Information cascades and Network effects

CS224W: Social and Information Network Analysis
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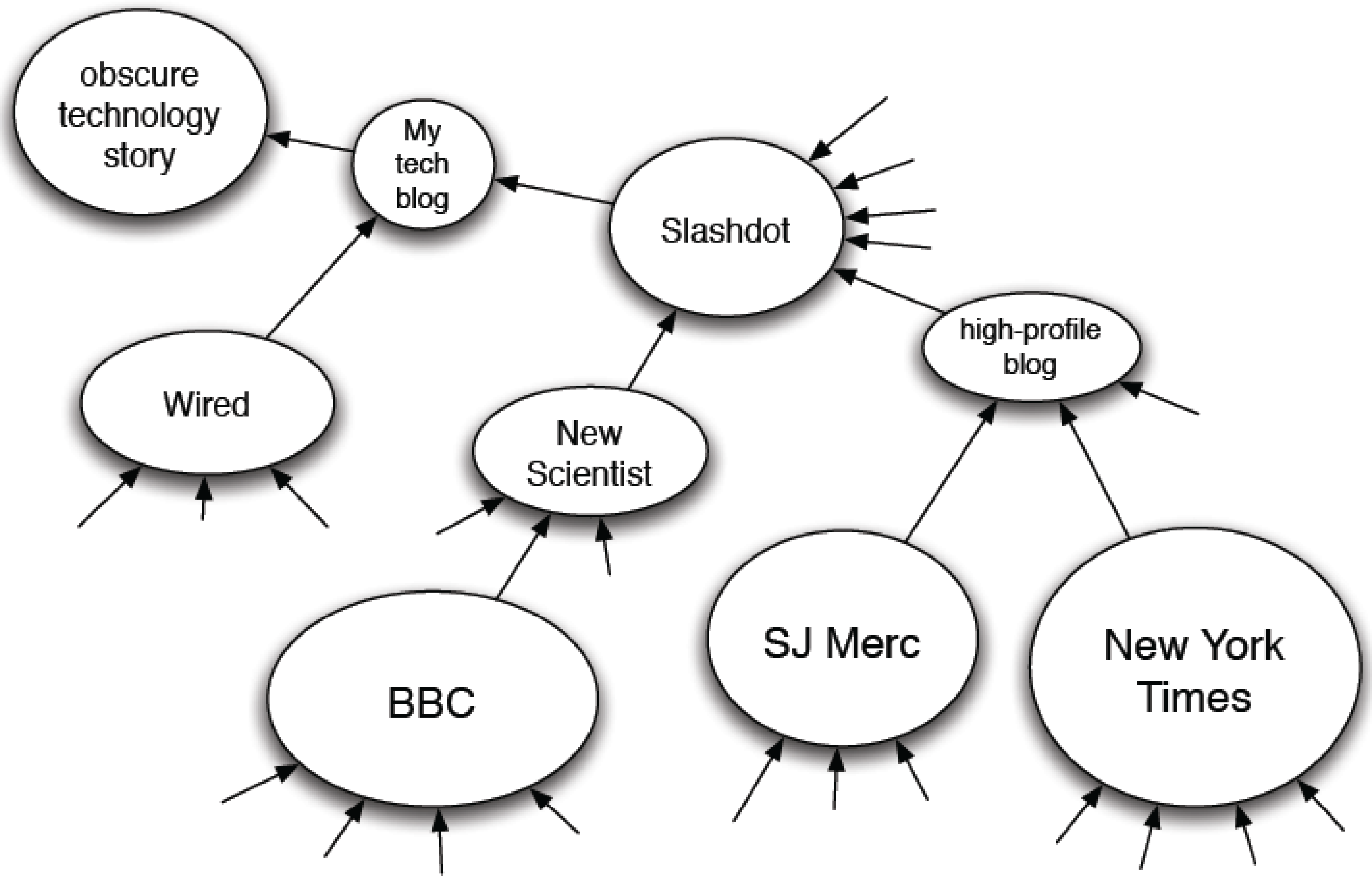
http://cs224w.stanford.edu

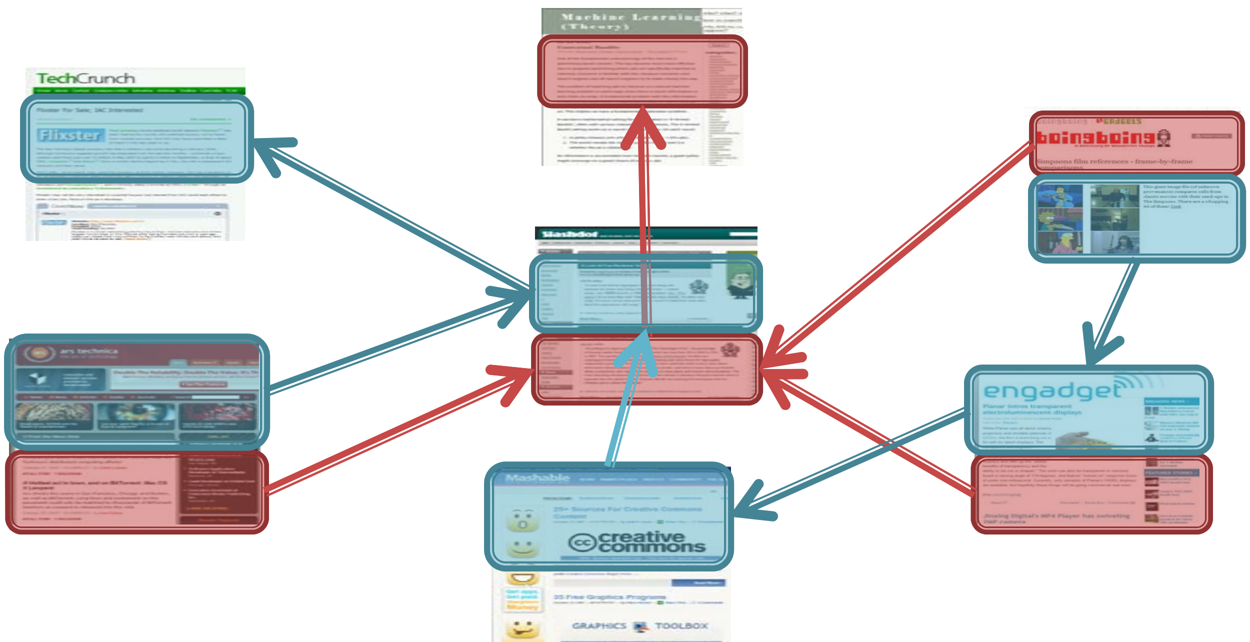
Processes and dynamics

- Spreading through networks:
  - Cascading behavior
  - Diffusion of innovations
  - Epidemics
- Examples:
  - Biological:
    - Diseases via contagion
  - Technological:
    - Cascading failures
    - Spread of information
  - Social:
    - Rumors, news, new technology
    - Viral marketing

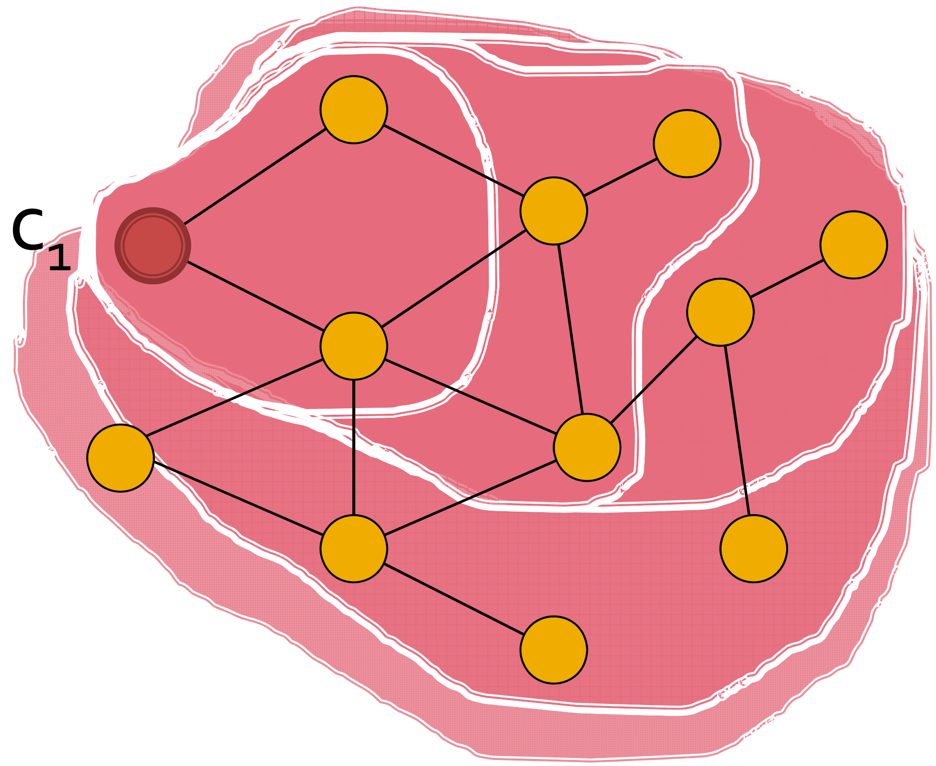
Information diffusion



Information diffusion

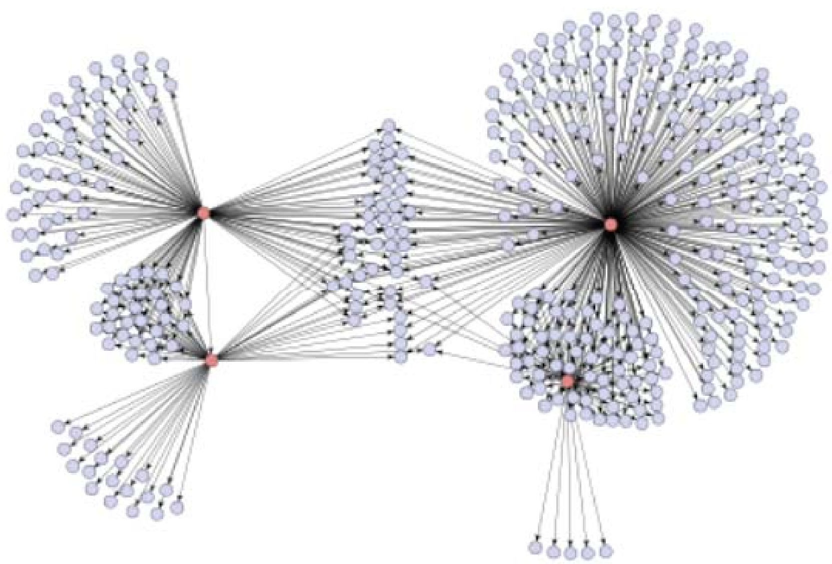


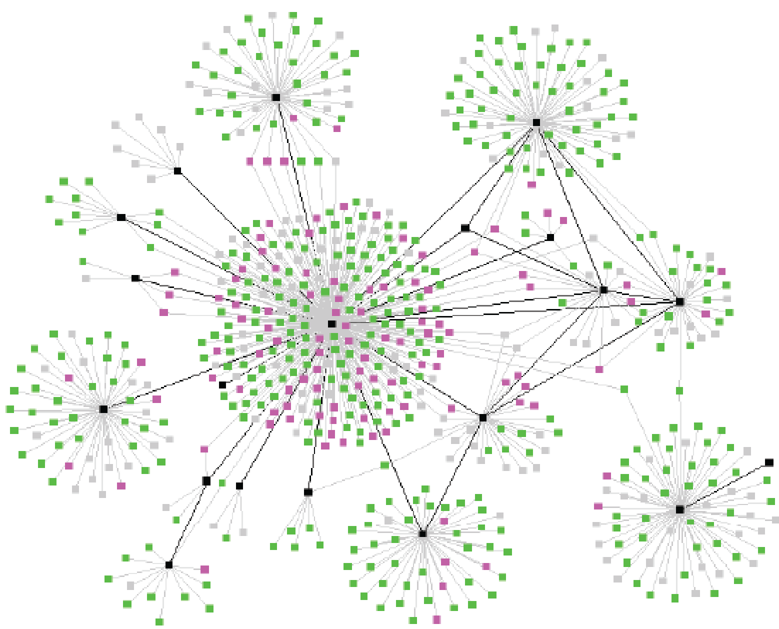
Spread of diseases



Diffusion in Social Networks

- One of the networks is a spread of a disease, the other one is product recommendations
- Which is which? ☺





