Cascading Behavior in Networks

CptS 591: Elements of Network Science

First, let's take a stock

DONE:
- ✓ Assignment 1
- ✓ Assignment 2
- ✓ Exercise 1
- ✓ Exercise 2
- ✓ Mid Term

DONE:
- ✓ Reaction paper
- ✓ Project proposal

TO DO:
- Project Presentation (April 27 and 29)
- Final Report (May 3)

Weights:
- Assignments (30%)
- Project (50%)
- Mid Term (18%)
- Participation (2%)

Weeks left:

Wk 4/13 – 4/15	Wk 4/20 – 4/22	Wk 4/27 – 4/29	Wk 5/3
		Project Presentations	Report

Cascading behavior

Influence maximization

Epidemic models

Connectedness of a complex system

- Means two things:
  - An underlying structure of *interconnecting links*
  - An *interdependence in the behavior* of individuals who inhabit the system, so that the outcome for any one depends on the combined behaviors of all

Connectedness of a complex system

- Means two things:
  - An underlying structure of *interconnecting links*
    - Studied via graph theory
  - An *interdependence in the behavior* of individuals who inhabit the system, so that the outcome for any one depends on the combined behaviors of all
    - Studied via game theory

Following the Crowd: information cascade

- When people are connected by a network, it becomes possible for them to influence each other's behavior and decisions
- This basic principle gives rise to a range of social processes in which networks serve to aggregate individual behavior and produce population-wide, collective outcomes

- There is limitless set of situations in which people are influenced by others:
  - Opinions they hold
  - Products they buy
  - Political positions they support
  - Activities they pursue
  - Technologies they use…

Following the Crowd

- There are many settings in which it may be rational for an individual to imitate the choice of others
- Two distinct reasons can be identified:
  - Information effects
    - choices made by others can provide information about what they know
  - Direct-benefit effects
    - there are direct benefits from copying the decisions of others
- Information effects may entail making choice contrary to one's own information
  - Example: restaurant choice
- This results in a phenomenon called *herding* or *information cascade*
- Information cascade has the potential to occur when people make decisions sequentially, with later people watching the actions of earlier people and making inferences

Diffusion in Networks

- When we model processes by which new ideas and innovations are adopted by a population, the underlying social network can be considered at two conceptually very different levels of resolution:
  - Network viewed as a relatively amorphous population of individuals and look at effects in aggregate
  - Look closer at the fine structure of the network and consider how individual nodes are influenced by their network neighbors
- The second view addresses a number of phenomena that cannot be modeled well at the level of homogenous populations

Diffusion of Innovations

- Influential early studies focused on informational effects
  - Ryan and Gross (1943)
    - Studied the adoption of hybrid seed corn among farmers in Iowa
    - Found that while most farmers first learned about hybrid seed from salesmen, most were first convinced to try using based on experience of neighbors in their community
  - Coleman, Katz and Menzel (1966)
    - Studied the adoption of tetracycline by physicians in the US
    - Mapped out the social connections among doctors making decisions about adoption
- Studies focused on direct-benefit effects
  - Long line of research on communication technologies (the spread of telephone, fax machine, email, etc)

Common principles out of diverse diffusion of innovation studies (Everett Rogers, 95)

- Success of innovation also depends on its
  - Complexity (for people to understand and implement)
  - Observability (people become aware that others are using it)
  - Triability (people can mitigate its risks by adopting it gradually and incrementally)
  - Compatibility (with the social system it is entering)

Modeling Diffusion through a Network

- Consider a model built in terms of basic underlying model of individual decision making
- As individuals make decisions based on decisions of their neighbors, a pattern of behavior begins to spread across the links of the network
- Possible to start with informational effects or direct-benefit effects
- We consider direct-benefit effects and start with a model due to Stephen Morris (2000)

Game theoretic model of diffusion

- Based on a two player coordination game
  - Each node has a choice between two possible behaviors, A and B.
  - If nodes v and w are linked by an edge, then there is an incentive for them to have their behaviors match.
  - Represented as a game in which v and w are players, and A and B are the possible strategies.
  - Define the payoffs as follows:
    - If v and w both adopt behavior A, they each get a payoff of $a > 0$;
    - If they both adopt B, they each get a payoff of $b > 0$; and
    - If they adopt opposite behaviors, they each get a payoff of 0.
  - This can be written as payoff matrix
- In the network at large
  - Each node v plays a copy of the game with each of its neighbors
  - Payoff of a node = sum of payoffs played on each edge

v \ w	A	B
A	a, a	0, 0
B	0, 0	b, b

Question faced by v

- Suppose some of v's neighbors adopt A, and some adopt B.
- What should v do to maximize its payoff?

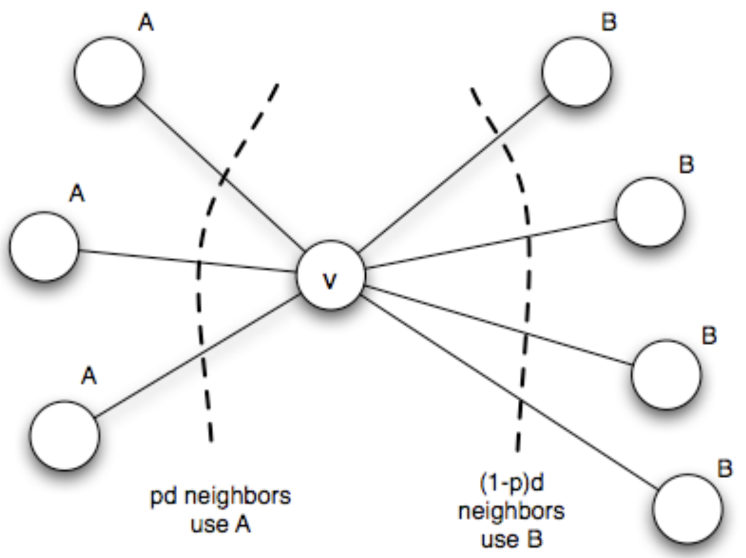
- Let v have d neighbors
- Suppose p fraction of A's neighbors adopt A
- Then
  - If v chooses A:

    Payoff = (pda)
  - if v chooses B:

    Payoff = (1-p)db
- Thus, A is a better choice if

  pda $\geq$ (1-p)db

  Or p $\geq$ b/a+b



Threshold:
v chooses A if
p $\geq$ q = b/a+b

Intuition:
small q =>
A is more enticing,
it takes a small fraction of your neighbors engaging in A for you to do so

Cascading behavior

- In any network, there are two obvious equilibria to the network-wide coordination game:
  - Everyone adopts A
  - Everyone adopts B
- We want to understand:
  - How easy it is to “tip” the network from one of these equilibra to the other
  - What other intermediate equilibria look like

    (states of coexistence where A is adopted in some parts of the network and B is adopted in others.)

