Cascading Behavior in Networks

Social Computing

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Lecture Topics

- Modeling Diffusion
- Cascades & Clusters
- Cascade Capacity

Diffusion

- Cascade from structural perspective:
  - Individuals influenced by neighbors
    - Technology that friends use
    - Friends political views, etc.

- "Nodes" adopt a new behavior once a **sufficient proportion of their neighbors** have done so.

Diffusion- Cnt.

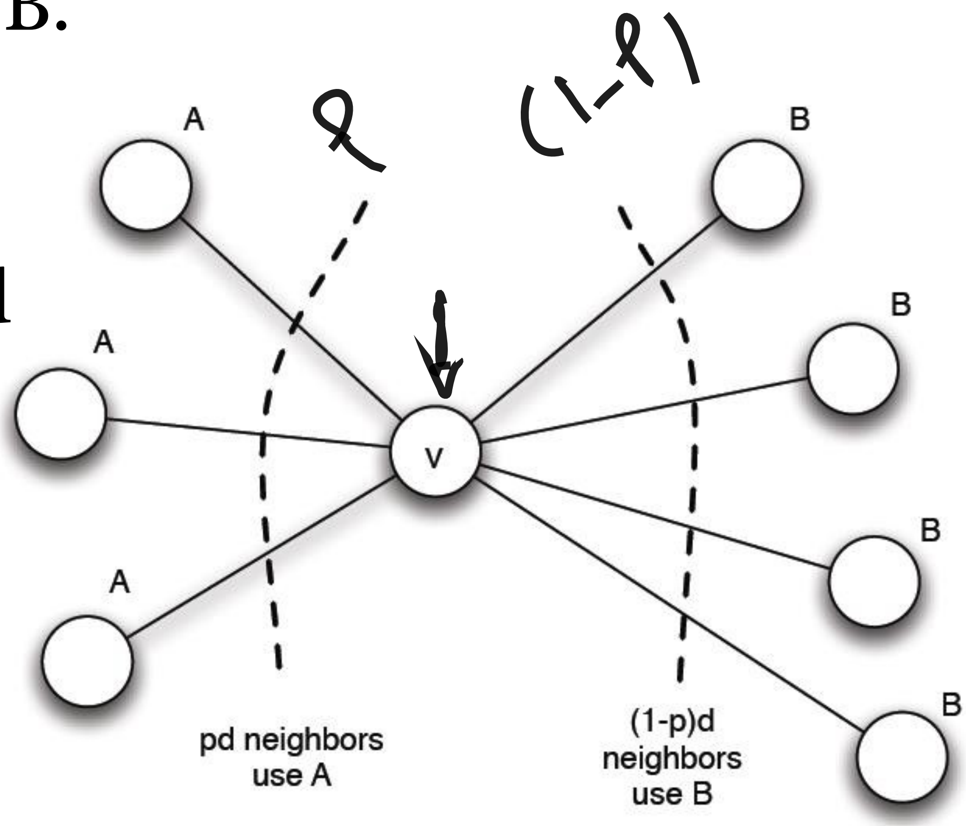
- Networked Coordination Game
  - Nodes choose btw behaviors A or B.
  - Neighbors receive payoff if their behaviors match.
    - v and w both adopt A, each get a payoff of **a > o**;
    - v and w both adopt B, each get a payoff of **b > o**;
    - **o** payoff if v and w adopt opposite behaviors.

- Nodes behavior depends on choices made by neighbors!

Diffusion- Cnt.

- p fraction of v's neighbors choose A
- $(1 - p)$ fraction choose B.
- v has d neighbors

- Which behavior should v adopt?



a
b

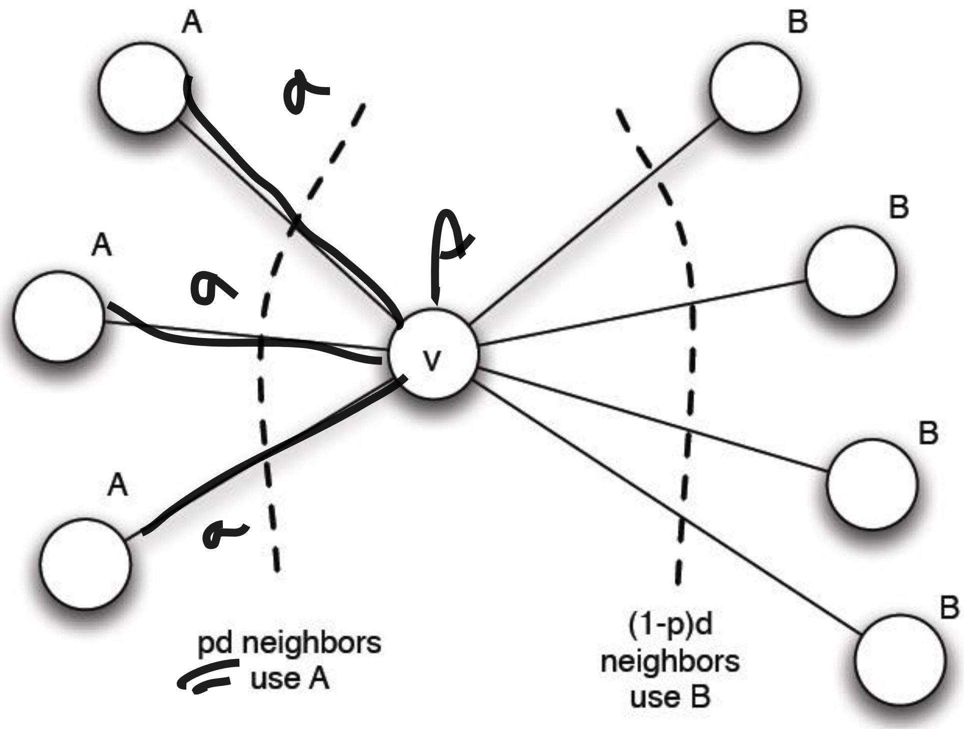
Diffusion- Cnt.

- p fraction of v's neighbors choose A
- $(1 - p)$ fraction choose B.
- v has d neighbors
  - If v chooses A

→ pda

  - If v chooses B

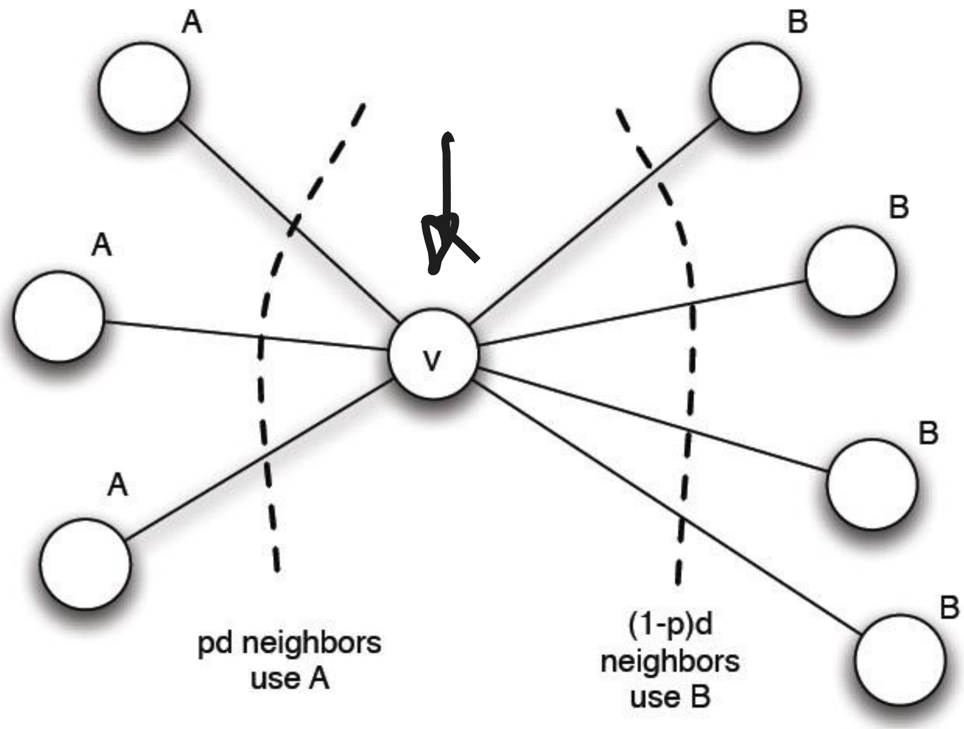
$(1-p)db$



Diffusion- Cnt.