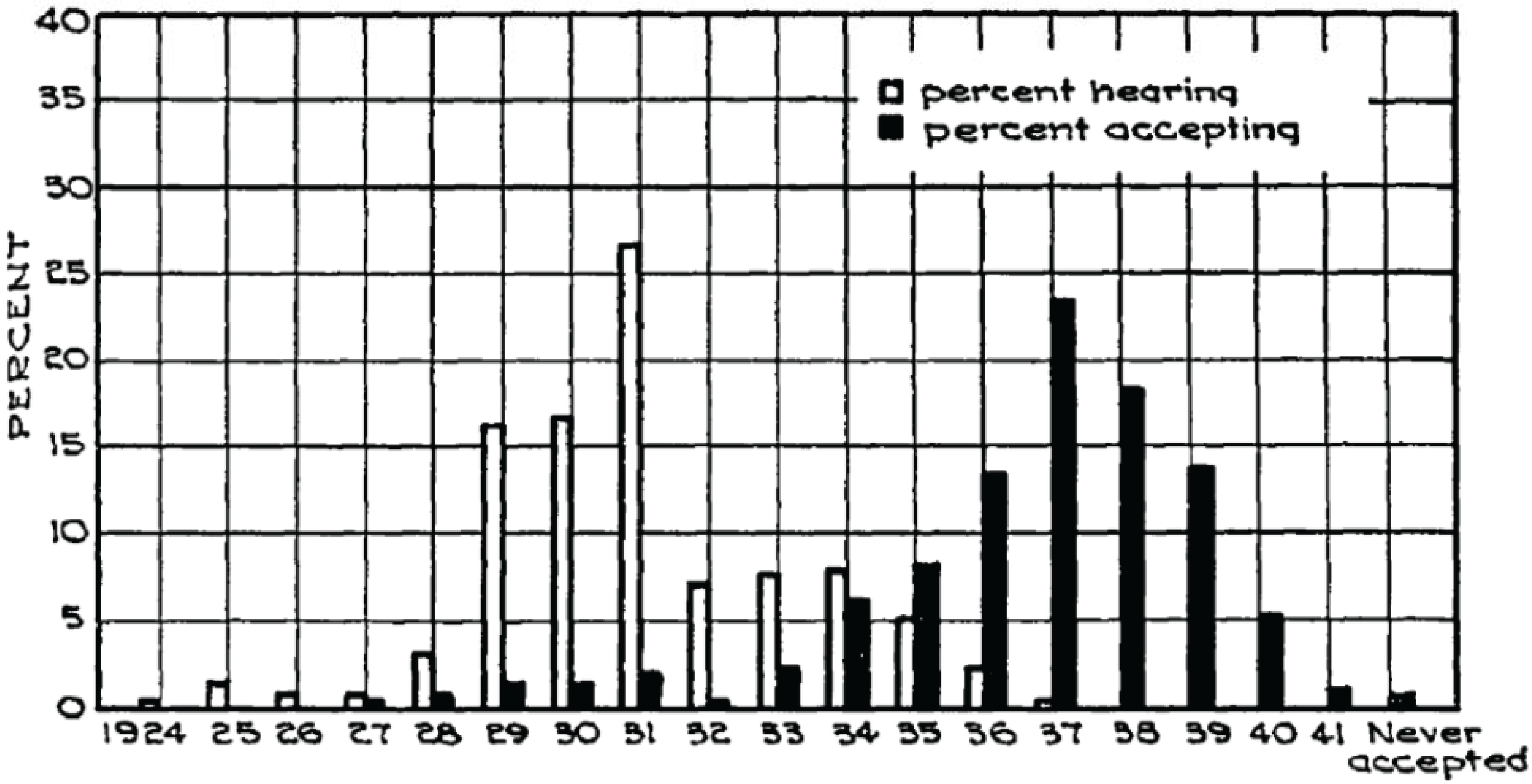
Diffusion in Networks

- A fundamental process in social networks: Behaviors that cascade from node to node like an epidemic
  - News, opinions, rumors, fads, urban legends, …
  - Word-of-mouth effects in marketing: rise of new websites, free web based services
  - Virus, disease propagation
  - Change in social priorities: smoking, recycling
  - Saturation news coverage: topic diffusion among bloggers
  - Internet-energized political campaigns
  - Cascading failures in financial markets
  - Localized effects: riots, people walking out of a lecture

Empirical Studies of Diffusion

- Experimental studies of diffusion:
  - Spread of new agricultural practices [Ryan-Gross 1943]
    - Adoption of a new hybrid-corn between the 259 farmers in Iowa
    - Classical study of diffusion
    - Interpersonal network plays important role in adoption → Diffusion is a social process
  - Spread of new medical practices [Coleman et al. 1966]
    - Studied the adoption of a new drug between doctors in Illinois
    - Clinical studies and scientific evaluations were not sufficient to convince the doctors
    - It was the social power of peers that led to adoption

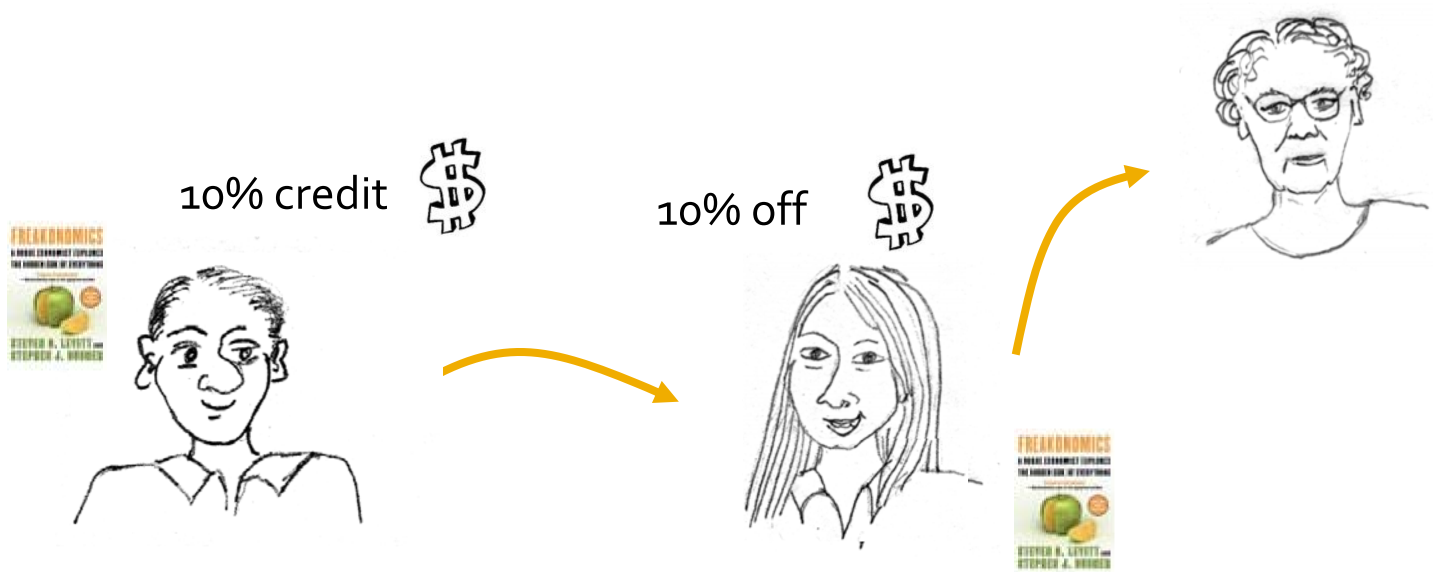
Hybrid Corn [Ryan-Gross 1966]



Diffusion is a social process

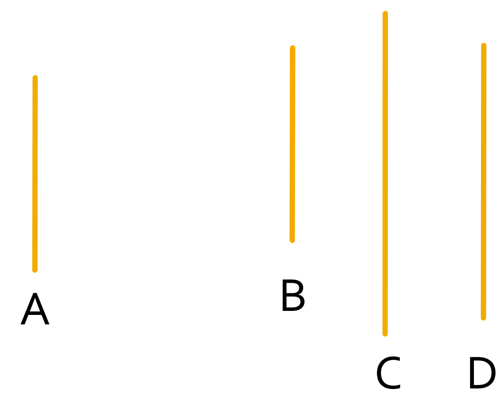
Diffusion in Viral Marketing

- Senders and followers of recommendations receive discounts on products



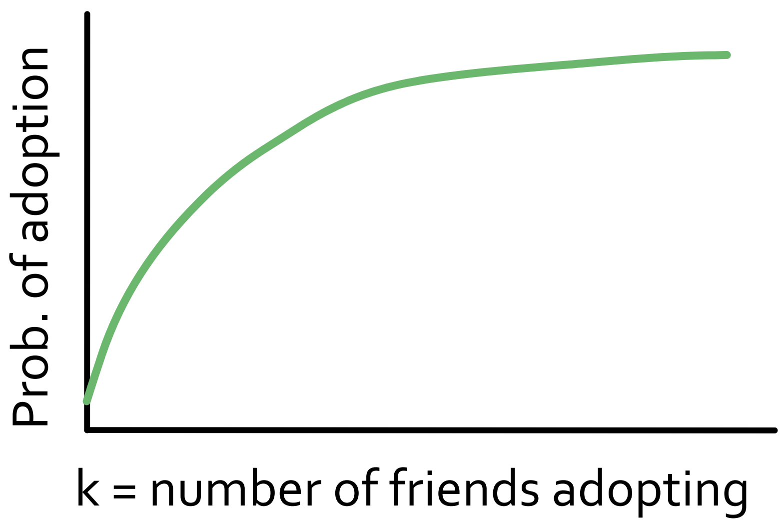
Empirical Studies of Diffusion (2)

- Diffusion has many (very interesting) flavors:
  - The contagion of obesity [Christakis et al. 2007]
    - If you have an overweight friend your chances of becoming obese increases by 57%
  - Psychological effects of others' opinions, *e.g.*: Which line is closest in length to A? [Asch 1958]

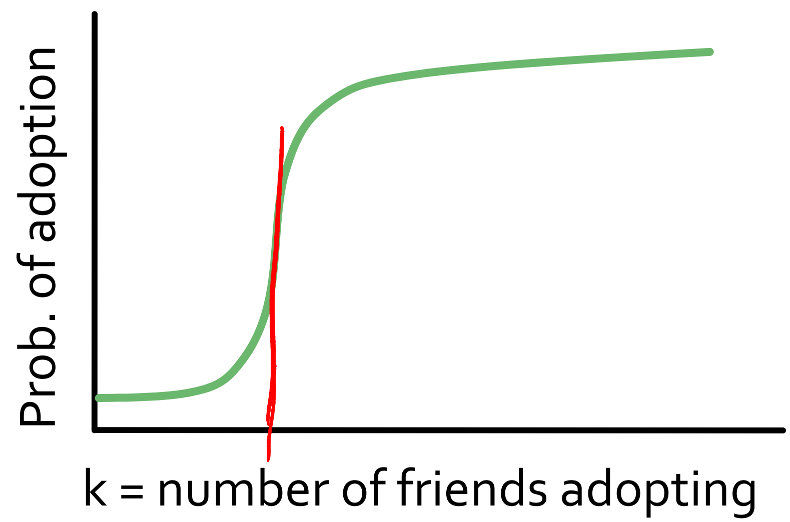


Diffusion Curves (1)

- Basis for models:
  - Probability of adopting new behavior depends on the number of friends who have adopted [Bass ‘69, Granovetter ‘78, Shelling ’78]
- What’s the dependence?