Cascading behavior: example scenario

- Suppose everyone in the network is initially using B
- Then a small set of "initial adopters" all decide to use A
- Some of the neighbors of initial adopters may now decide to switch to A as well
- And then some of their neighbors may switch and so forth, in a potentially cascading fashion
- When does this result in every node eventually switching to A? When this isn't the result, what causes the spread of A to stop?

Example 1 (complete cascade)

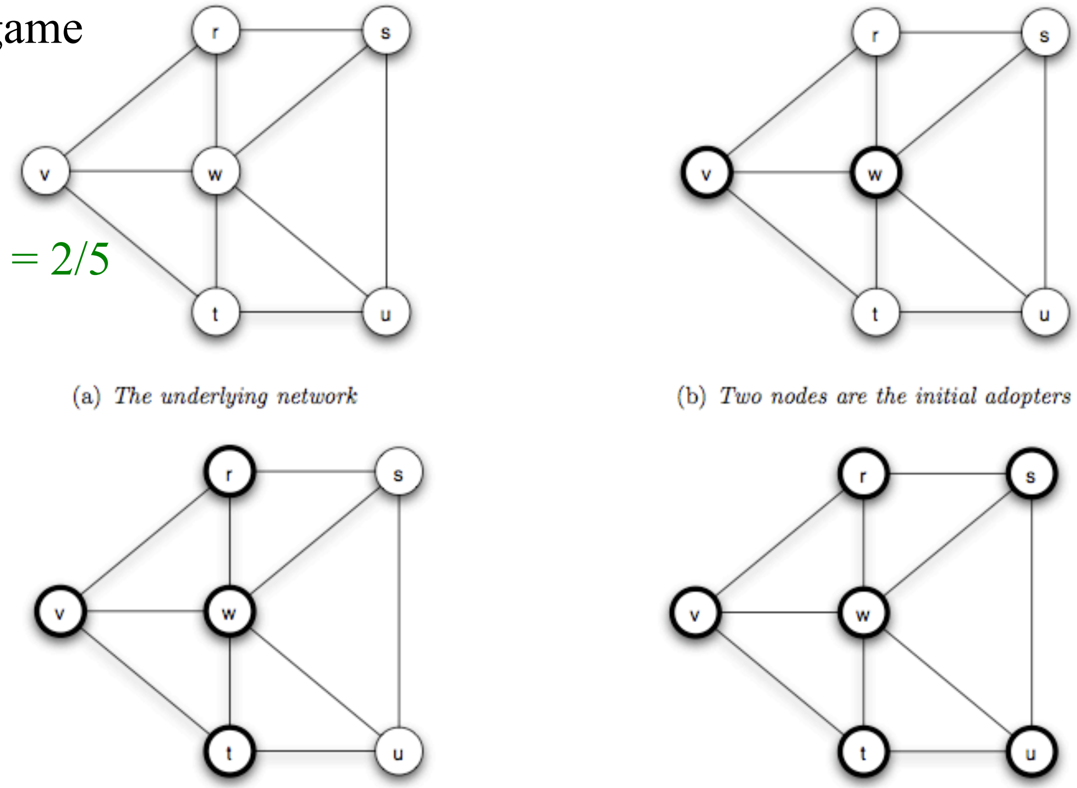
Coordination game

Setup:

a = 3

b = 2

=> q = 2/(3+2) = 2/5



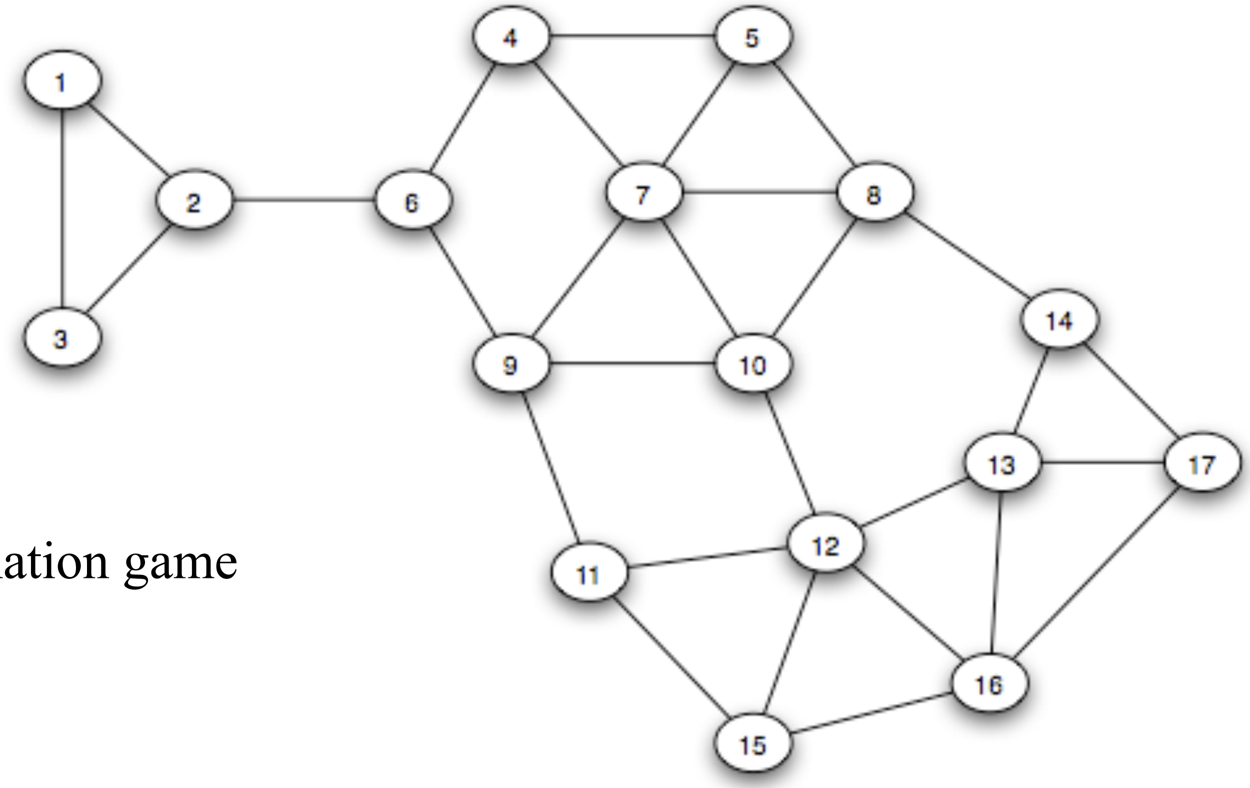
(a) *The underlying network*

(b) *Two nodes are the initial adopters*

(c) *After one step, two more nodes have adopted*

(d) *After a second step, everyone has adopted*

Example 2



Coordination game

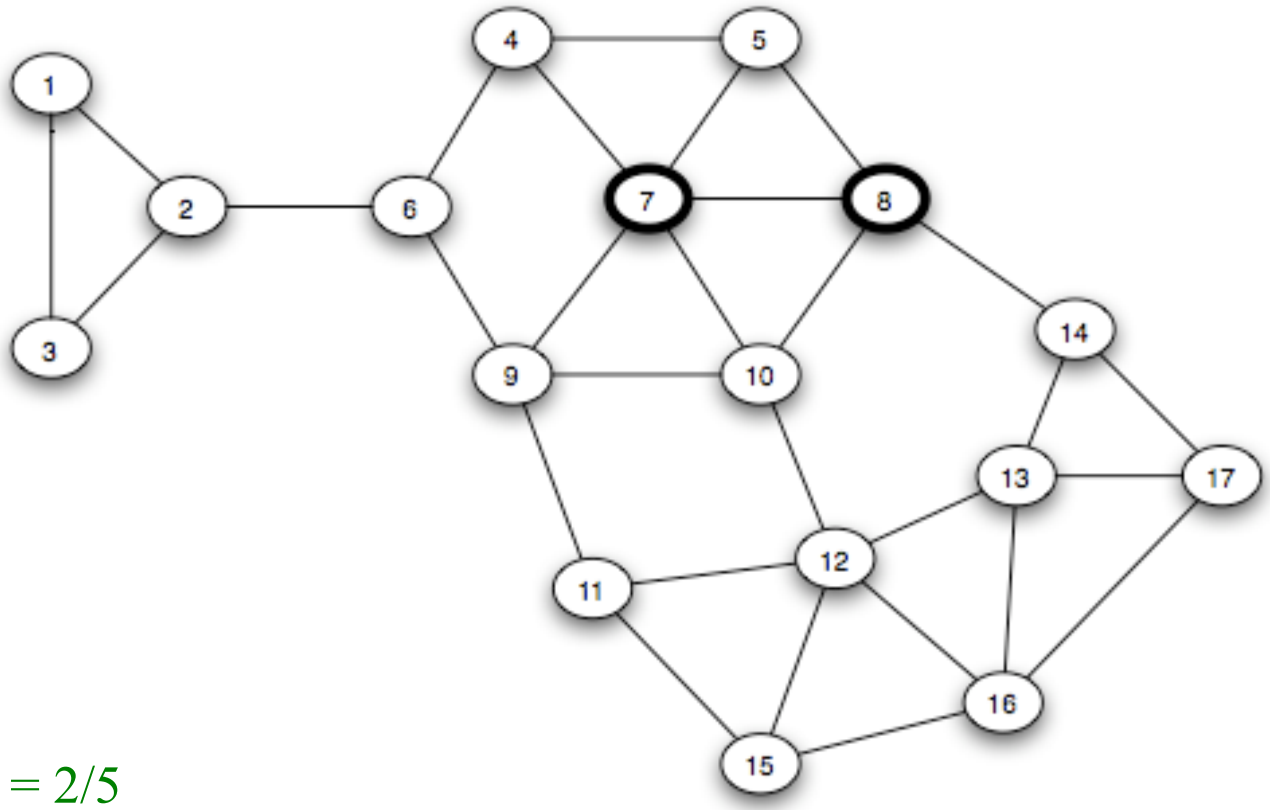
Setup:

$a = 3$

$b = 2$

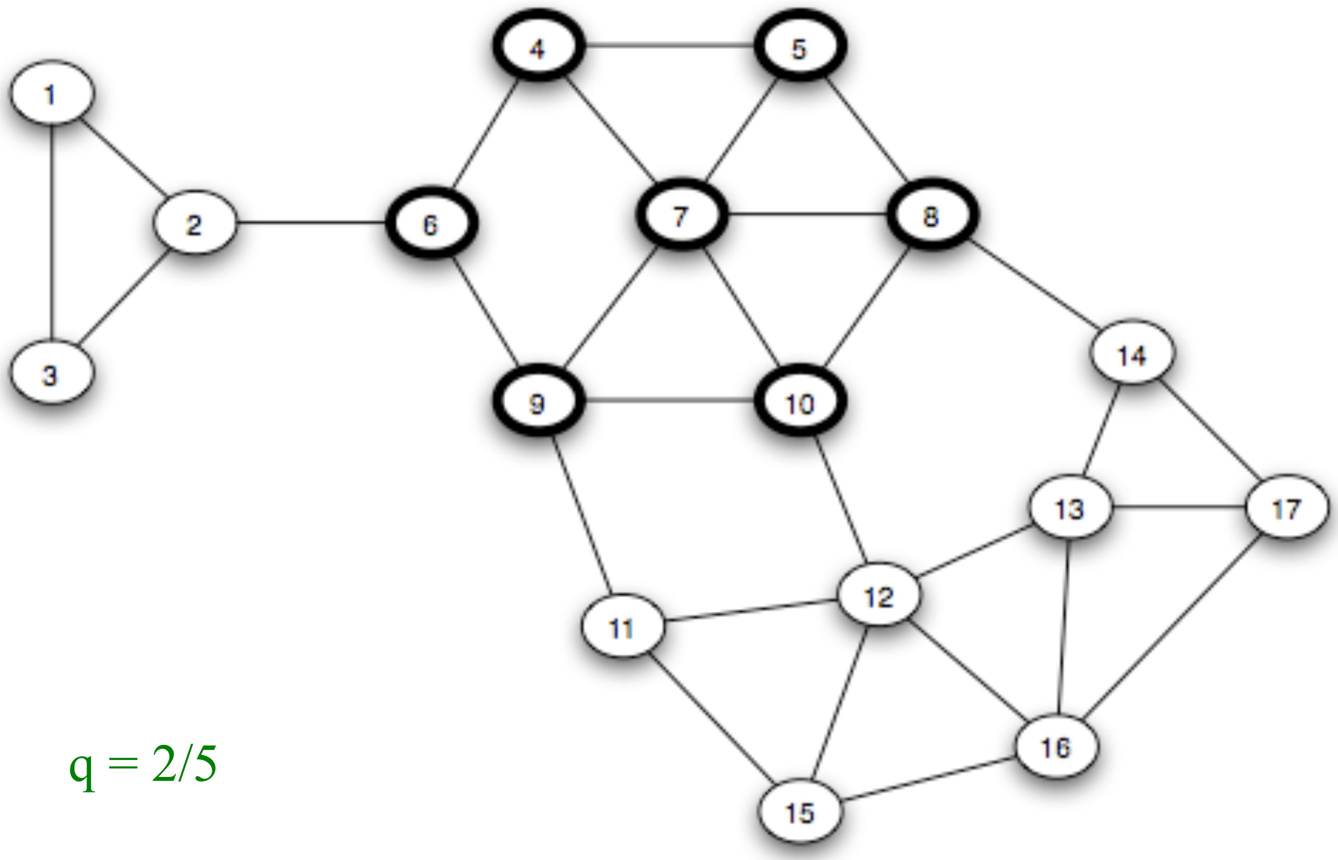
$\Rightarrow q = 2/(3+2) = 2/5$

Example 2



q = 2/5

Example 2



q = 2/5

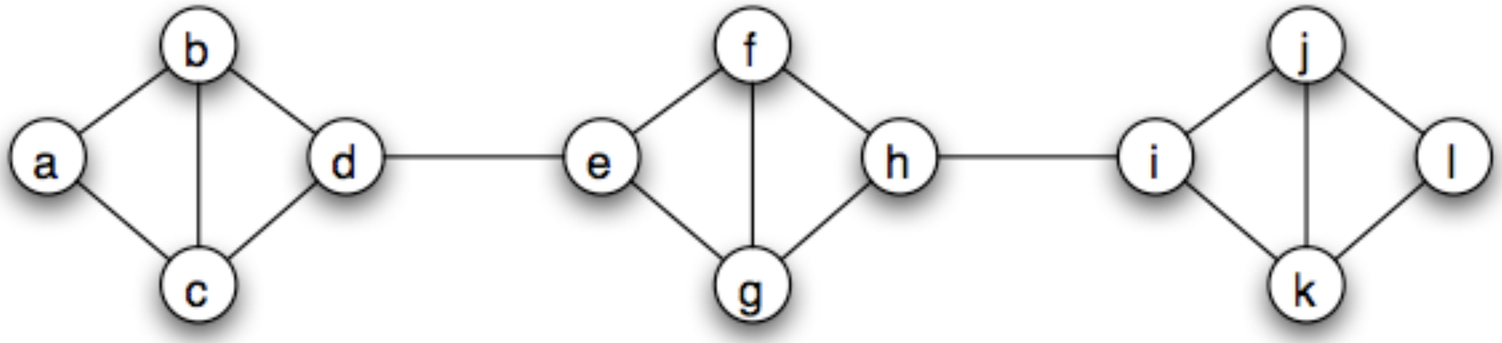
Cascading behavior and viral marketing

- Observations from Example 2:
  - Tightly-knit communities can work to hinder the spread of innovation
  - As a result we get coexistence between A and B (a common real world phenomenon; e.g. political views, age/life style groups in social networking sites)
  - Suggests strategy for market competition
    - maker of A can increase its reach by raising the quality of its product
    - maker of A could try to convince a small set of key people using B to switch to A
    - The latter issue is considered in research in viral marketing

Cascades and Clusters

- Saw that tightly-knit communities stop spreading of cascades. Need to make this more precise.