- p fraction of v's neighbors choose A
- $(1 - p)$ fraction choose B.
- v has d neighbors
  - If v chooses A
    - payoff = p×d×a
  - If v chooses B
    - payoff = (1 – p)×d×b
  - A is the better if

$pda > (1-p)db$



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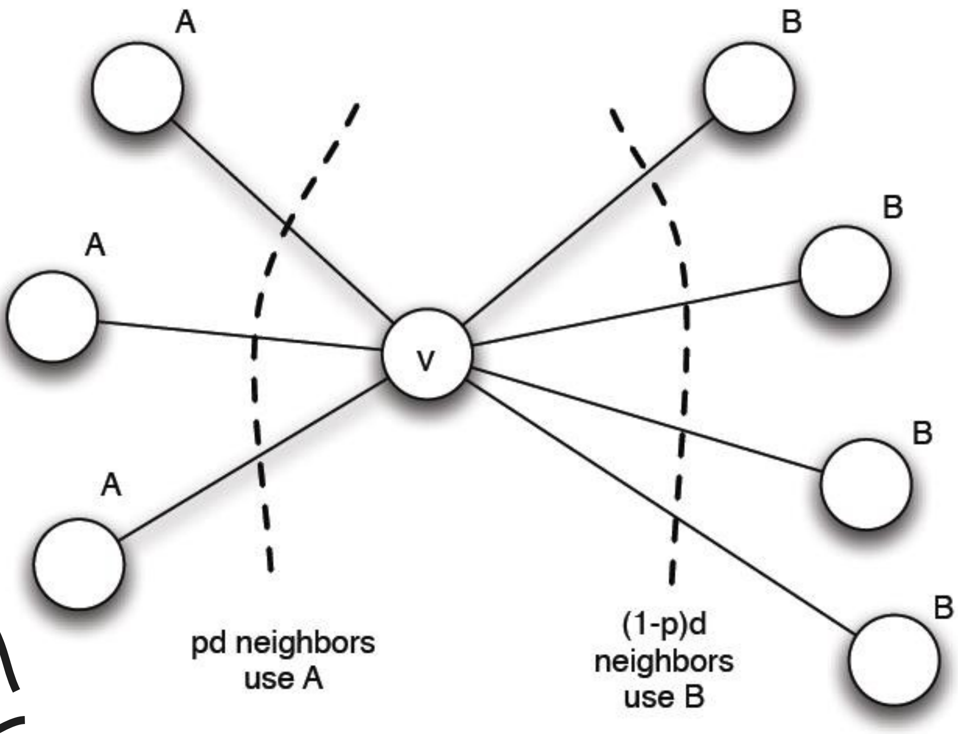
$$pda \geq (1-p)db \rightarrow p \geq \boxed{\frac{b}{a+b}}.$$

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



q = 0.05 vs q = 0.95

Diffusion- Cnt.

- Cascading
  - Everyone adopts A,
  - [redacted]
  - **Intermediate state: some adopt A and some adopt B!**

Diffusion- Cnt.

- Suppose B is the default behavior.
- Some **initial adopters (IA)** switch to A.
- Cascade may start:
  - neighbors of IA may switch to A, their neighbors, etc.
- Cascade stops if:
  - Complete cascade: every node switch over to A!
  - No node wants to switch: Coexistence btw A and B.

Diffusion- Cnt.

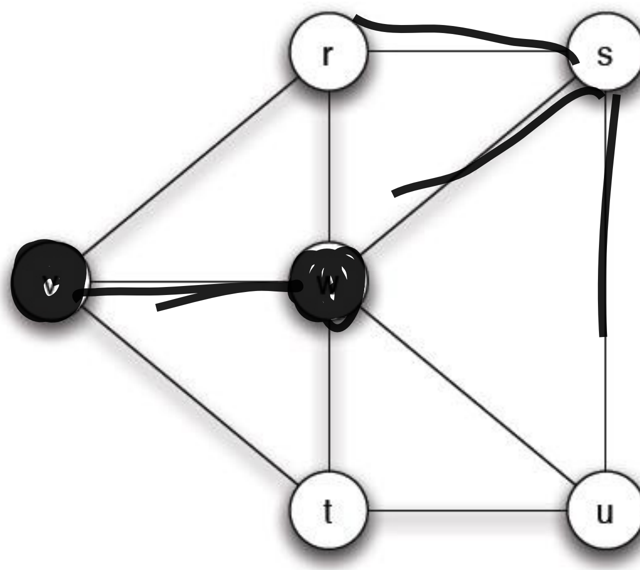
- What factors contribute to start/stop of cascades?

Diffusion- Cnt.

- What factors contribute to start/stop of cascades?
  - network structure,
  - choice of initial adopters,
  - value of the threshold q

Diffusion- Cnt.

- Payoff a=3 and b=2.
- $q = 2/5$, nodes switch to A if at least 40% of their neighbors are using A!
- v and w are initial adopters of A!

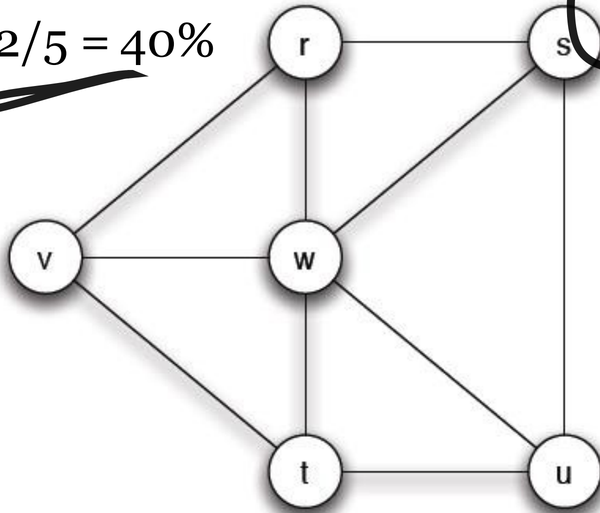


$\frac{1}{3} = 33\% < 40\%$

Diffusion- Cnt.

