summary

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

Vulnerable nodes important but not necessa 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. PoCS | @pocsvox Social Contagion

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200 98 of 110

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UVN OO

Implications

line and the influential vulnerables.

Create entities that can be transmitted successfully through many individuals rather tha 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. PoCS | @pocsvox Social Contagion

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200 99 of 110

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Spreading and unspreading: Empires

http://www.youtube.com/watch?v=FEaCflp9qR4?rel=0

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