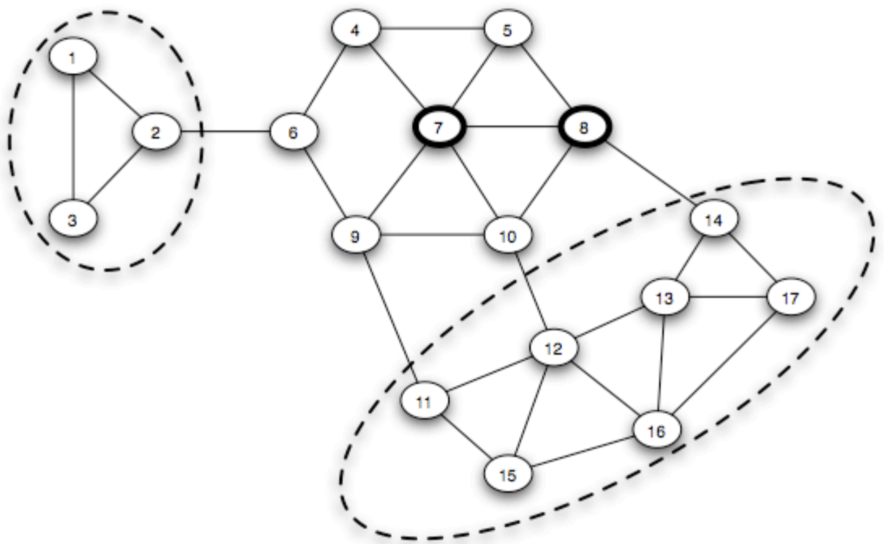
- Def: a cluster of density p is a set of nodes such that each node in the set has at least a fraction p of its network neighbors in the set.



Each 4-node cluster has density 2/3

Relationship between clusters and cascades

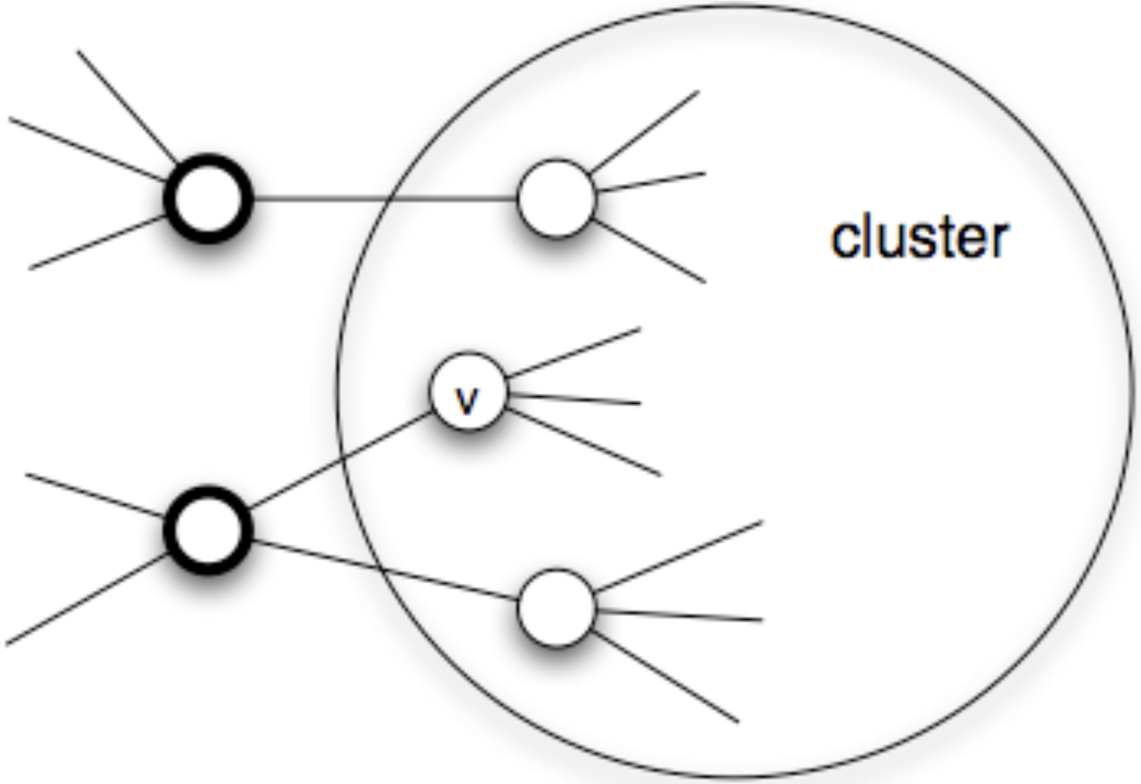
- Consider a set of initial adopters of A, with a threshold of q for nodes in the remaining network
  - i) if the remaining network contains a cluster of density greater than 1-q, then the set of initial adopters will not cause a complete cascade
  - ii) whenever a set of initial adopters does not cause a complete cascade with threshold q, the remaining network must contain a cluster of density greater than 1-q