$q = 2/5 = 40\%$

1



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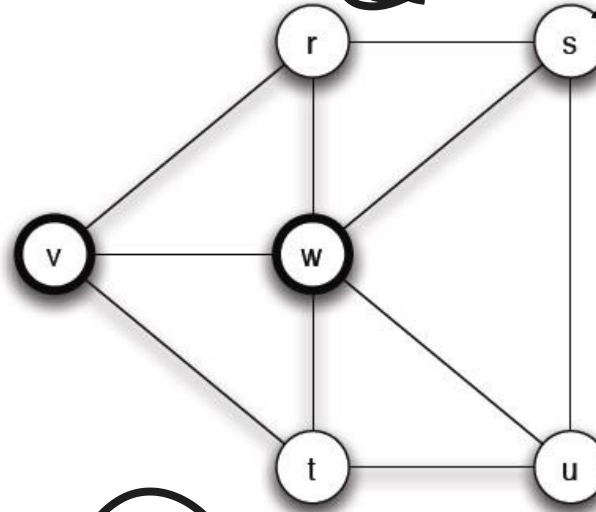
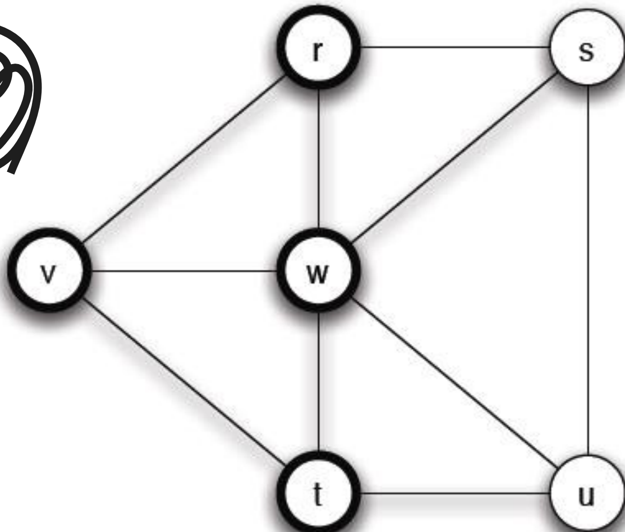


$\rightarrow \frac{1}{3}$

33%

x

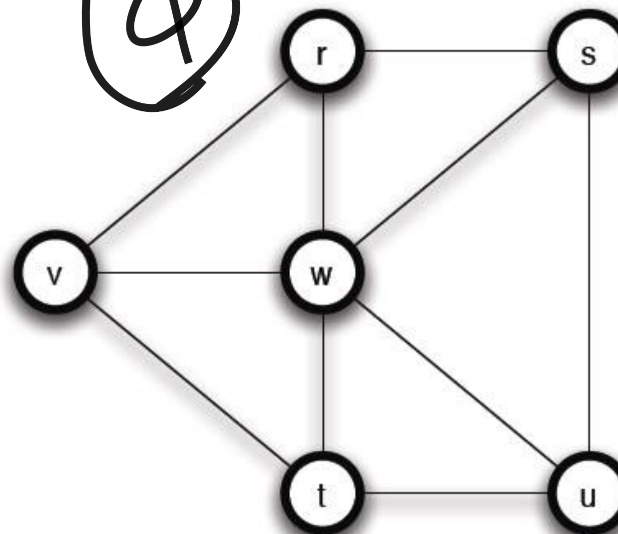
3



$\rightarrow \frac{2}{3} = 66\%$

✓

4



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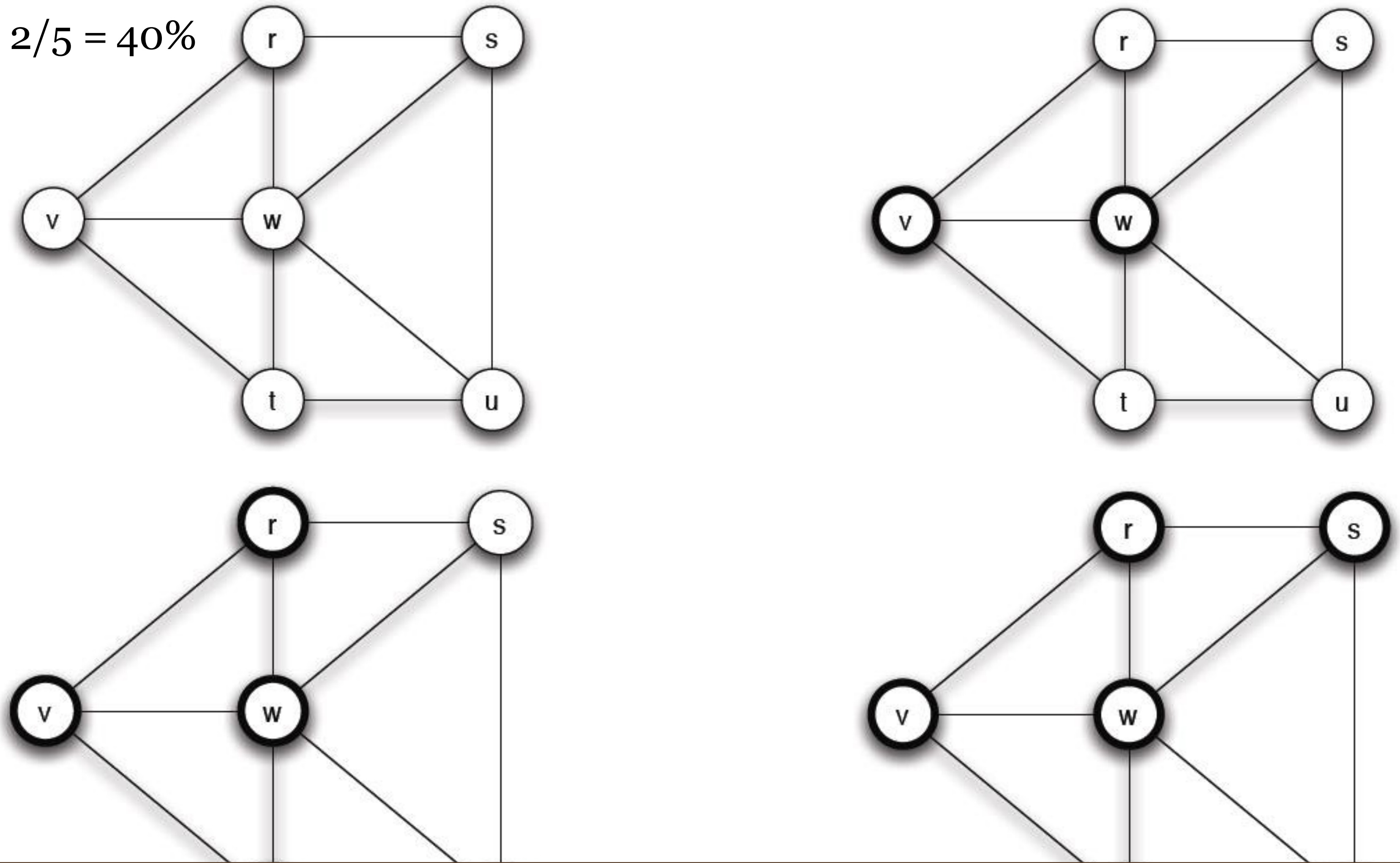
Diffusion- Cnt.

$q = 2/5 = 40\%$



chain reaction: *v* and *w* aren't able to get *s* and *u* to switch by themselves, but once they've converted *r* and *t*, this provides enough leverage.

Diffusion- Cnt.