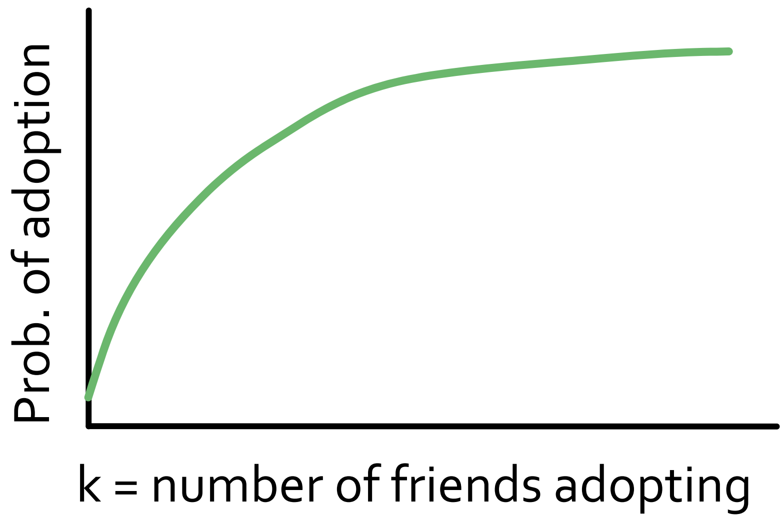


Diminishing returns?

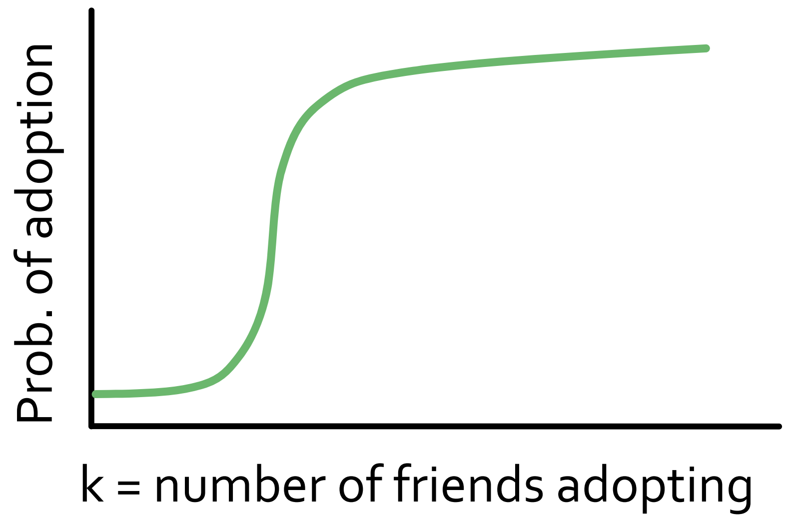


Critical mass?

Diffusion Curves (2)



Diminishing returns?



Critical mass?

- Key issue: qualitative shape of diffusion curves
  - Diminishing returns? Critical mass?
  - Distinction has consequences for models of diffusion at population level

How to model diffusion?

- Probabilistic models:
  - Example:
    - “catch” a disease with some prob. from neighbors in the network
- Decision based models:
  - Example:
    - Adopt new behaviors if *k* of your friends do

Models

- Two flavors, two types of questions:
  - A) Probabilistic models: Virus Propagation
    - SIS: Susceptible–Infective–Susceptible (*e.g.*, flu)
    - SIR: Susceptible–Infective–Recovered (*e.g.*, chicken-pox)
    - Question: Will the virus take over the network?
    - Independent contagion model
  - B) Decision based models: Diffusion of Innovation
    - Threshold model
    - Herding behavior
    - Questions:
      - Finding influential nodes
      - Detecting cascades

[Banerjee '92]

Decision based model: Herding

- Influence of actions of others
  - Model where everyone sees everyone else's behavior
- Sequential decision making
  - Picking a restaurant:
    - Consider you are choosing a restaurant in an unfamiliar town
    - Based on Yelp reviews you intend to go to restaurant A
    - But then you arrive there is no one eating at A but the next door restaurant B is nearly full
  - What will you do?
    - Information that you can infer from other's choices may be more powerful than your own

Herding: Structure

- Herding:
  - There is a decision to be made
  - People make the decision sequentially
  - Each person has some private information that helps guide the decision
  - You can’t directly observe private info of others but can see what they do
    - Can make inferences about their private information

Herding: Simple experiment

- Consider an urn with 3 marbles. It can be either:
  - Majority-blue: 2 blue, 1 red, **or**
  - Majority-red: 1 blue, 2 red
- Each person wants to **best guess** whether the urn is majority-blue or majority-red
- Experiment: One by one each person:
  - Draws a marble
  - Privately looks are the color and puts the marble back
  - Publicly guesses whether the urn is majority-red or majority-blue
- You see all the guesses beforehand
- How should you guess?

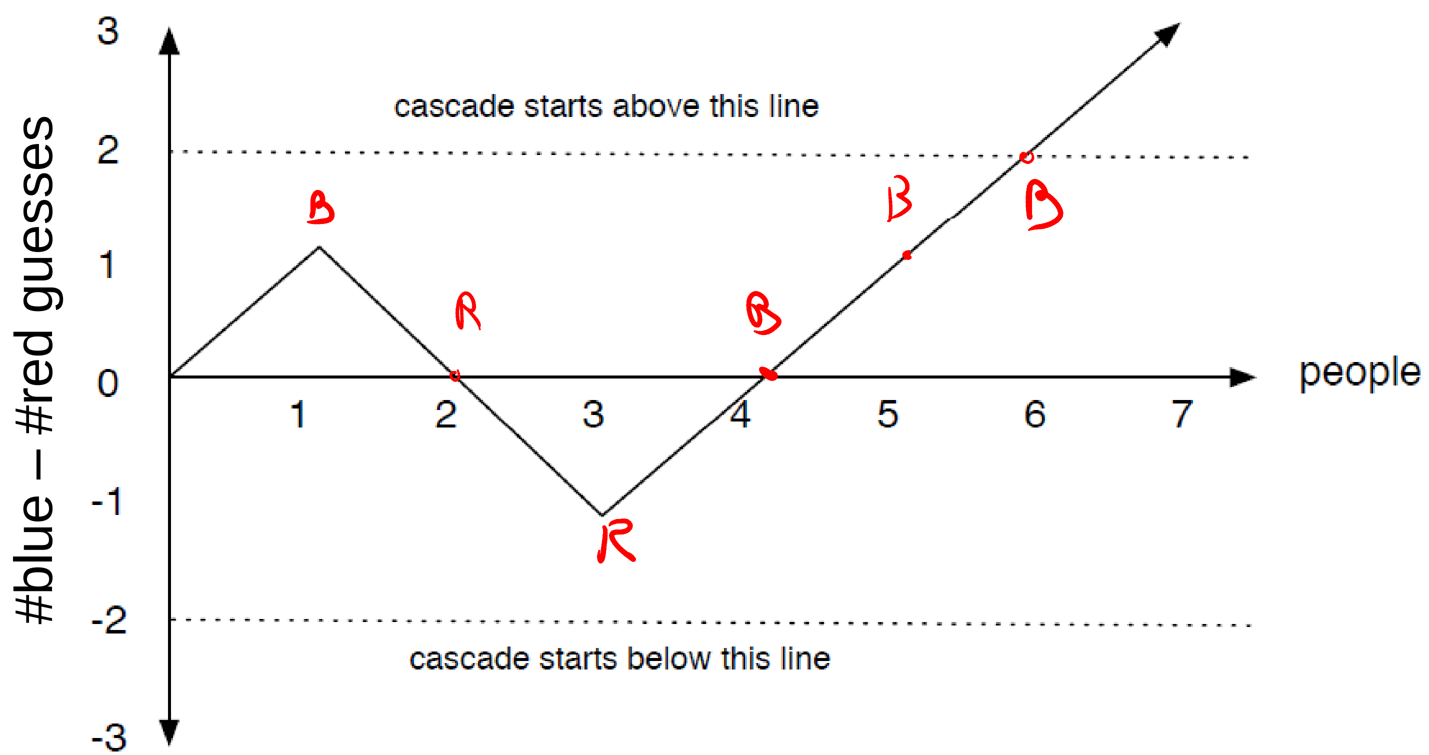
[Banerjee '92]

Herding: What happens?

- What happens:
  - 1st person: Guess the color you draw from the urn
  - 2nd person: Guess the color you draw from the urn
    - if same color as 1st, then go with it
    - If different, break the tie by doing with your own color ← TIE BREAKING
  - 3rd person:
    - If the two before made different guesses, go with your color
    - Else, just go with their guess (regardless of the color you see)
  - 4th person:
    - If the first two guesses were the same, go with it
      - 3rd person's guess conveys no information
- Can model this type of reasoning using the Bayes rule
  - see chapter 16 of Easley-Kleinberg

Herding: What happens?

- Cascade begins when the difference between the number of blue and red guesses reaches 2



Herding: Observations

- Easy to occur given right structural conditions
  - Can lead to bizarre patterns of decisions
- Non-optimal outcomes
  - With prob. $\frac{1}{3} \cdot \frac{1}{3} = \frac{1}{9}$ first two see the wrong color, from then on the whole population guesses wrong
- Can be very fragile
  - Suppose first two guess blue
  - People 100 and 101 draw red and cheat by showing their marbles
  - Person 102 now has 4 pieces of information, she guesses based on her own color
  - Cascade is broken

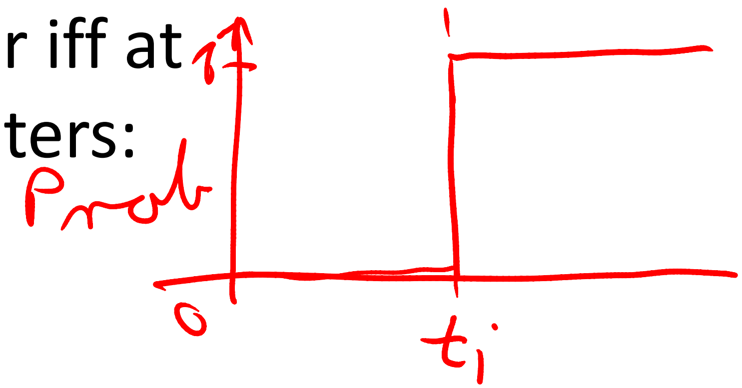
Decision based models

[Granovetter '78]

- Collective action [Granovetter, '78]
  - Model where everyone sees everyone else's behavior
  - Examples:
    - Clapping or getting up and leaving in a theater
    - Keeping your money or not in a stock market
    - Neighborhoods in cities changing ethnic composition
    - Riots, protests, strikes

Collective action: The model

- n people – everyone observes all actions
- Each person i has a threshold t_i
  - Node i will adopt the behavior iff at least t_i other people are adopters:
    - Small t_i: early adopter
    - Large t_i: late adopter

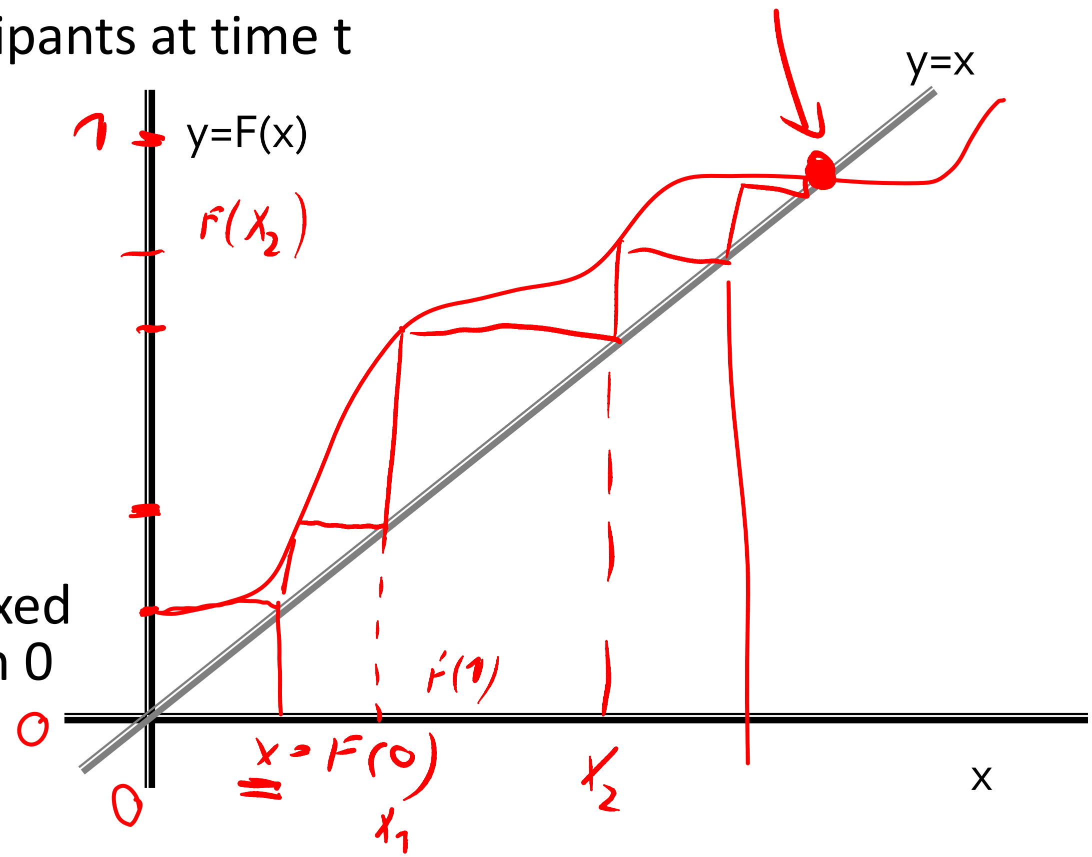


- The population is described by $\{t_1,\ldots,t_n\}$
  - F(x) … fraction of people with threshold $t_i \leq x$