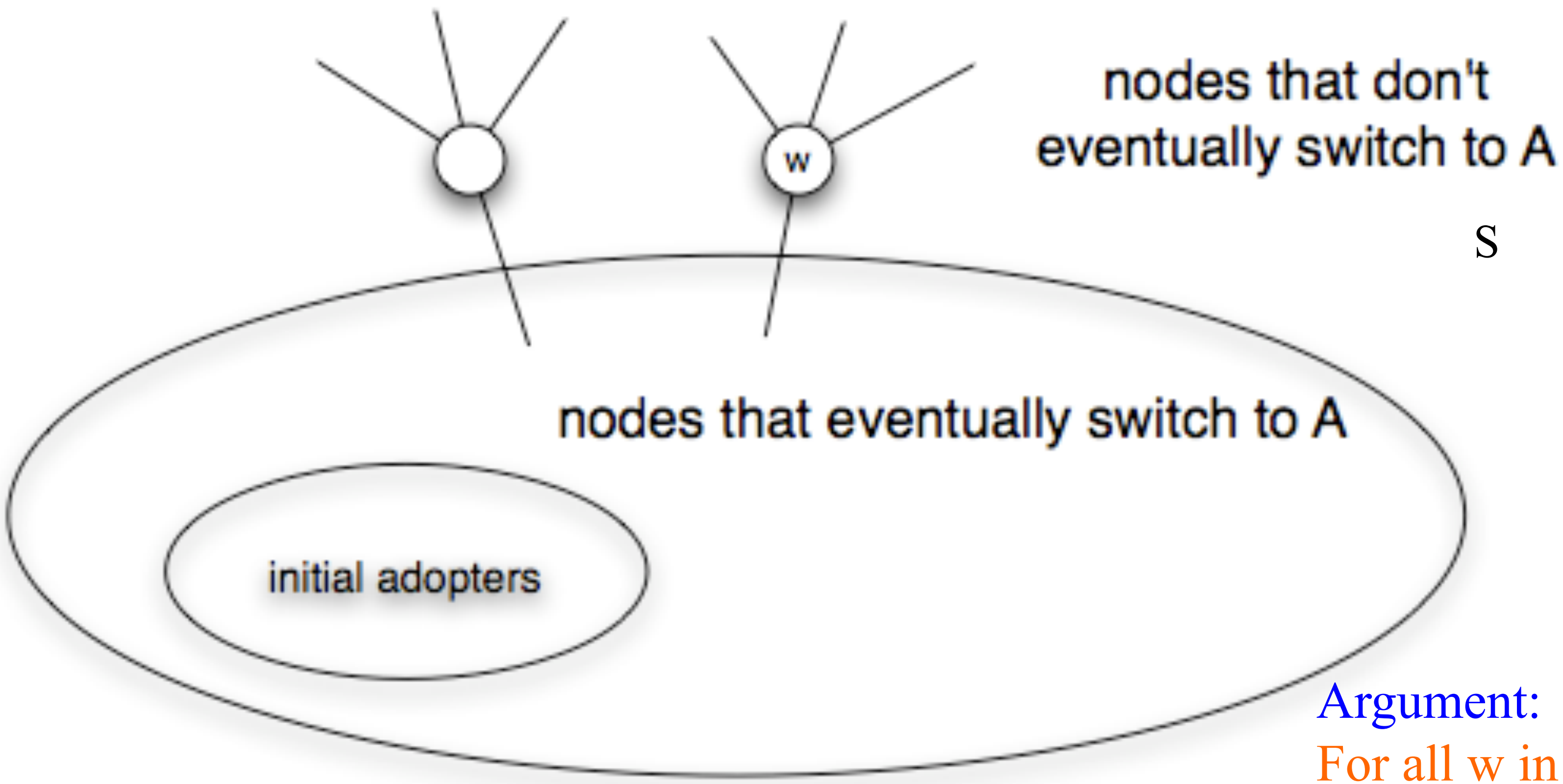
We see two clusters, each of density 2/3

Proof (i): clusters are obstacles to cascades

- Suppose A is spreading with threshold q,
- Remaining ntk has a cluster of density > 1-q
- Assume v adopts A
- Since v is in a C with density greater than 1-q, more than 1-q neighbors of v are inside C => less than q are outside C=> v could not have switched.



Proof (ii): clusters are the only obstacles to cascades



Argument:

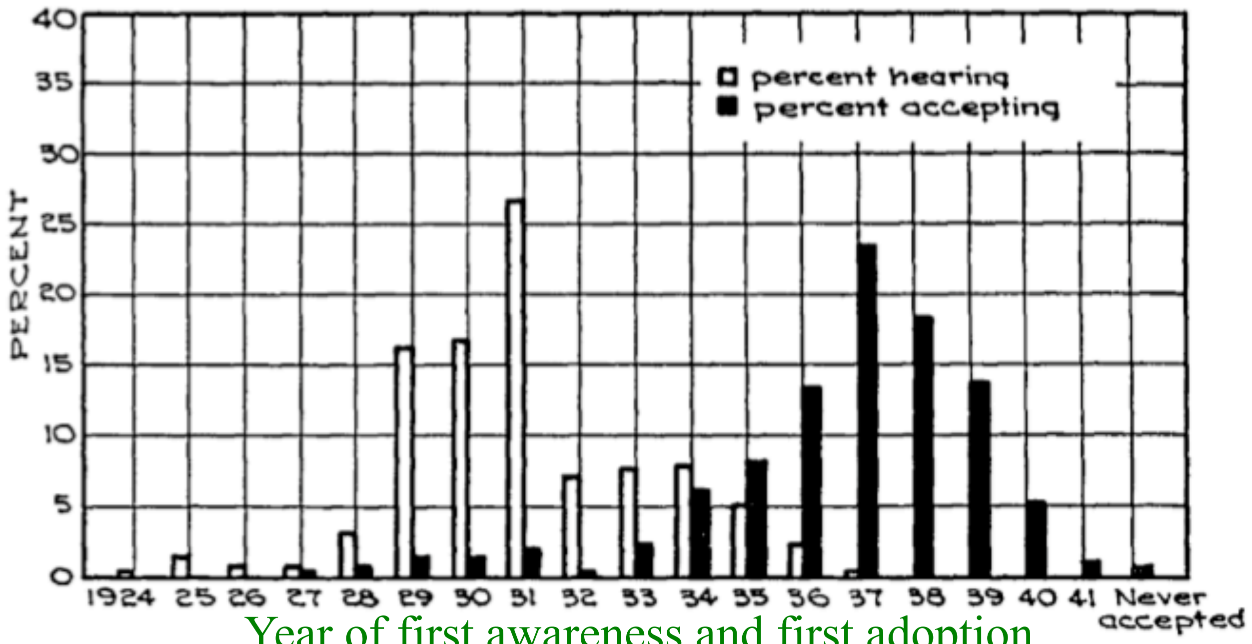
For all w in S:

fraction of neigs of w using B > 1-q.