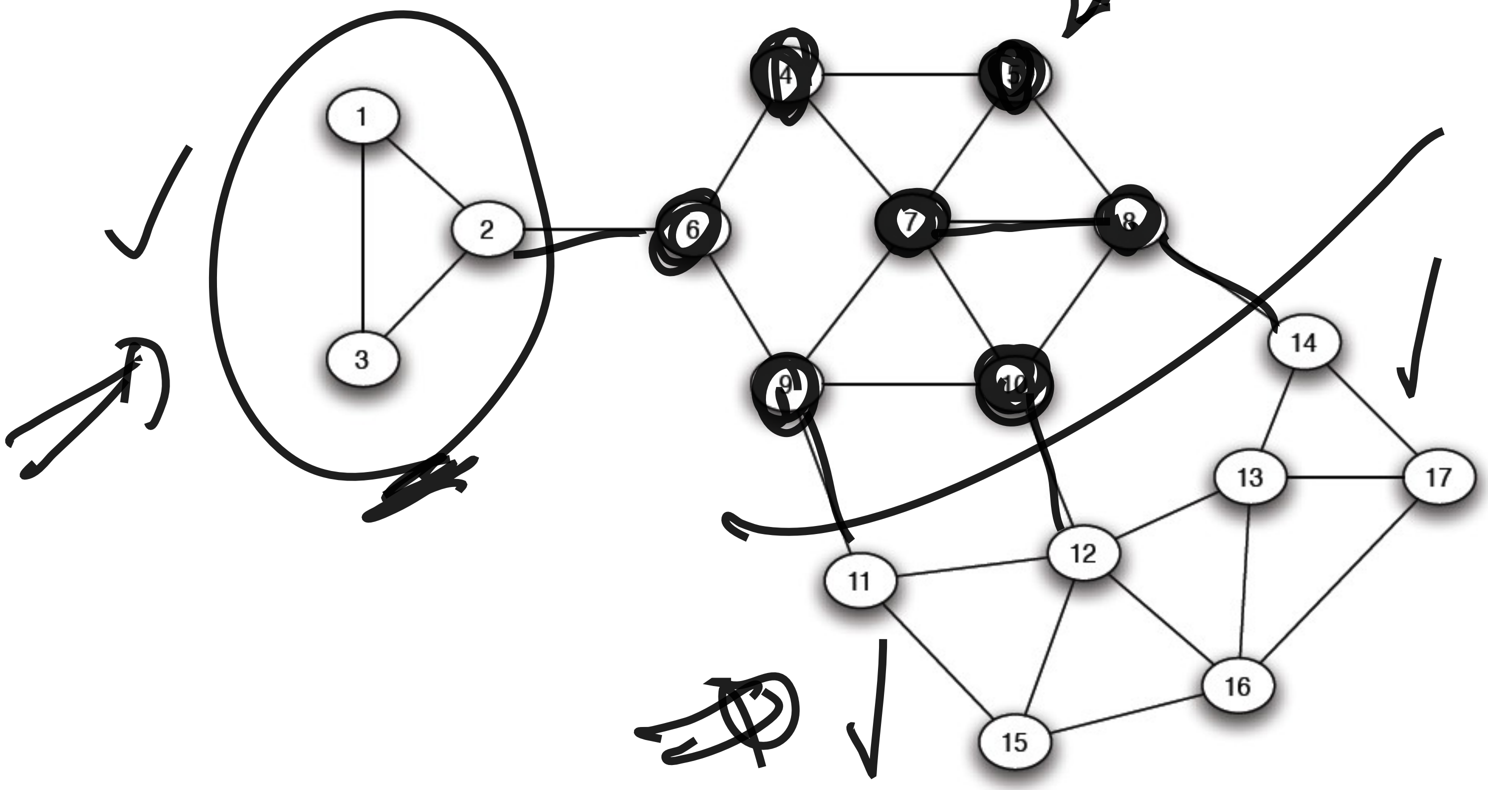
2 4

$q = \frac{4}{6}$

$A \to B$

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

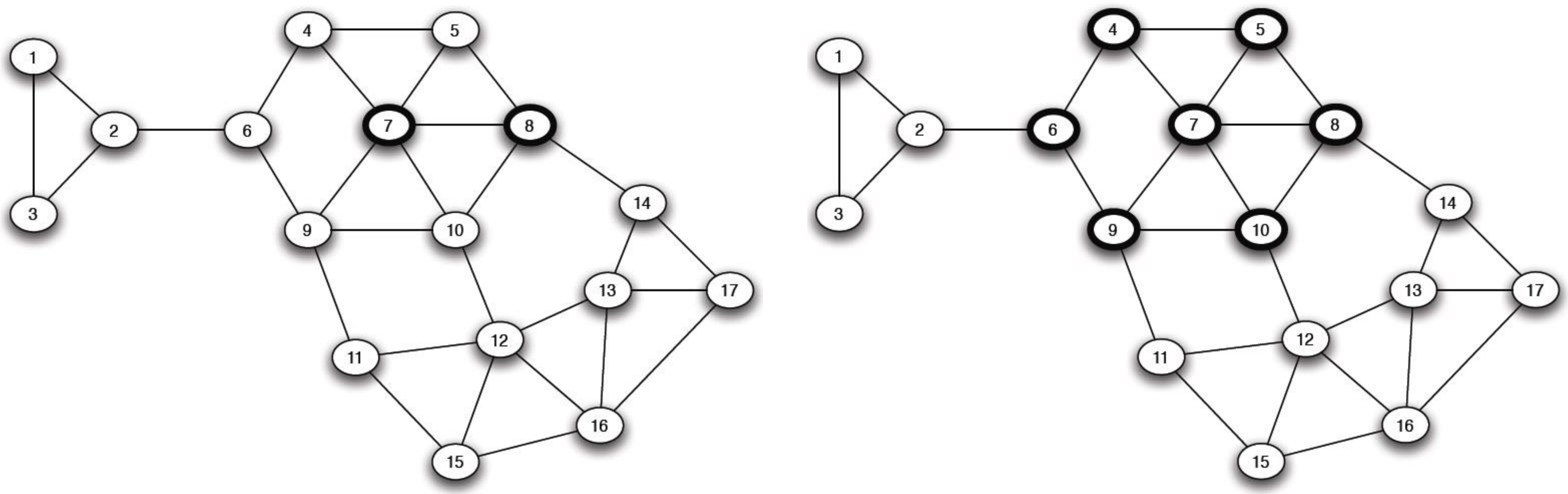
- a=3 and b=2.
- q = 2/5 = 40%
- 7 and 8 are initial adopters of A!



Diffusion- Cnt.

- Takes 3 steps for the cascade to stop!
  - 5 and 10 switch to A, then
  - nodes 4 and 9, then
  - node 6.