Collective action: Dynamics

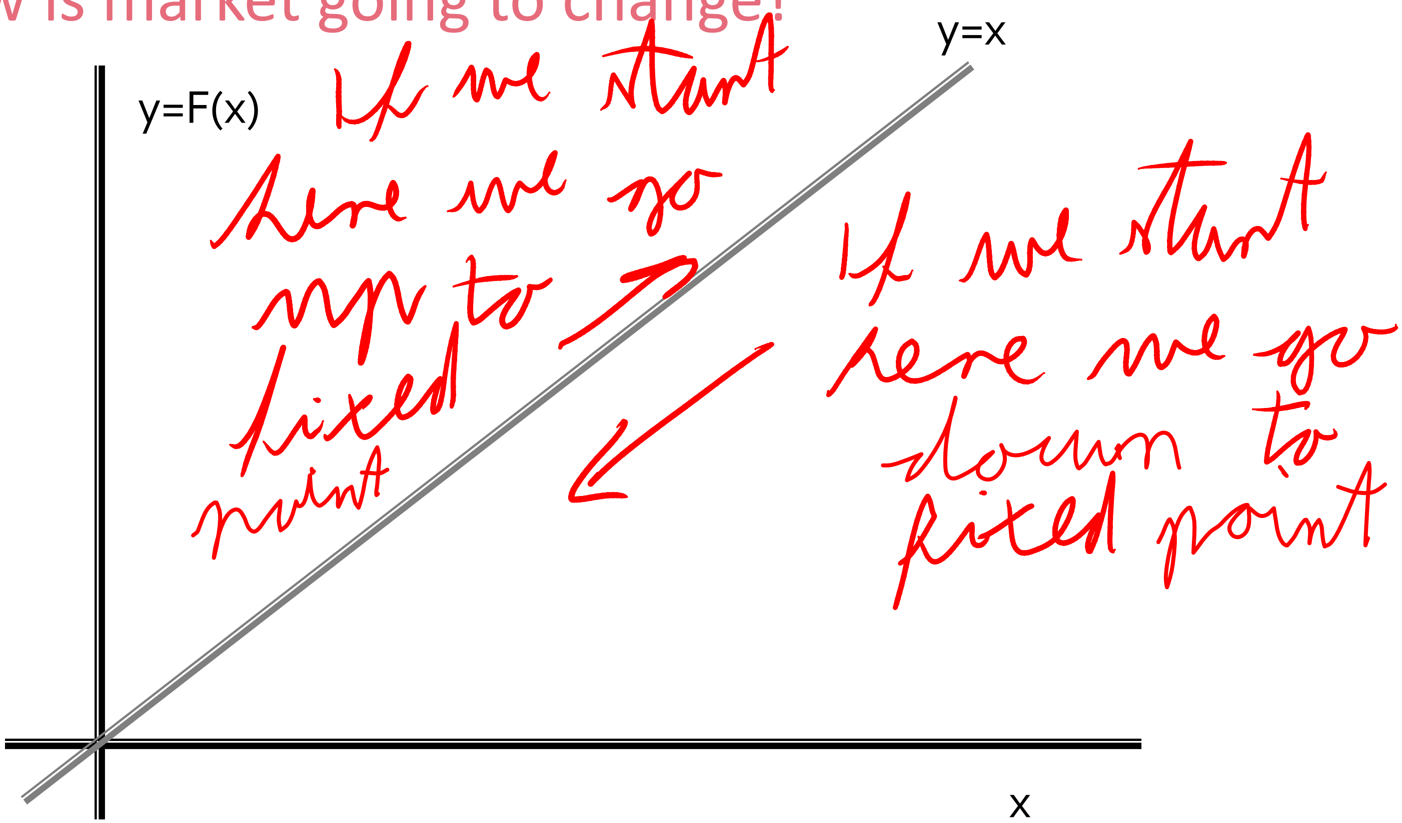
- Think of the step-by-step change in number of people adopting the behavior:
  - F(x) … fraction of people with threshold ≤ x
  - s(t) … number of participants at time t
- Easy to simulate:
  - s(0) = 0
  - s(1) = F(0)
  - s(2) = F(s(1)) = F(F(0))
  - s(t+1) = F(s(t)) = $F^{t+1}(0)$
- F(x)=x – stable point
  - There could be other fixed points but starting from 0 we never reach them

FIXED POINT F(X)=X

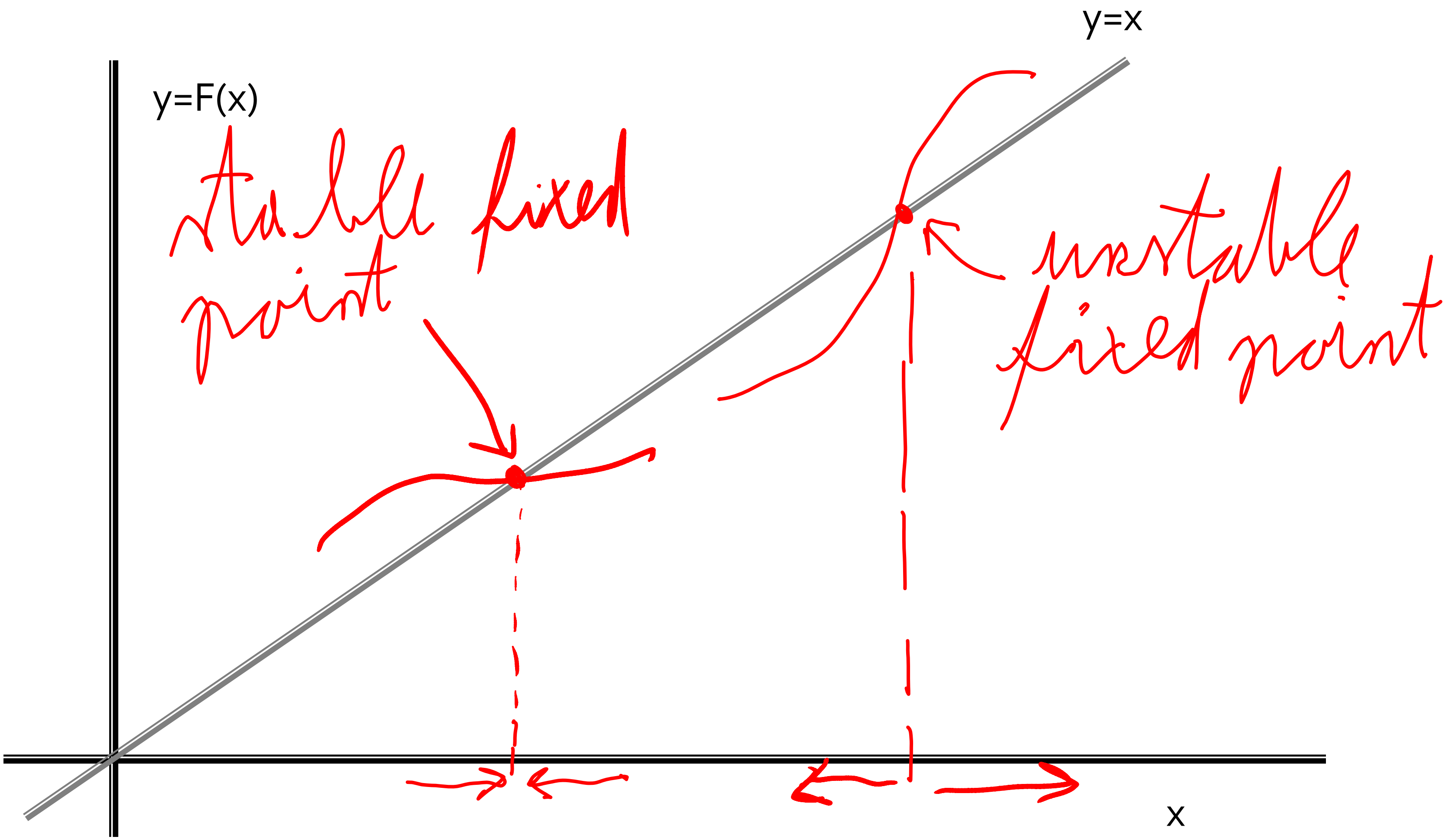


Starting elsewhere

- What if we start the process somewhere else?
  - We move up/down to the next fixed point
  - How is market going to change?



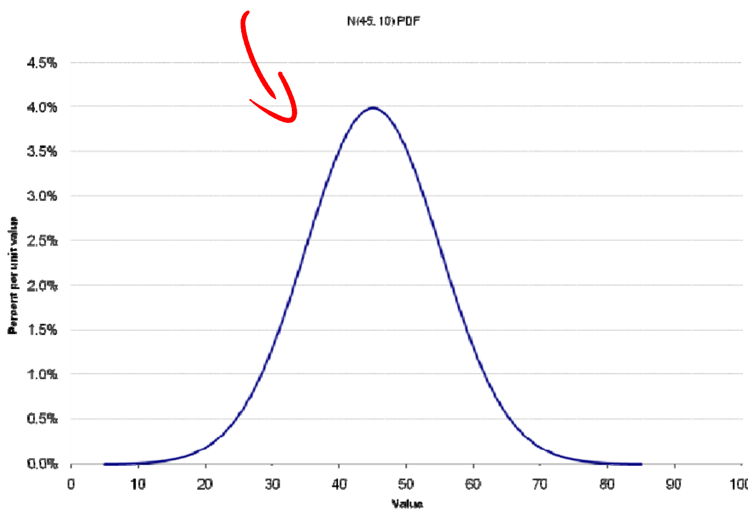
Fragile vs. robust fixed point



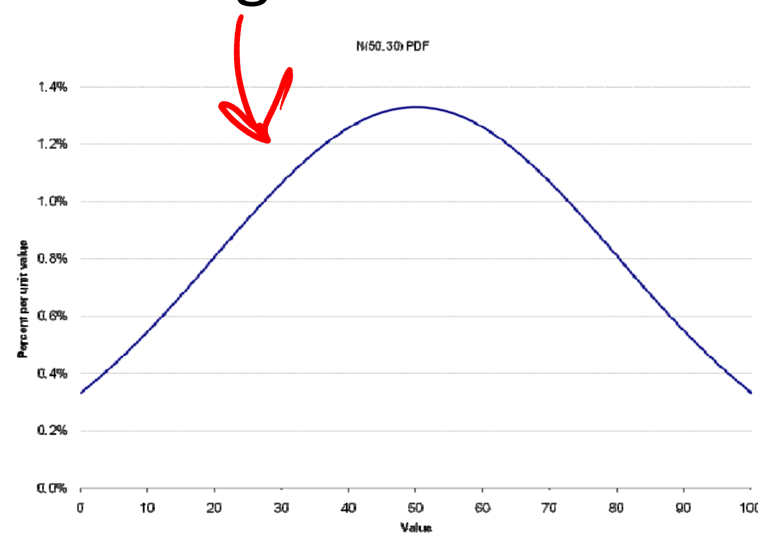
Discontinuous transition

- Each threshold t_i is drawn independently from some distribution *F(x) = Pr[thresh ≤ x]*
  - Suppose: Normal with μ=n/2, variance σ