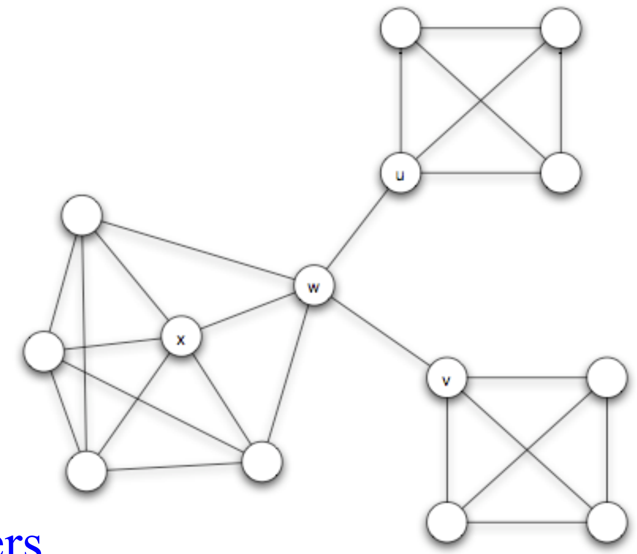
But all such neighs are in S.

So S is a cluster of density > 1-q

Diffusion, Thresholds and the Role of Weak Ties



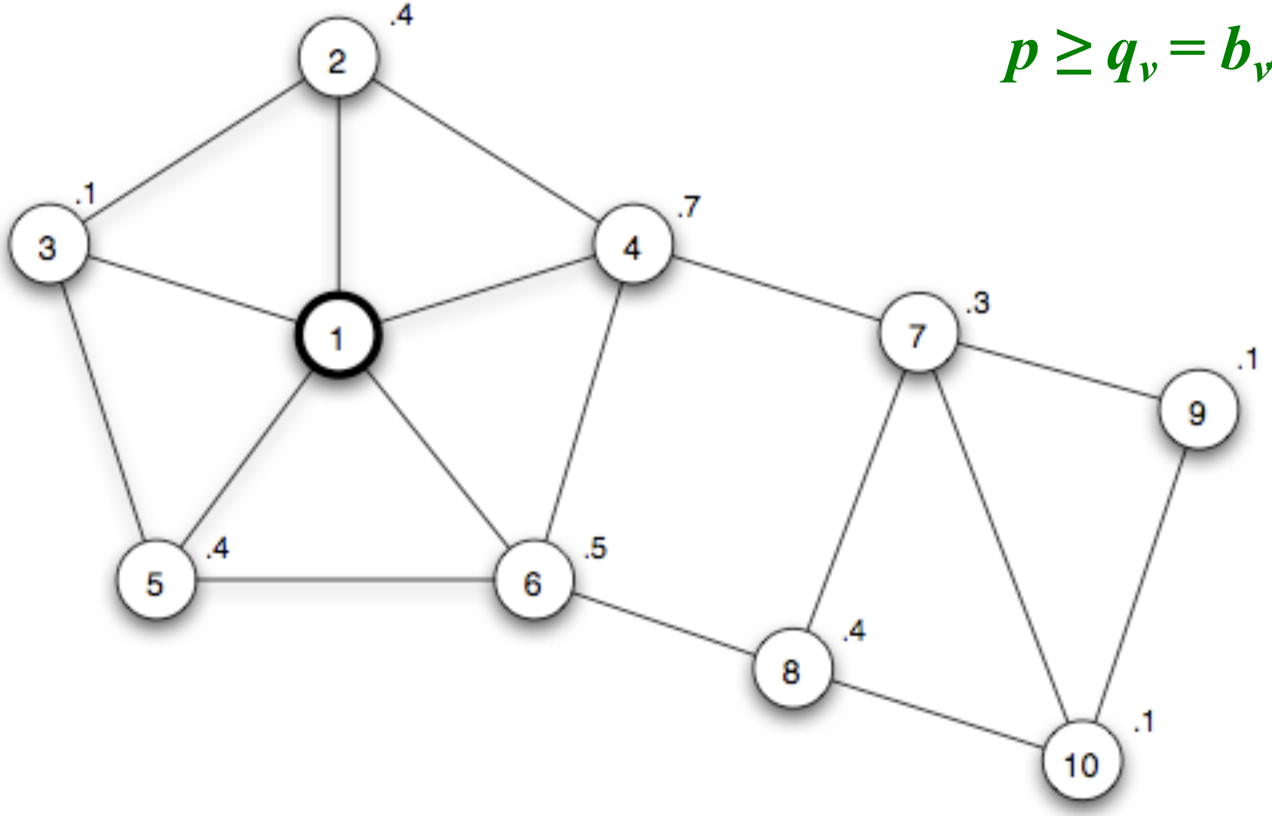
Year of first awareness and first adoption in the Ryan-Gross study



Suppose v, x are intial adopters, and q is ½.
All but u and v will adopt.
⇒double-edged aspect to bridges and local bridges