$q = 2/5$



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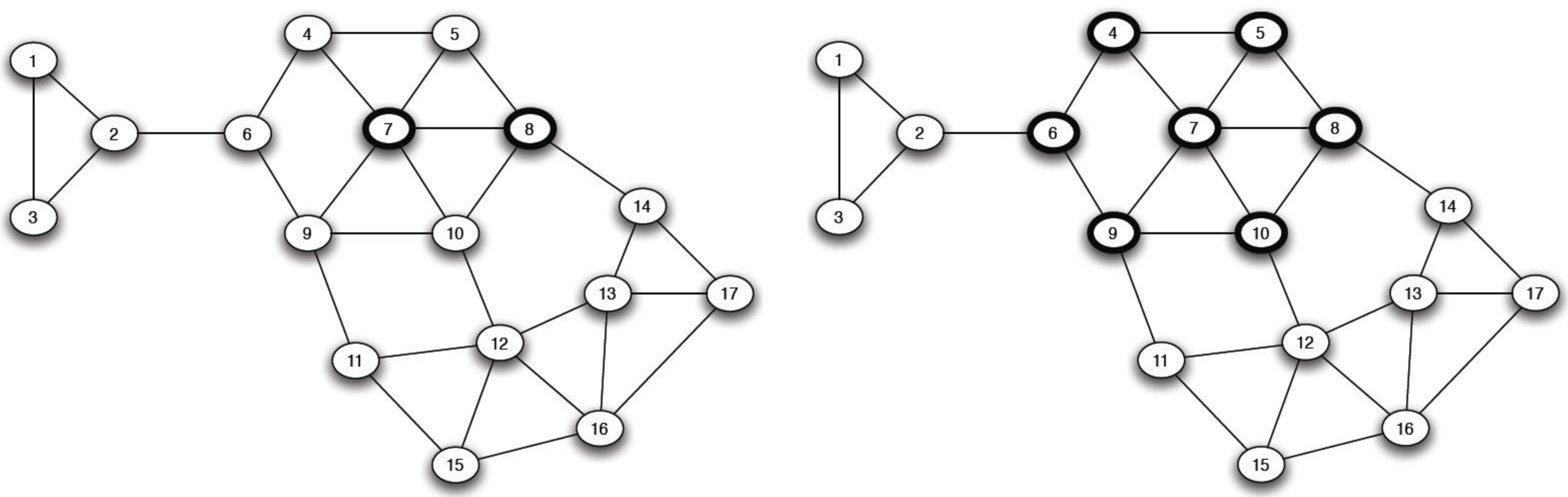


Tightly-knit communities in the network can hinder the spread of a behavior.

Diffusion- Cnt.

- What are useful strategies to push adoption of A (assume A and B are competing technologies)?

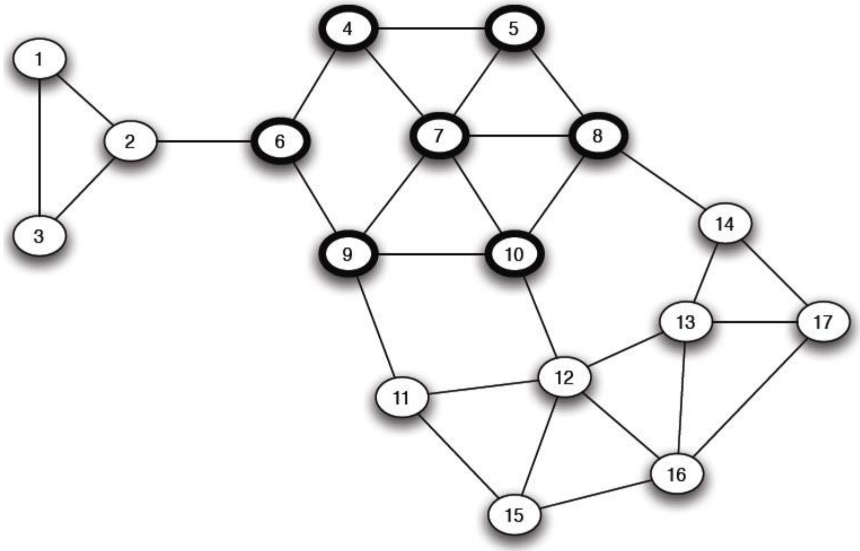
Diffusion- Cnt.

- Strategies that are useful to push adoption of A
  - Change the payoff
    - Say from a = 3 to a = 4!
    - q drops from 2/5 down to 1/3
      - then all nodes will switch to A in the above example.

$q = b/(a+b).$

Diffusion- Cnt.

- Strategies that are useful to push adoption of A
  - Convince a small number of key nodes in the part of the network using B to switch to A
    - Choose carefully to get the cascade going again!
    - Convince 12?
    - Convince 14?



Lecture Topics

- Modeling Diffusion
- **Cascades & Clusters**
- Cascade Capacity

Cascades & Clusters

- Question: What makes a cascade stop? Or prevents it from breaking into all parts of a network?

Cascades & Clusters

- Question: What makes a cascade stop? Or prevents it from breaking into all parts of a network?
  - A cascade comes to stop when it runs into a **dense cluster** (tightly-knit **communities** & **homophily**),
  - This is the **only** thing that causes cascades to stop!

Cascades & Clusters- Cnt.

- **Cluster Density**
  - Cluster density p: a set of nodes where each node has **at least** p fraction of its neighbors in the set.

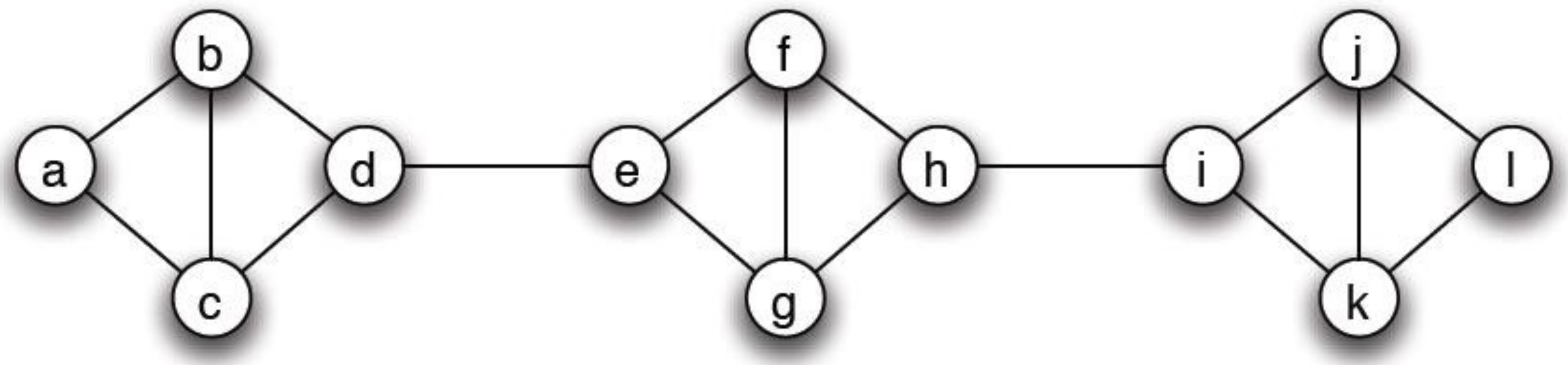
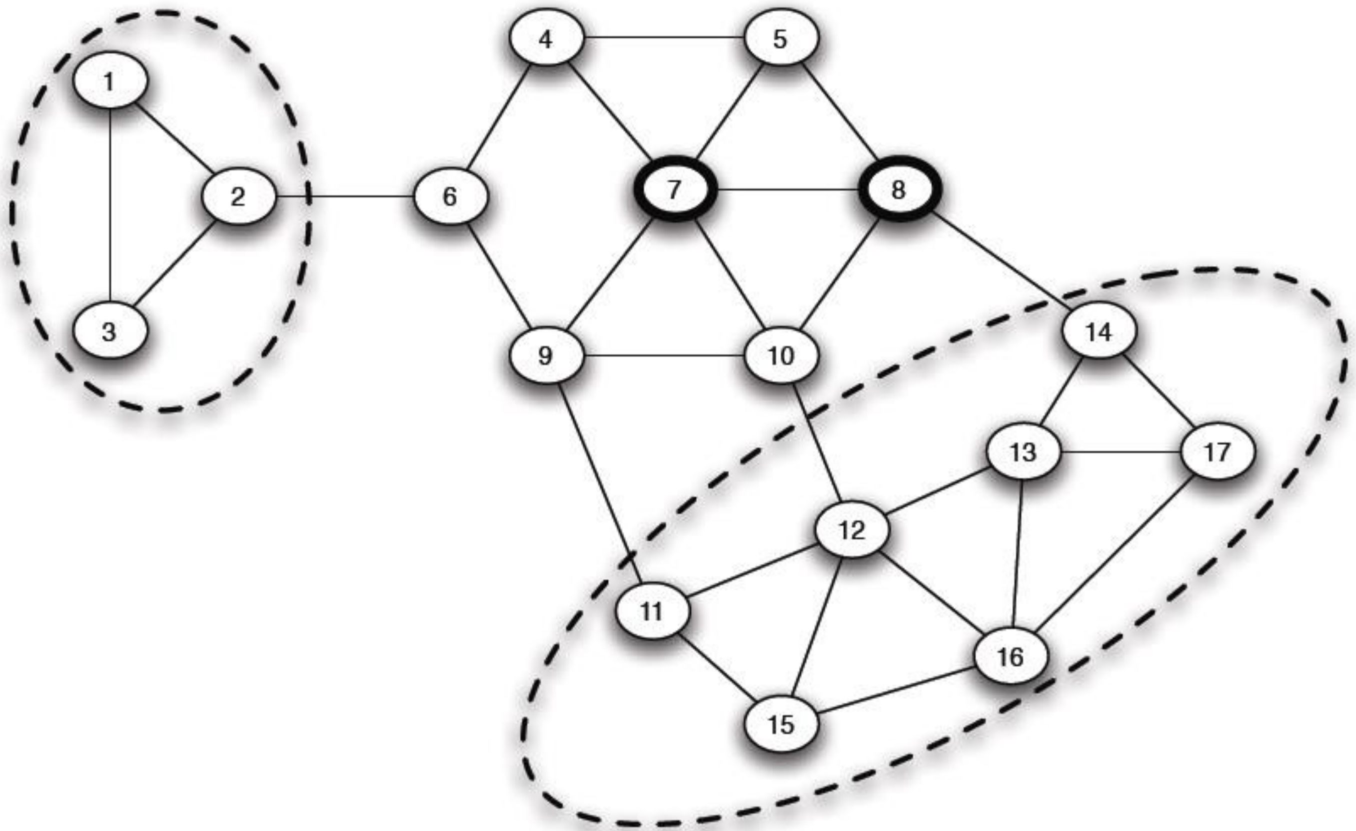