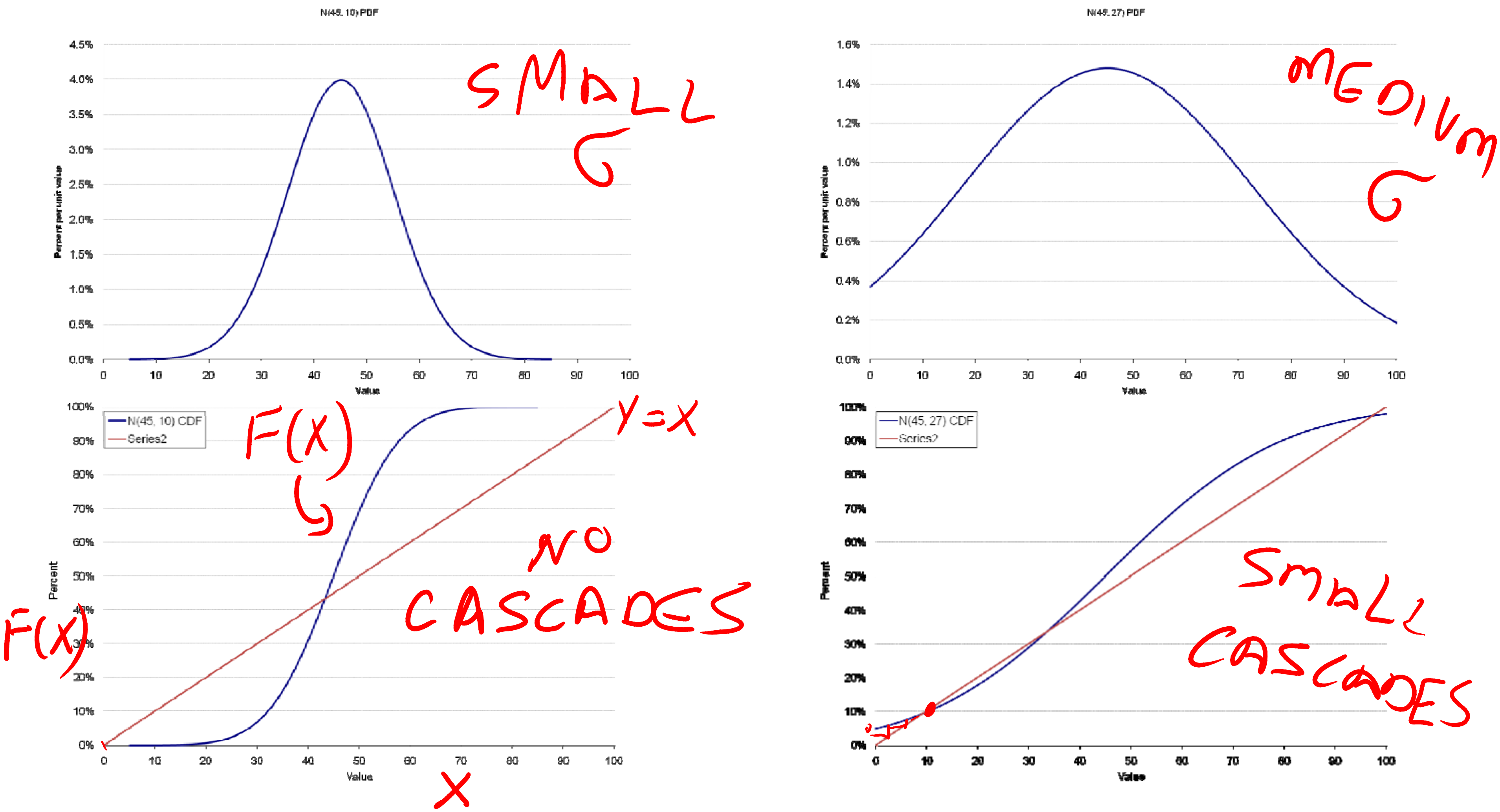
Small σ:



Large σ:

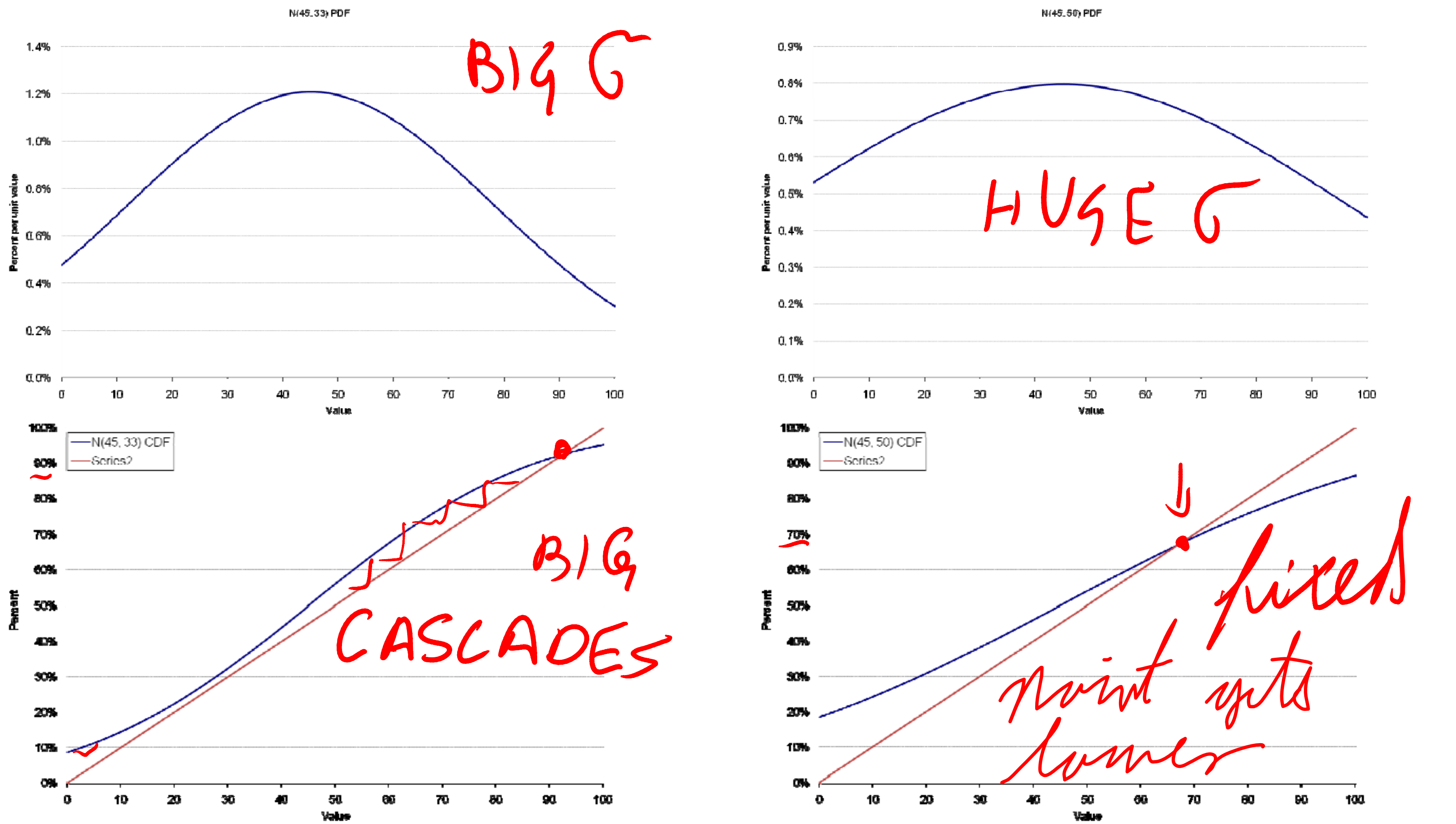


Discontinuous transition



Bigger variance let's you build a bridge from early adopters to mainstream

Discontinuous transition



But if we increase the variance even more we move the higher fixed point lover

Weaknesses of the model

- It does not take into account:
  - No notion of social network – more influential users
  - It matters who the early adopters are, not just how many
  - Models people's awareness of size of participation not just actual number of people participating
  - Modeling thresholds
    - Richer distributions
    - Deriving thresholds from mode basic assumptions
      - game theoretic models

Weaknesses of the model

- It does not take into account:
  - Modeling perceptions of who is adopting the behavior/ who you believe is adopting
  - Non monotone behavior – dropping out if too many people adopt
  - Similarity – thresholds not based only on numbers
  - People get "locked in" to certain choice over a period of time
- Network matters! (next slide)

How should we organize a revolt?

- You live in an oppressive society
- You know of a demonstration against the government planned for tomorrow
- If a lot of people show up, the government will fall
- If only a few people show up, the demonstrators will be arrested and it would have been better had everyone stayed at home

Pluralistic ignorance

- You should do something if you believe you are in the majority!
- Dictator tip: Pluralistic ignorance – erroneous estimates about the prevalence of certain opinions in the population
  - Survey conducted in the U.S. in 1970 showed that while a clear minority of white Americans at that point favored racial segregation, significantly more than 50% believed that it was favored by a majority of white Americans in their region of the country

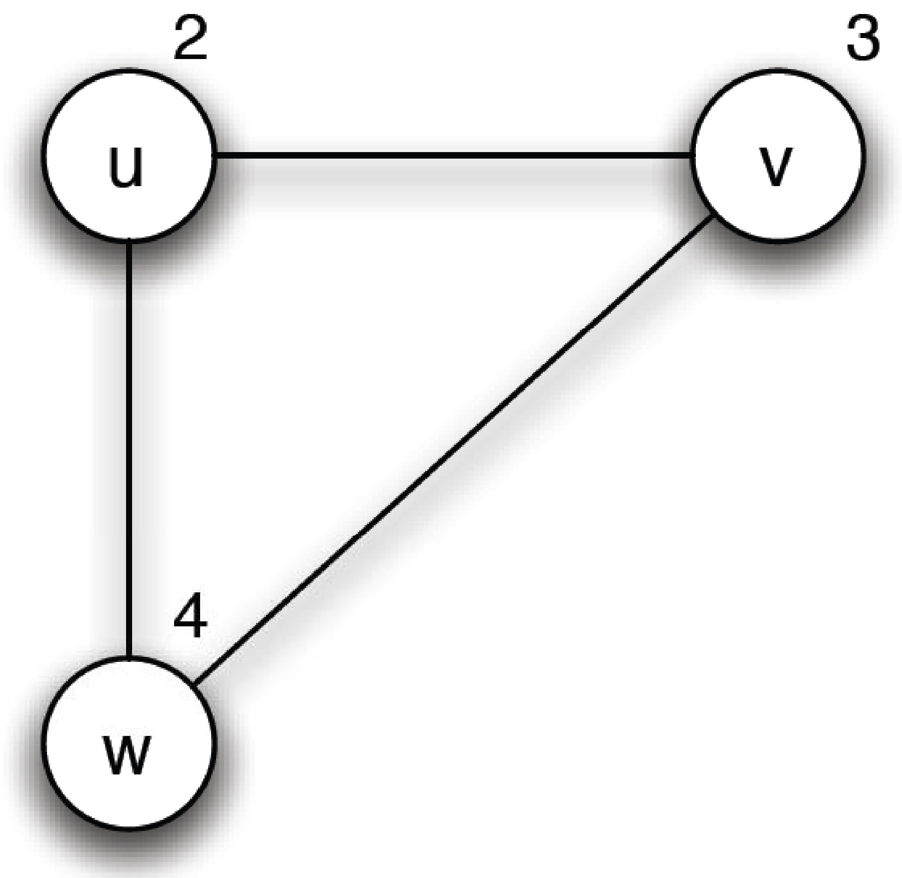
Organizing the revolt: The model

- Personal threshold k: “I will show up to the protest if I am sure at least k people in total (including myself) will show up”

- Each node in the network knows the thresholds of all their friends

Subtle issues

- Will uprising occur?



No!