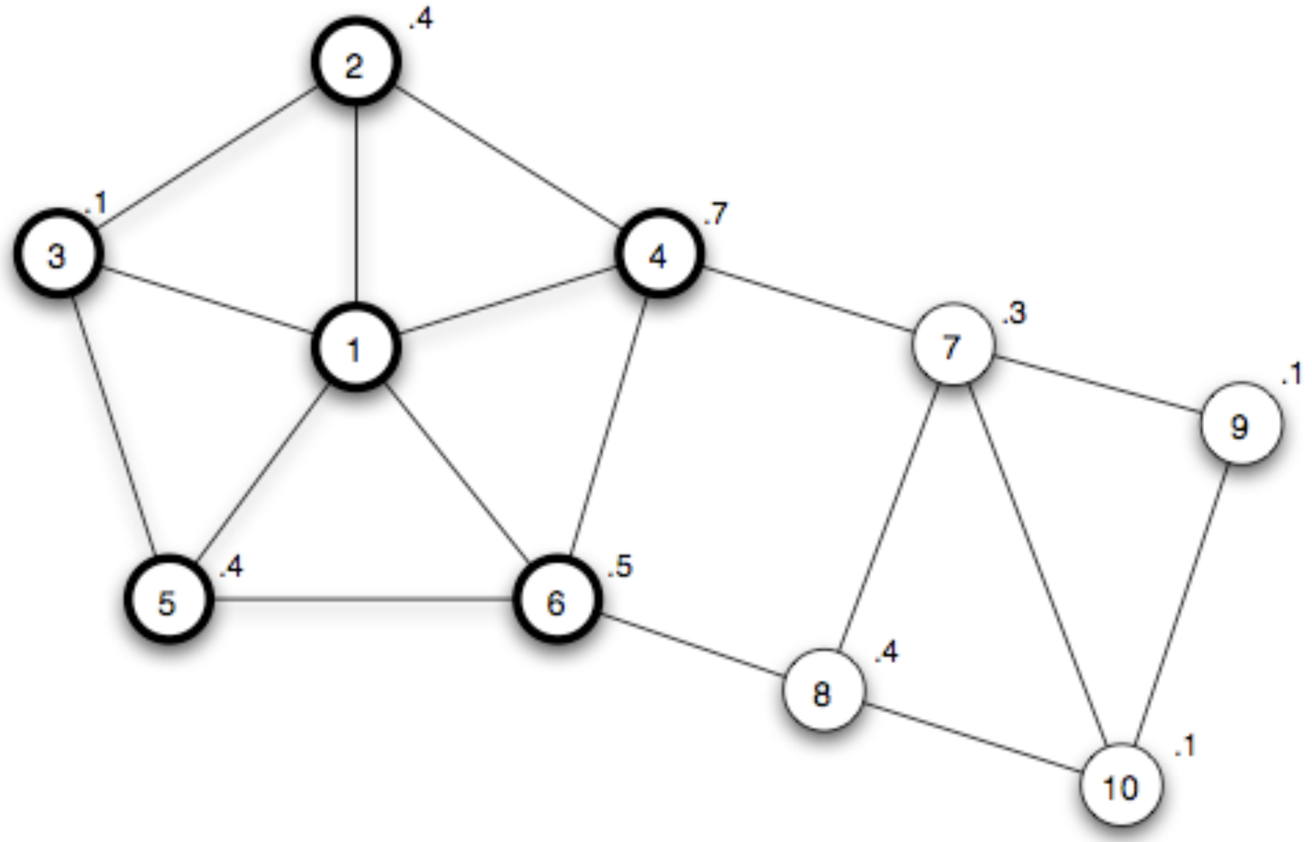
Extensions of the basic cascade model

- Heterogeneous thresholds



$p \geq q_v = b_v/a_v+b_v$

Heterogeneous thresholds



Observations from the previous example

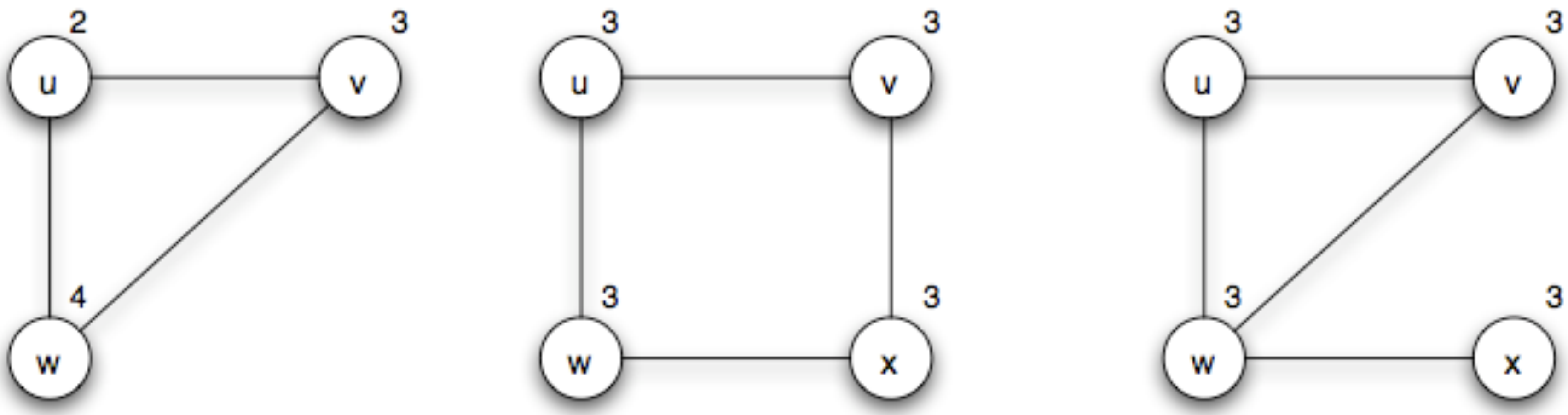
- Diversity in node thresholds plays an important role that interacts in complex ways with the structure of the network.
  - E.g. Despite its central position, node 1 would not have succeeded in converting anyone at all to A were it not for the extremely low threshold on node 3.
  - This relates with the observation that, to understand spread of behaviors in social networks, we need to take into account not just the power of influential nodes but also the extent to which these influential nodes have access to easily influenceable people.
- The notion of clusters as obstacles to cascades can be extended to the case where thresholds are heterogeneous.

Knowledge, Thresholds, and Collective Action

Consider a related topic that integrates network effects at both the population level and the local network level.

- Collective action and pluralistic ignorance
  - E.g problem of organizing a protest
- Model for the effect of knowledge on collective action
  - Effect of structure of underlying social network on individual’s decision making
  - Example: next slide
- Common knowledge and social institutions
  - Widely publicized speech
  - Super Bowl commercials

Knowledge, Thresholds and Collective Action



Threshold k : I will participate if I am sure that at least k people in total participate

Recap

- Diffusion in Networks
- Modeling Diffusion through a Network
  - A networked coordination game
  - Cascading Behavior
  - Cascading Behavior and Viral Marketing
- Cascades and Clusters
- Diffusion, Thresholds, and the Role of Weak Ties
- Extensions of the Basic Cascade Model
  - Heterogeneous Thresholds
- Knowledge, Thresholds, and Collective Action
  - Collective Action and Pluralistic Ignorance
  - A model for the effect of knowledge on collective action
  - Common knowledge and social institutions

- Further reading: Chapter 19 of Easley-Kleinberg