Figure 19.6: A collection of four-node clusters, each of density 2/3.

Cascades & Clusters- Cnt.

- **Claim**: Given initial adopters of A & threshold q:
  i. If remaining network contains a cluster of density greater than $1 - q$, then no complete cascade.
  ii. If there is no complete cascade, the remaining network contains a cluster of density $> 1 - q$.

Cascades & Clusters- Cnt.



q = 2/5 = 40%

Cluster density = 2/3 = 66%

Cluster density > (1-q) = 60%

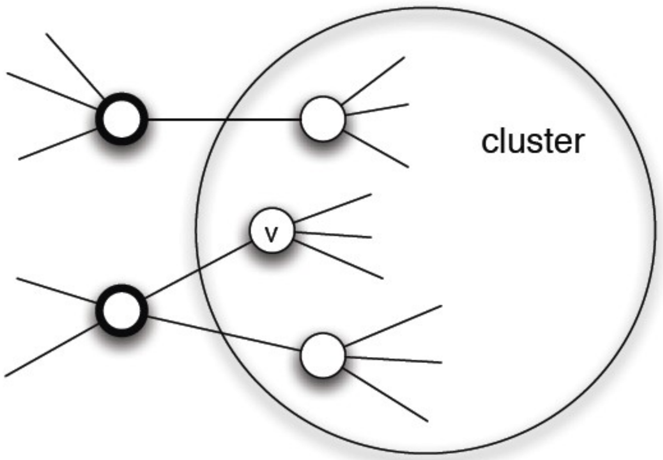
Cascades & Clusters- Cnt.

i. If remaining network contains a cluster of density greater than $1 - q$, then no complete cascade.

Cascades & Clusters- Cnt.

i. If remaining network contains a cluster of density greater than $1 - q$, then no complete cascade.

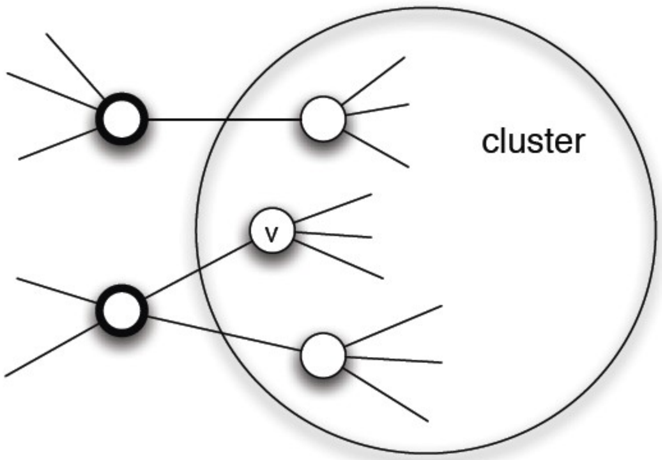
- **Solution**
  - Assume there is a node inside the cluster (density > 1-q) that adopts A
  - Let v be the **first** node that does so.



Cascades & Clusters- Cnt.

i. If remaining network contains a cluster of density greater than $1 - q$, then no complete cascade.

- **Solution**
  - Neighbors of v that use A are **outside** cluster.
  - More than 1-q fraction of v's neighbors are inside the cluster → less than q fraction of v's neighbors are outside the cluster.
    - v cannot adopt A #



clusters block the spread of cascades

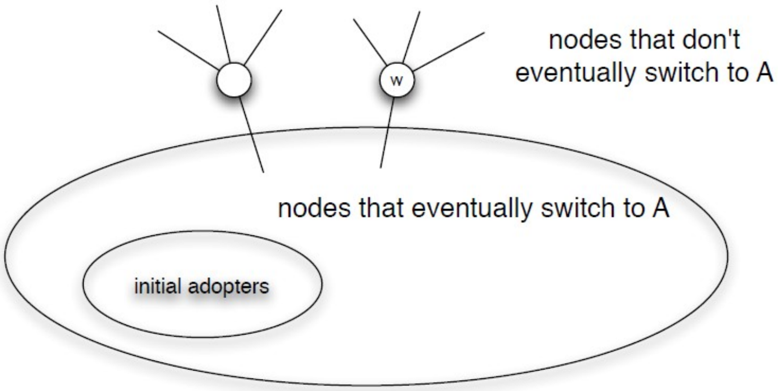
Cascades & Clusters- Cnt.

ii. If there is no complete cascade, the remaining network contains a cluster of density $> 1 - q$.

Cascades & Clusters- Cnt.

ii. If there is no complete cascade, the remaining network contains a cluster of density > 1 – q.