Subtle issues

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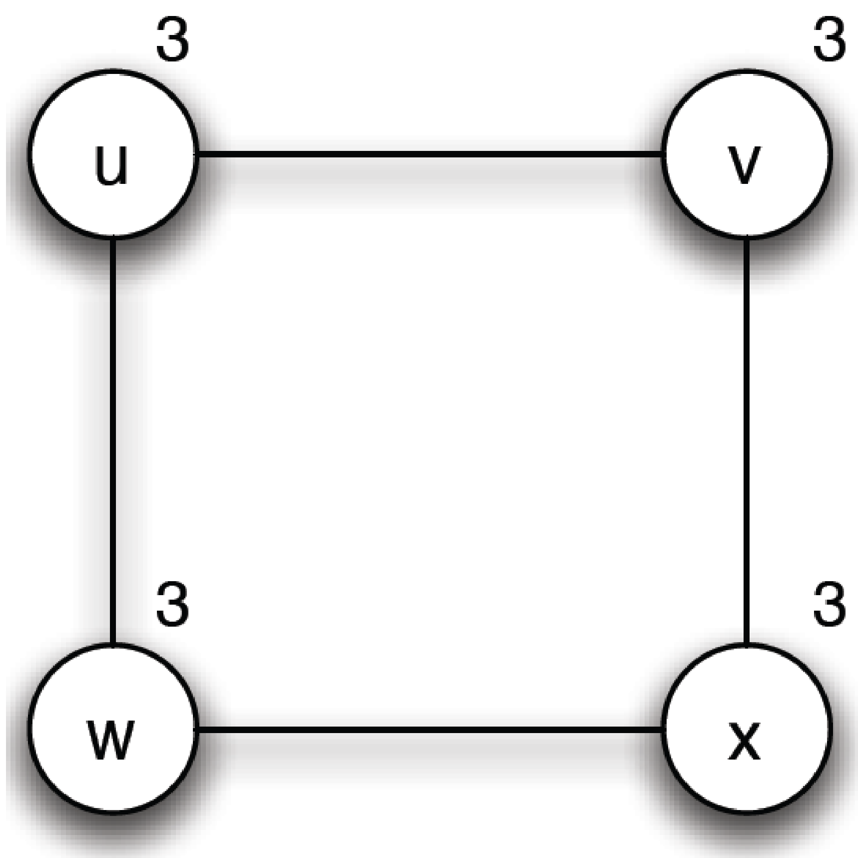

No!

Subtle issues

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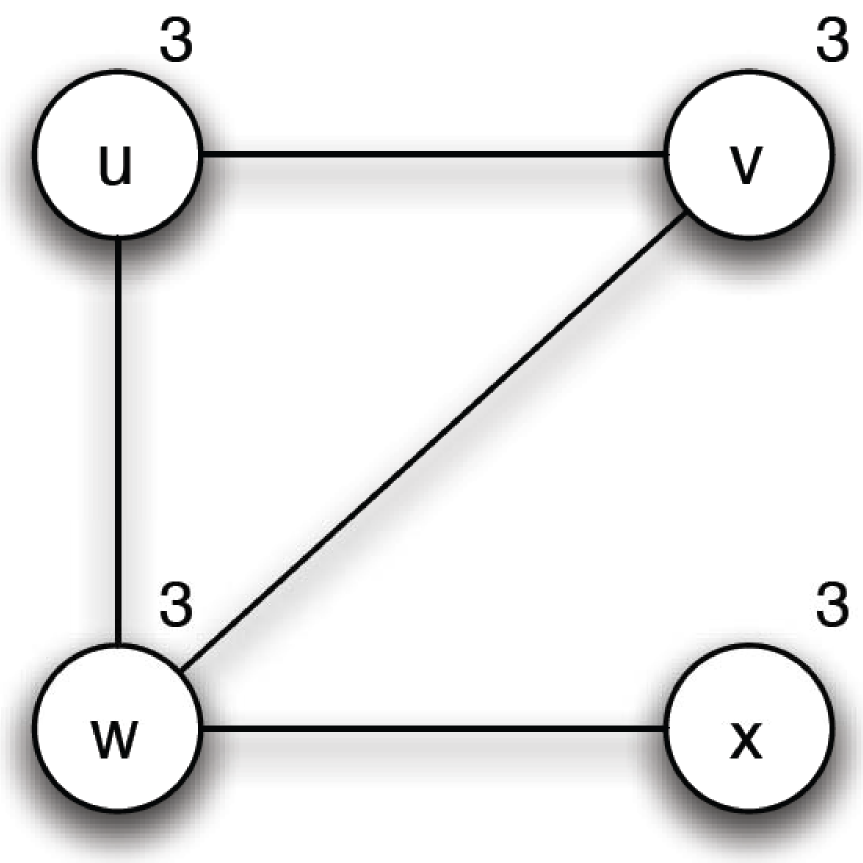
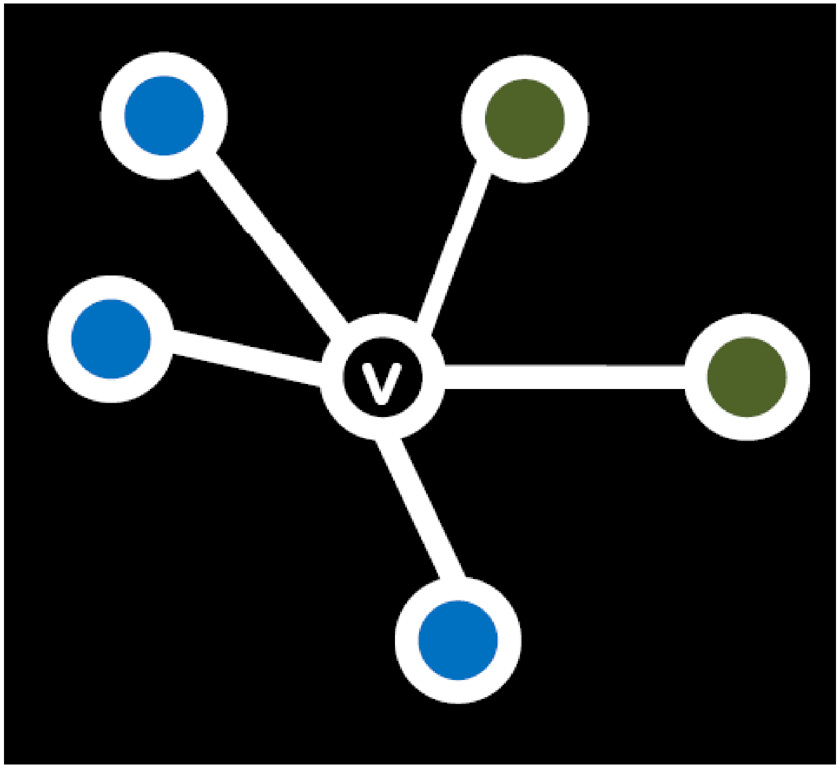


Yes!

[Morris 2000]

Game theoretic model of diffusion

- Based on 2 player coordination game
- 2 players – each chooses technology A or B



NODE v

LOCAL VIEW OF THE NETWORK


BASF L750
BASF
Do not touch the video tape
Ne touchez pas la bande vidéo
REC. DATE

[redacted]


PHILIPS
DOUBLE LAYER
50
270
HD DVD
30GB
Dual Layer
TOSHIBA
Blu-ray Disc
HD DVD

Diffusion of inovation

1. Each person can only adopt one “behavior”
2. You gain more if your friends have adopted the same behavior as you

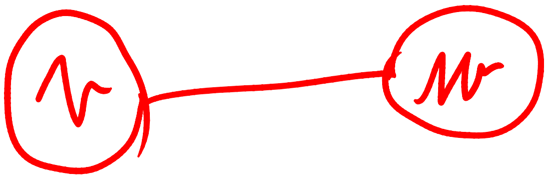
The model for two nodes

- If both v and w adopt behavior A, they each get payoff a>0

- If v and w adopt behavior B, they reach get payoff b>0

- If v and w adopt the opposite behaviors, they each get 0

Payoff matrix



w

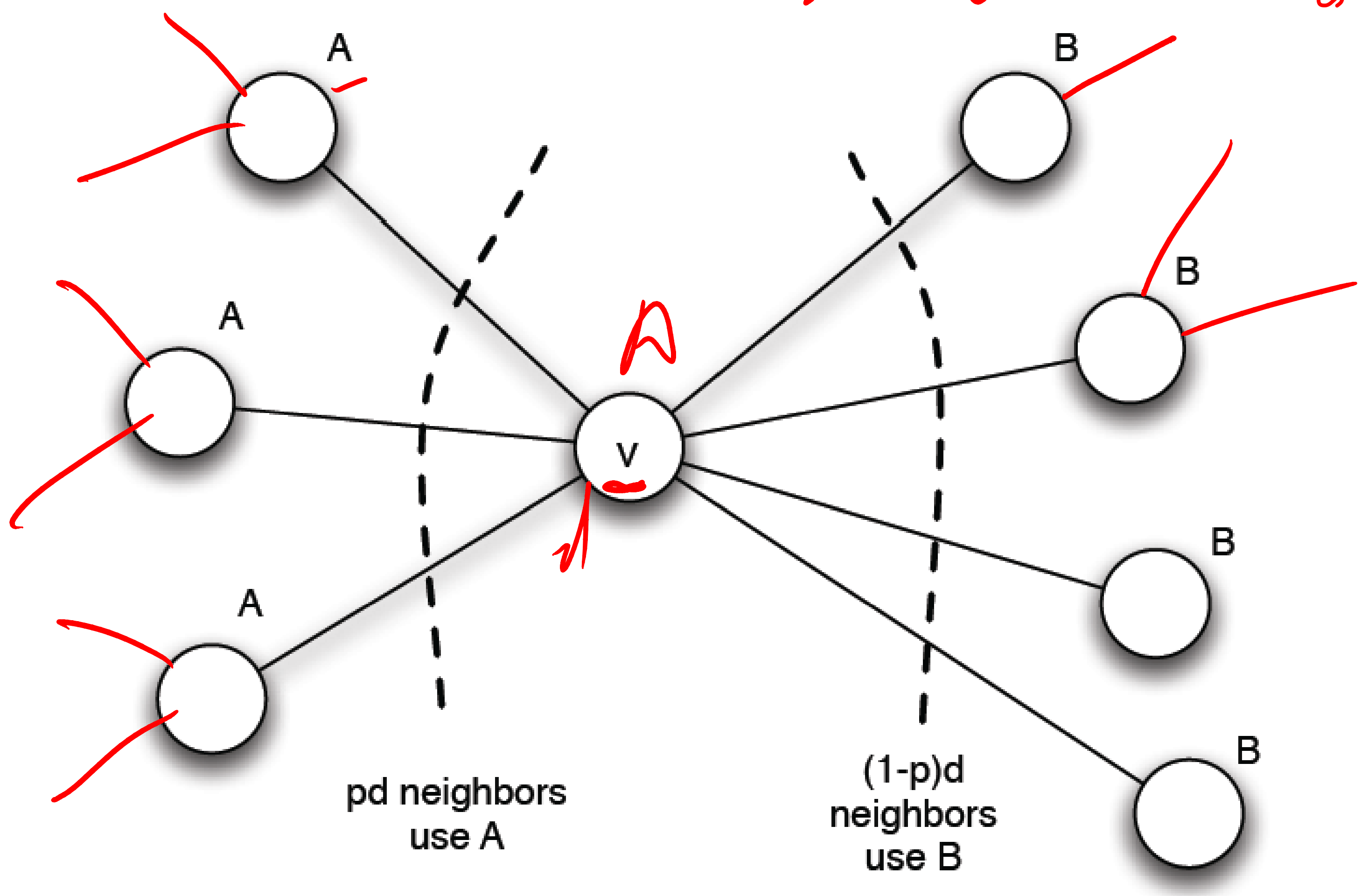
		A	B
v	A	a, a	$0, 0$
	B	$0, 0$	b, b

PAYOFF

- In some large network:
  - Each node v is playing a copy of this game with each of its neighbors
  - Payoff = sum of payoffs per game