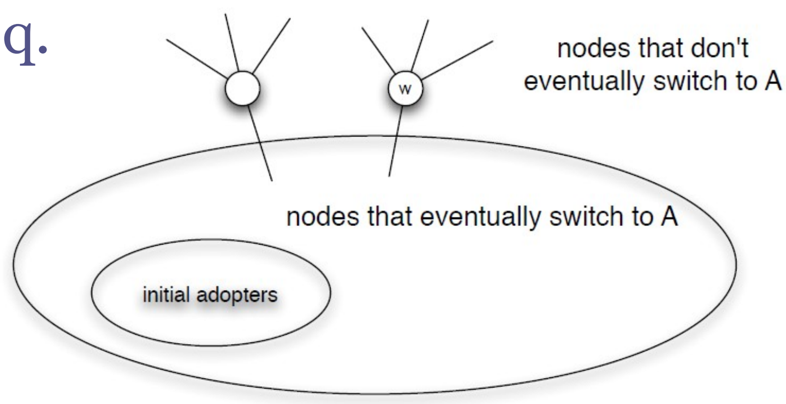
- **Solution**
  - Run the process until it stops!
    - there are nodes using B that don't want to switch.
    - let S denote such nodes.



Cascades & Clusters- Cnt.

ii. If there is no complete cascade, the remaining network contains a cluster of density > 1 – q.

- **Solution**
  - Run the process until it stops!
    - consider any node $w \in S$
    - fraction of w's neighbors using A is < q.
    - fraction of w's neighbors using B is > 1 – q.
    - This holds for any node $w \in S$
      - S is a cluster of density > 1 – q.



Whenever a cascade comes to a stop, there's a cluster that can be used to explain why.

Extensions of Cascade Model

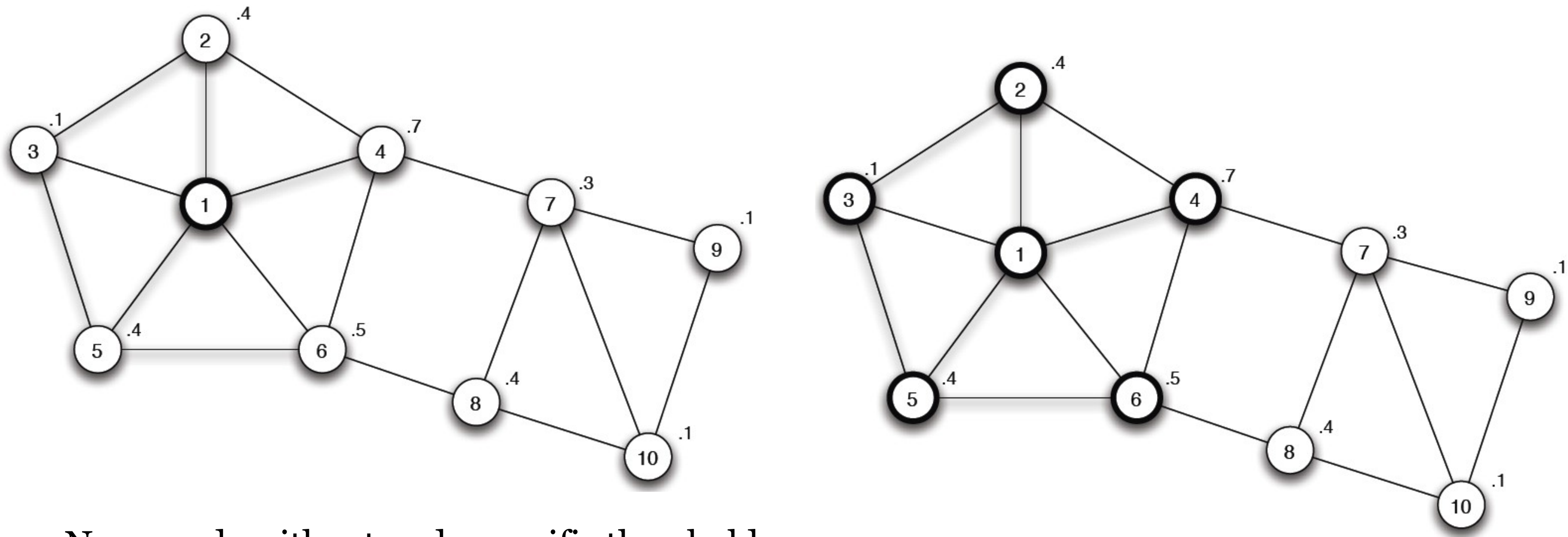
- Heterogeneous thresholds
  - **node-specific** thresholds for adopting a behavior!

- Payoff for v:
  - Choosing A: pda_v
  - Choosing B: $(1-p)db_v$.

- A is better for v if
  - $pda_v > (1-p)db_v$.

$$p \geq \frac{b_v}{a_v + b_v}.$$

Extensions of Cascade Model- Cnt.



- No cascade without node-specific thresholds.
- The extremely low threshold of node 3 lead to diffusion.

> The power of **influential nodes** is correlated to the extent to which such nodes have access to easily **influenceable nodes**.

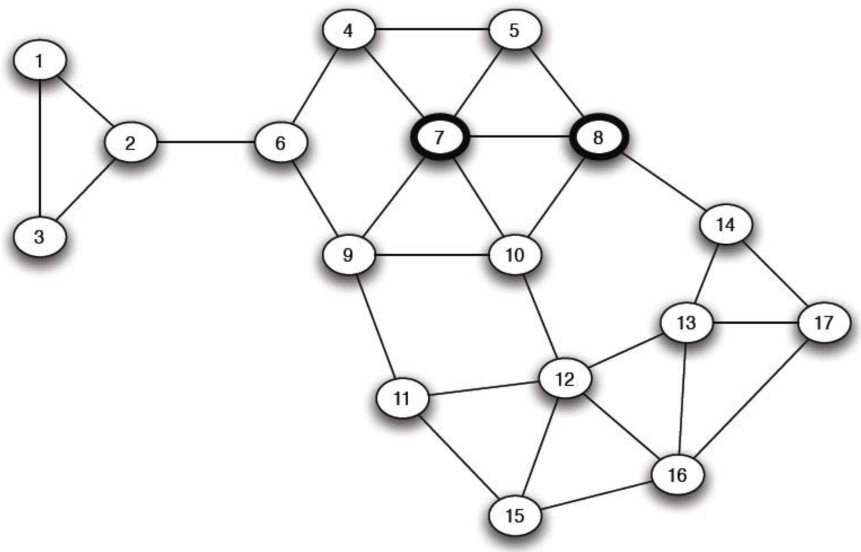
- Clusters are still obstacle to cascades
- A ***blocking cluster*** is a set of nodes for which each node v has > 1-q_v fraction of its neighbors in the set.

Lecture Topics

- Modeling Diffusion
- Cascades & Clusters
- **Cascade Capacity**

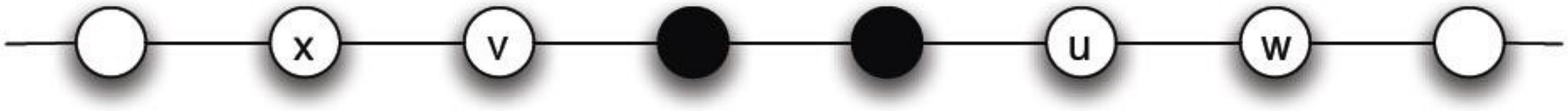
Cascade Capacity

- The maximum q for which some **small** set of initial adopters can cause a **complete cascade**!
  - Indicates how different network structures are **hospitable** to cascades!



Cascade Capacity- Cnt.

- Let black nodes be the early adopters of A.
- What is cascade capacity?
  - the maximum q for complete cascade?