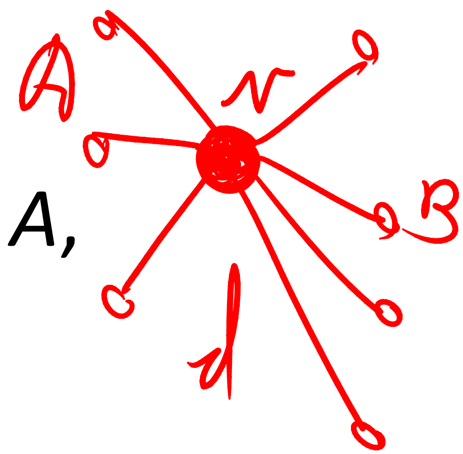
v's calculation

v's view of the network



v's calculation

- Let v have *d* neighbors
- If a fraction *p* of its neighbors adopt *A*, then:



- $Payoff_v$ $= a \cdot p \cdot d$ if v chooses A
  $= b \cdot (1-p) \cdot d$ if v chooses B

- v chooses A if: $a \cdot p \cdot d > b \cdot (1-p) \cdot d$

$$p > \frac{b}{a+b} = q$$

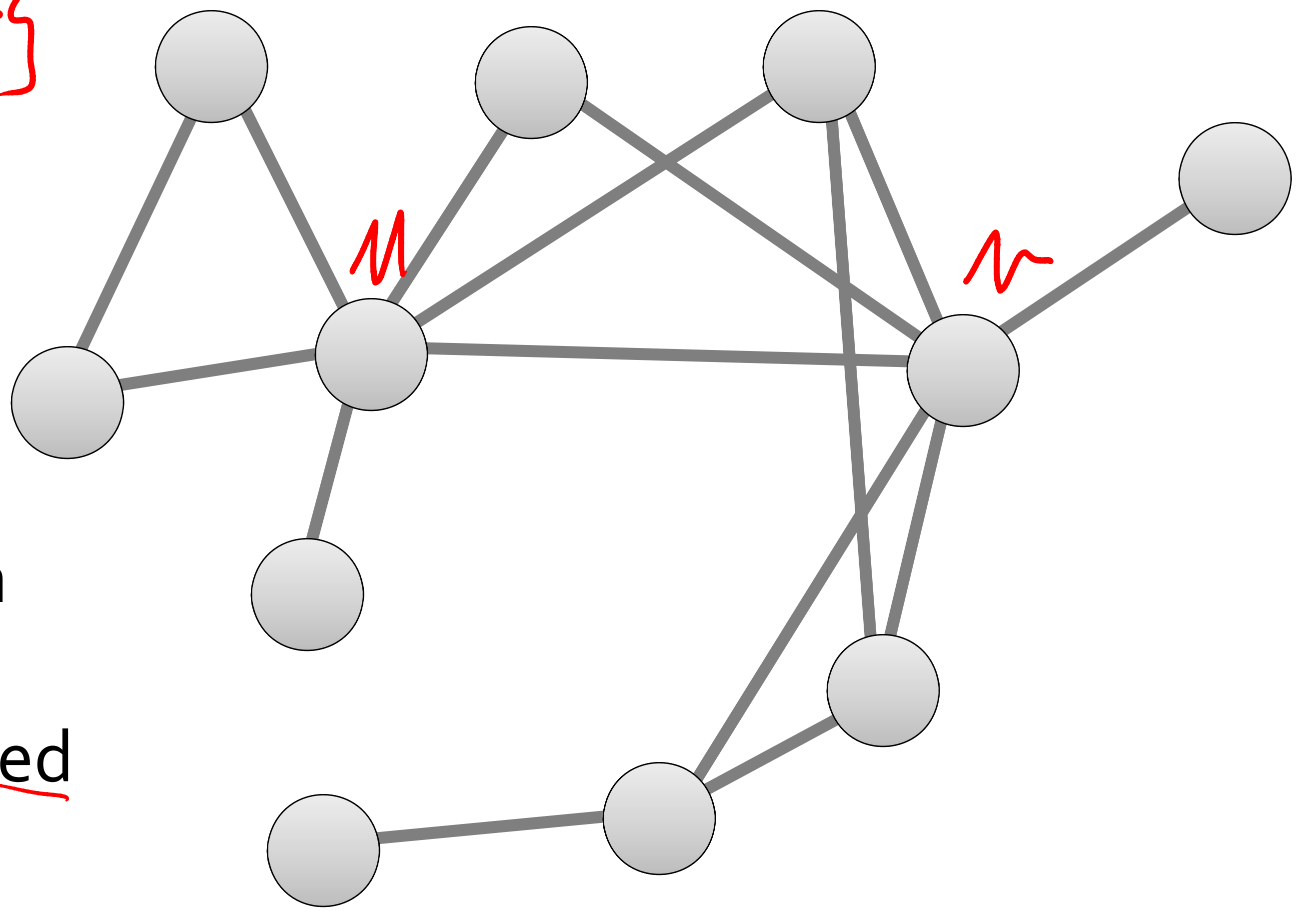
threshold

Scenario

- <u>Scenario:</u>
  Graph where everyone starts with B.
  Small set S of early adopters of A
  - hard wire S – they keep using A no matter what payoffs tell them to do

Example

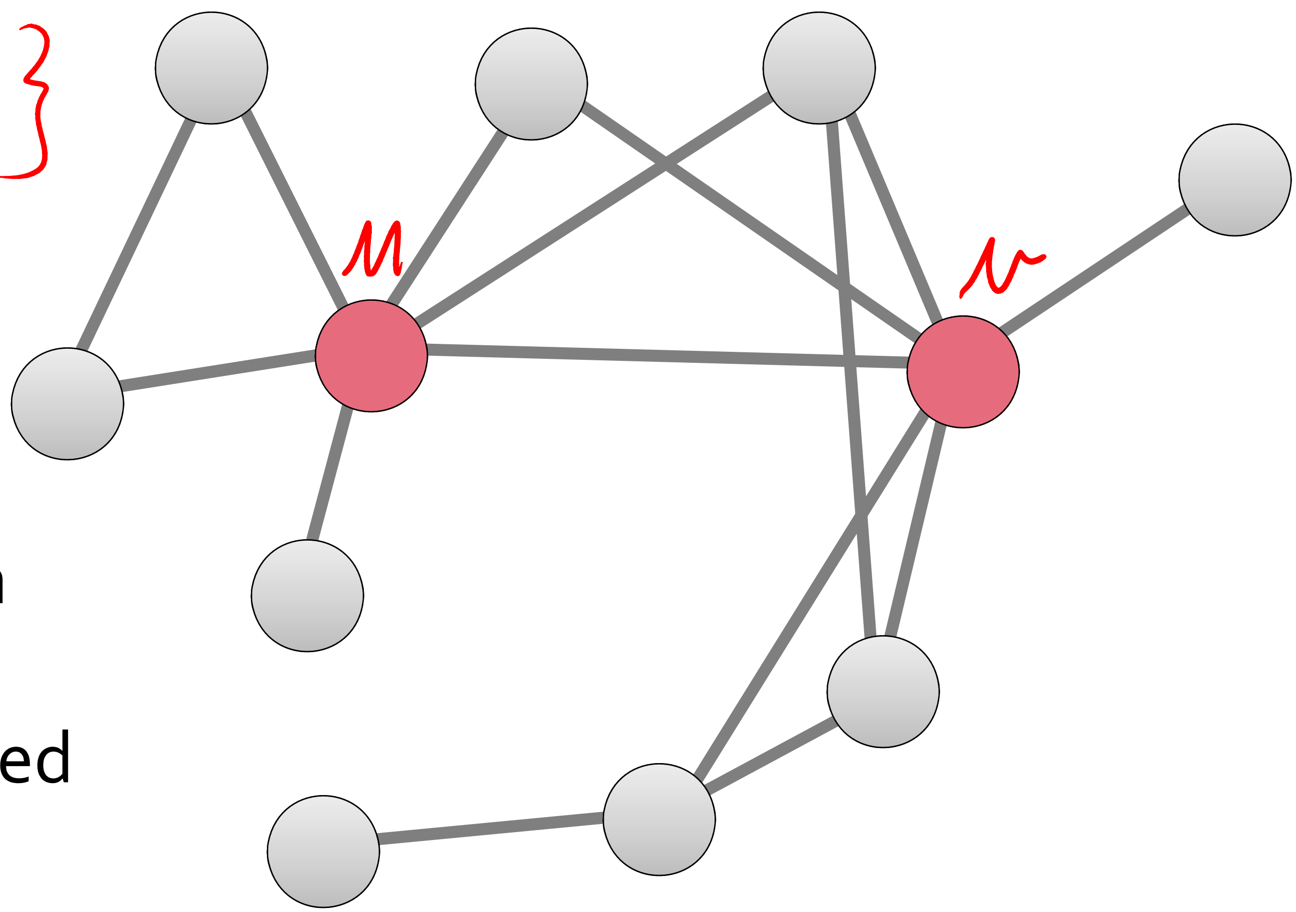
$S = \{u, v\}$



If more than 50% of my friends are red I'll be red

Example

$S = \{u, v\}$



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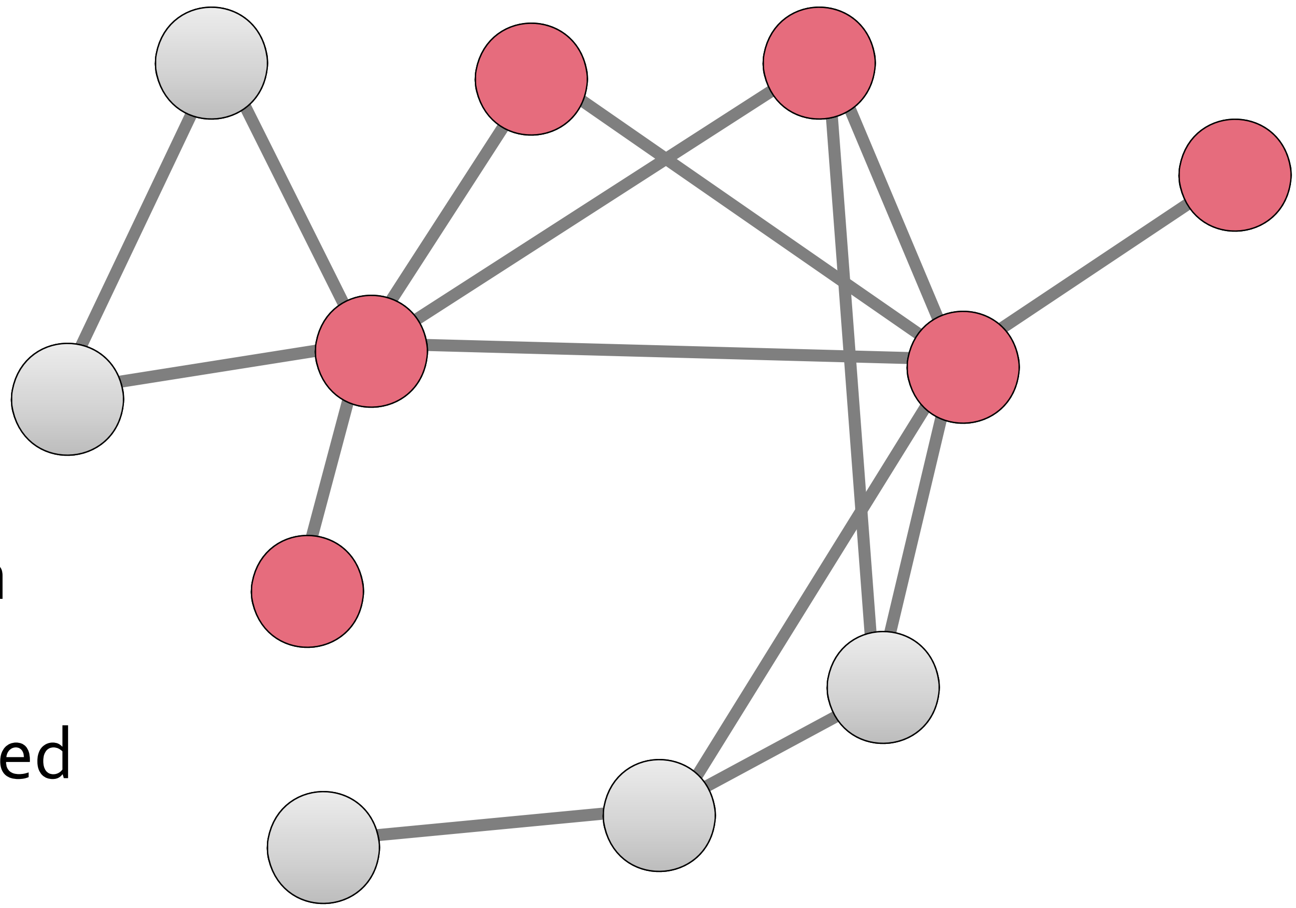