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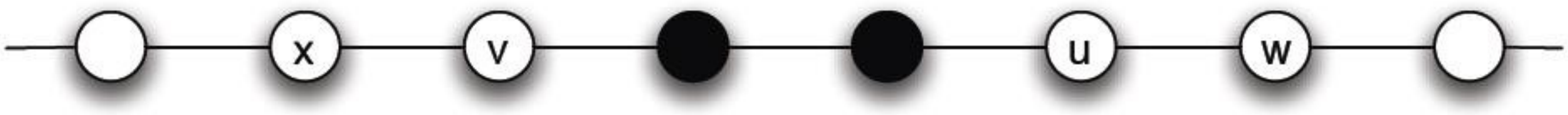
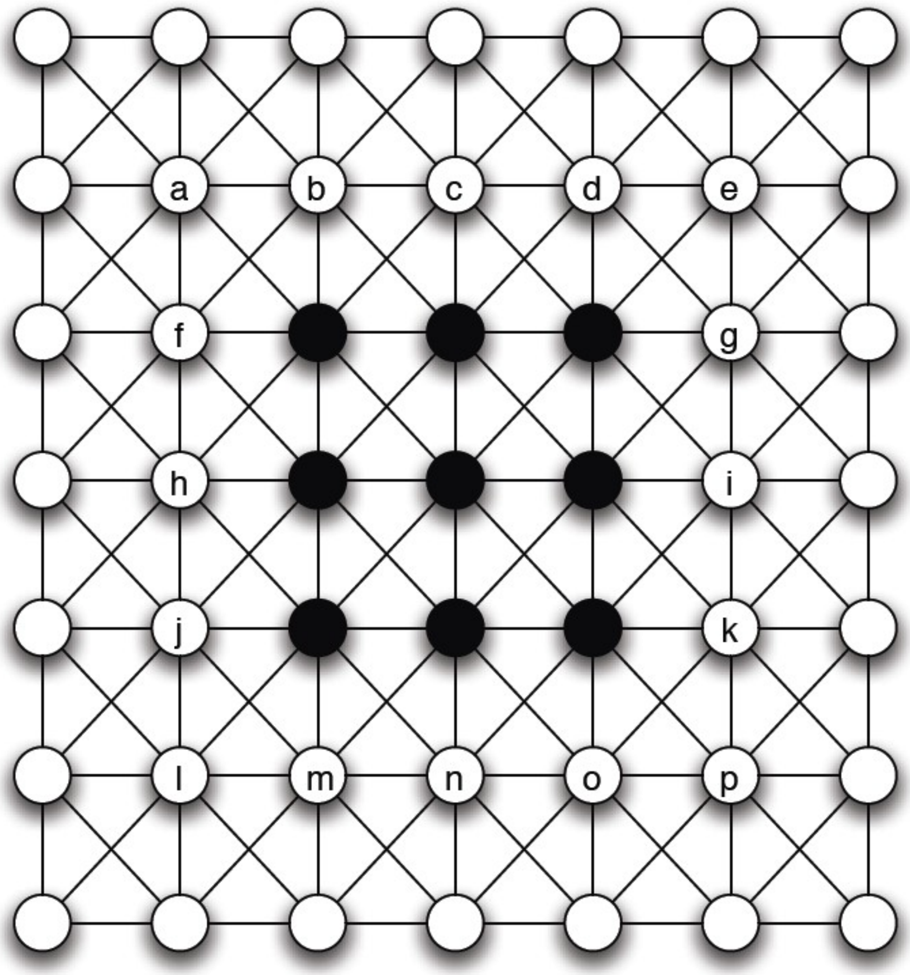


If $q <= 1/2$, complete cascade.
If $q > 1/2$, no finite set of initial adopters can get any node to switch to A.

Cascade capacity= ½

Cascade Capacity- Cnt.

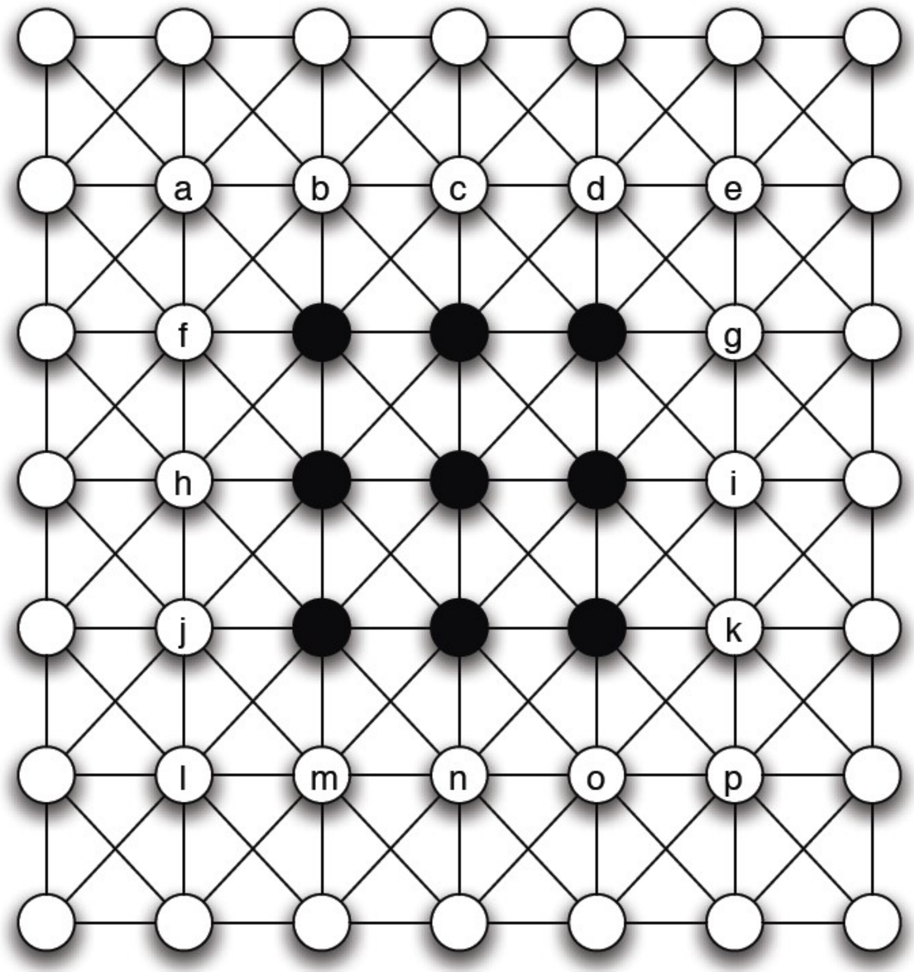


Cascade Capacity- Cnt.

If q <= 3/8, then there is a complete cascade: first to nodes *c*, *h*, *i*, *n*; then to nodes *b*, *d*, *f*, *g*, *j*, *k*, *m*, *o*; and then to others

If q > 3/8, no node will choose to adopt A.

Cascade Capacity=3/8



Cascade Capacity- Cnt.

- How easy cascades propagate in a network with *large* cascade capacity?

Cascade Capacity- Cnt.

- How easy cascades propagate in a network with *large* cascade capacity?
  - Happen more "easily!"
  - Cascades happen even for behaviors A that don't offer much payoff advantage over the B.

Cascade Capacity- Cnt.

- What is the maximum possible value for cascade capacity?

Information diffusion on Twitter

- https://snikolov.wordpress.com/2012/11/12/information-diffusion-on-twitter/

Reading

- Ch.19 Cascading Behavior in Networks [NCM]