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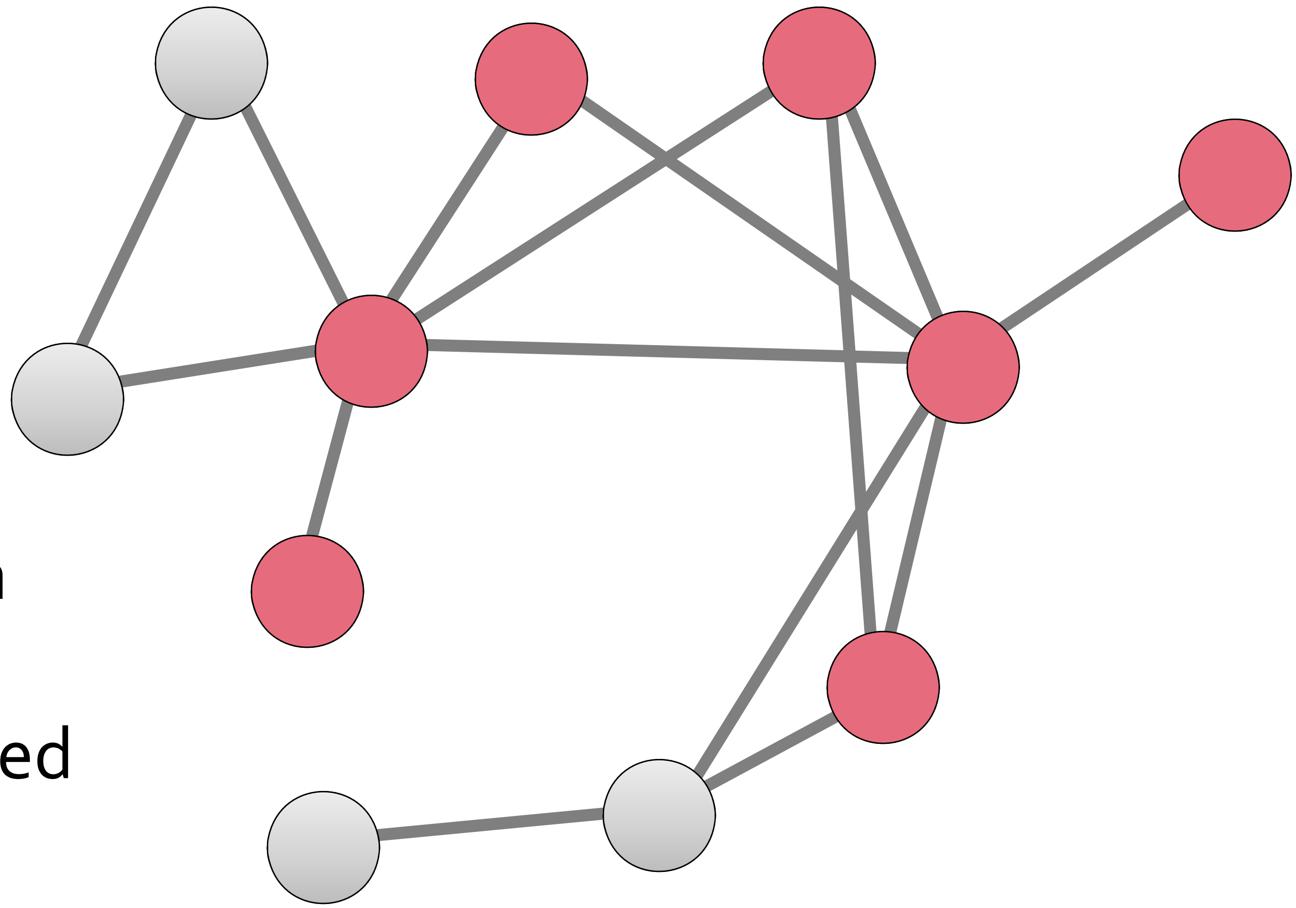

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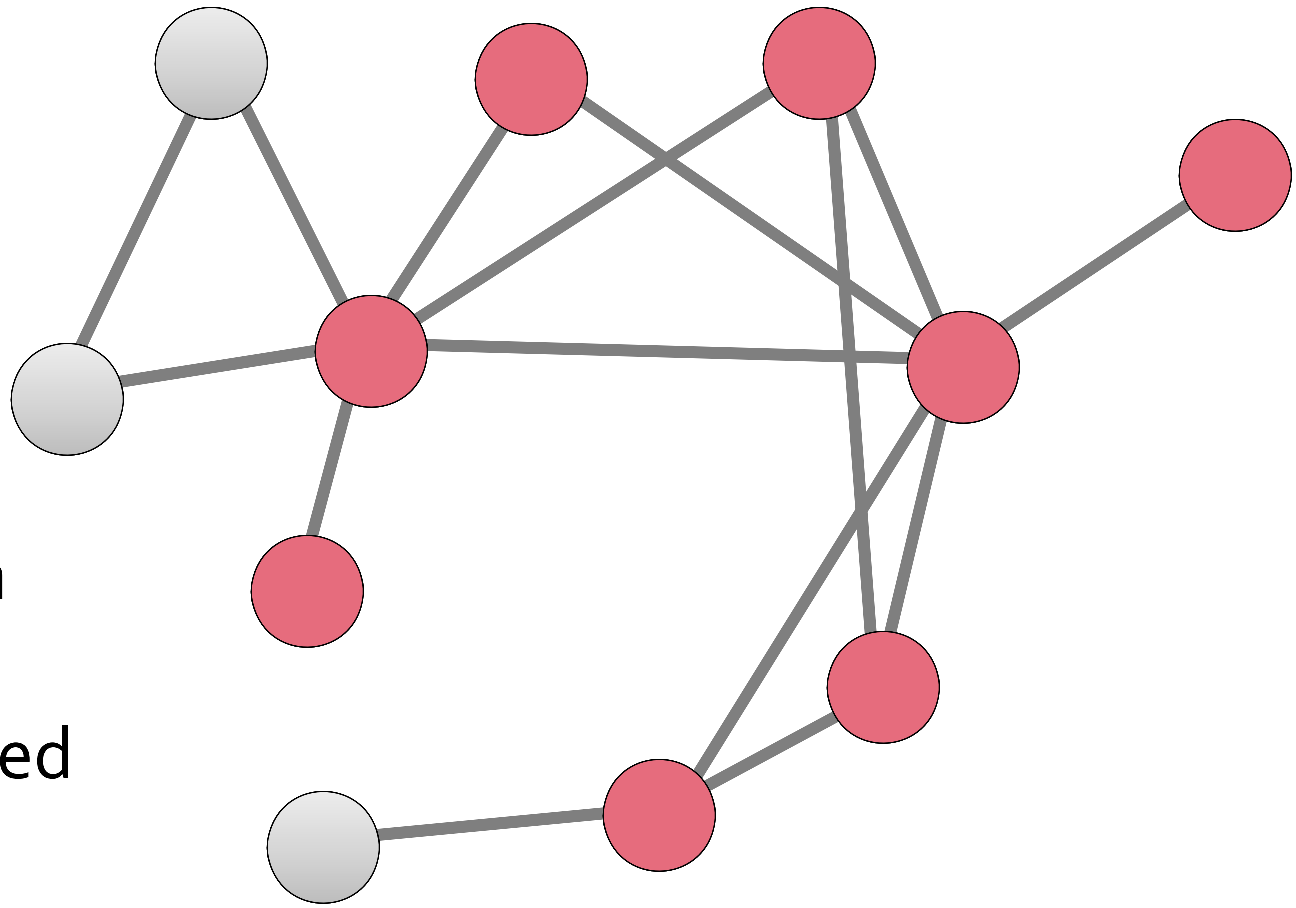

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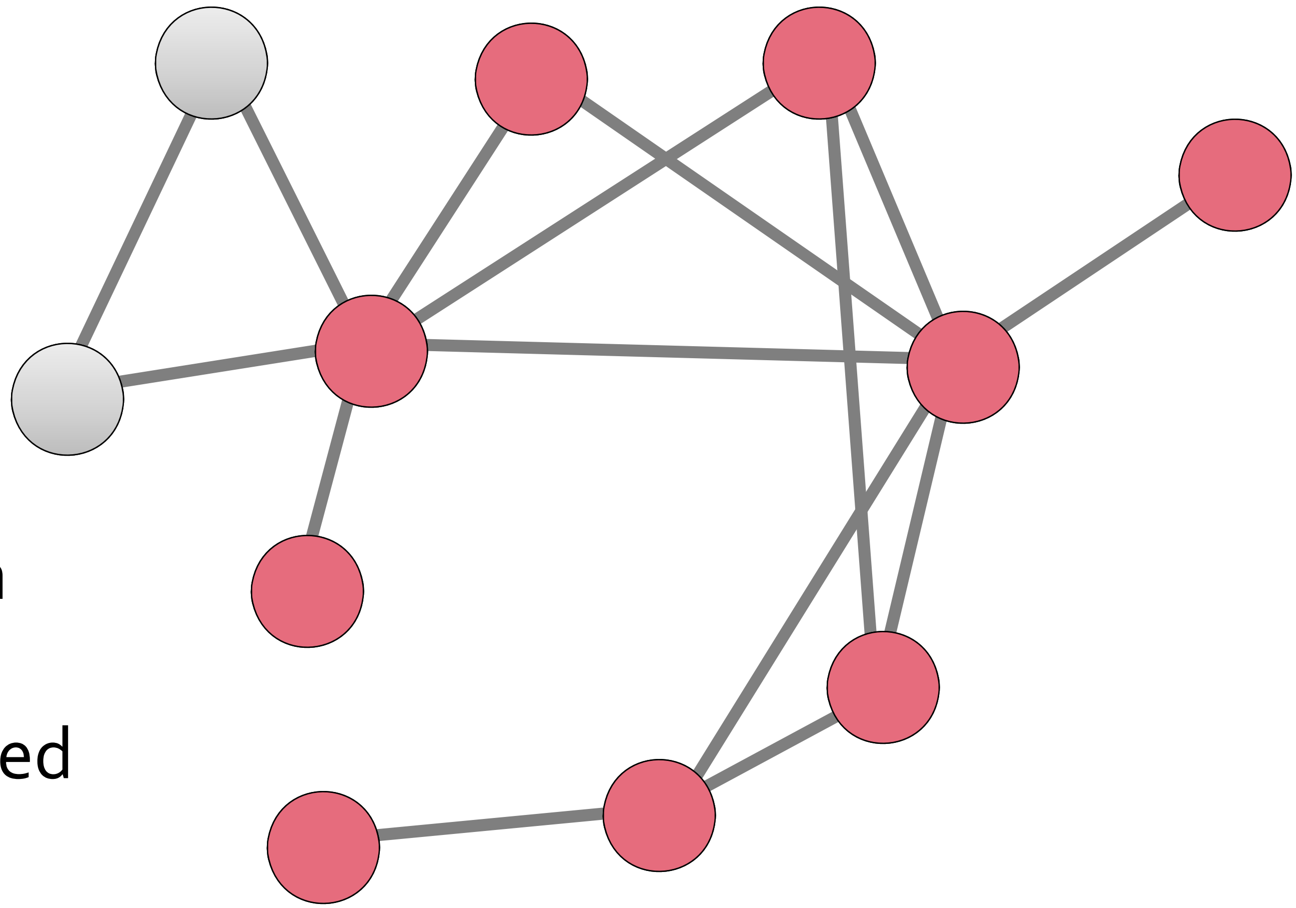

If more than 50% of my friends are red I'll be red

Monotonic spreading

- Observation:
  - The use of A spreads monotonically (nodes only switch from B to A, and never back to B)
- Why?
  - Induction on time
  - Suppose a node switches from $A \rightarrow B$, consider the **first** node v to do this at time t
  - Earlier at some time t' ($t' < t$) node v switched $B \rightarrow A$
  - So at time t' v was above threshold for A
  - Up to time t no node switches back, so node v can only have more neighbors who use A at t compared to t'

$\rightarrow\leftarrow$ CONTRADICTION