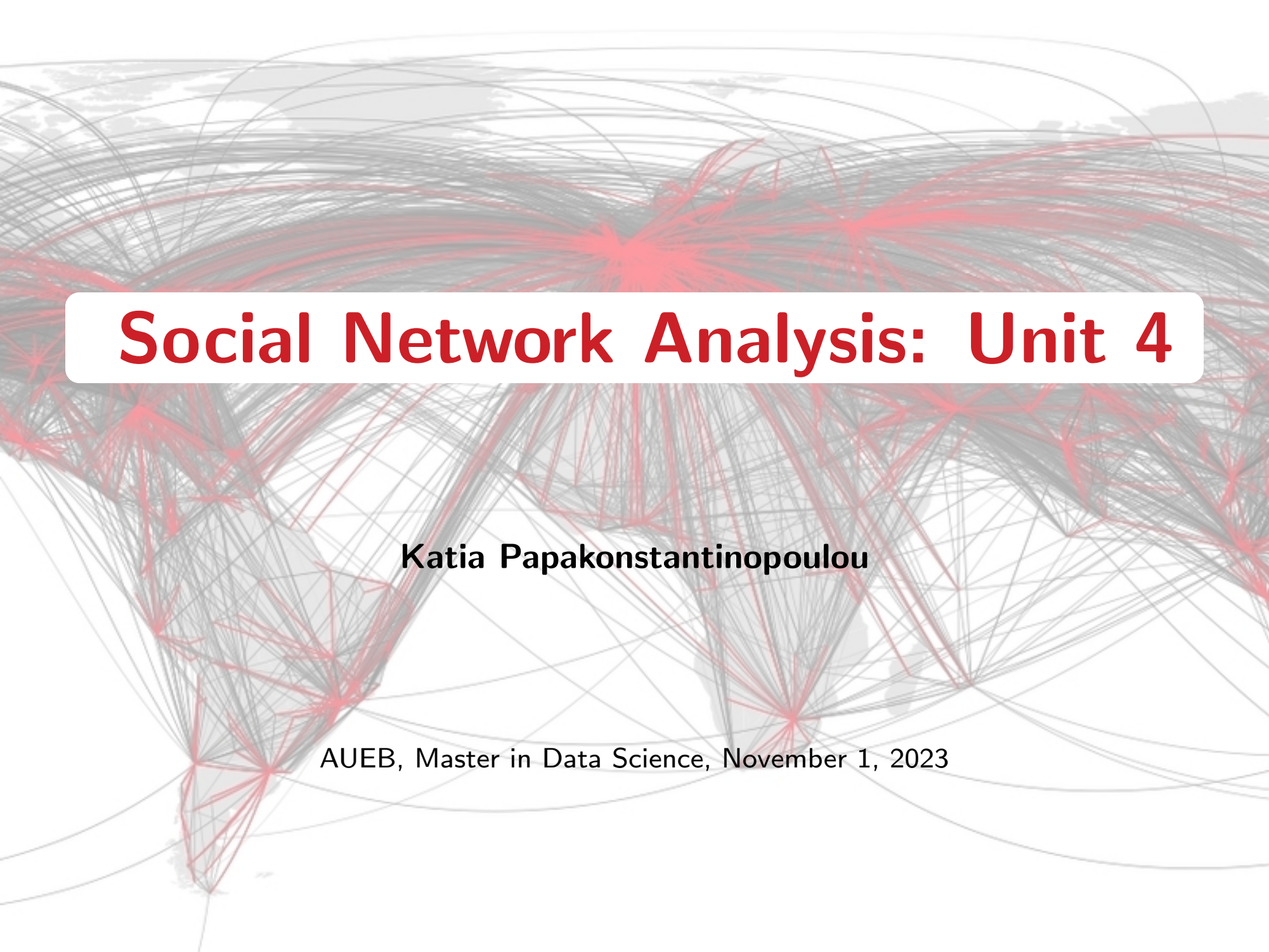

Social Network Analysis: Unit 4

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AUEB, Master in Data Science, November 1, 2023

Outline:

- Cascading behavior
- Information diffusion
- Contagion
- Epidemics
- Opinion formation
- Coordination and cooperation
- Mobilization
- Innovation

Processes on networks

- Network effects and Cascading behavior
- Probabilistic contagion and Models of influence
- Influence maximization in networks
- Collective action
- Innovation
- Problem solving

Such network processes can be affected by the *topology* of the underlying structure.

Information diffusion

How do innovations (e.g. ideas, products, technologies, behaviors) diffuse (spread) within a society?

This is a question that occupied sociologists and economists as early as the 1900's.

Information diffusion

Information diffusion depends on the *topology* of the underlying network.
We next consider three network models:

- Erdös-Rényi networks
- Preferential Attachment (or Scale-free) networks
- Small-world networks

Infection rate

The number of time-steps needed for me to get infected from the time a neighbor of mine gets infected

Information diffusion in Erdös-Rényi graphs

Live demo:

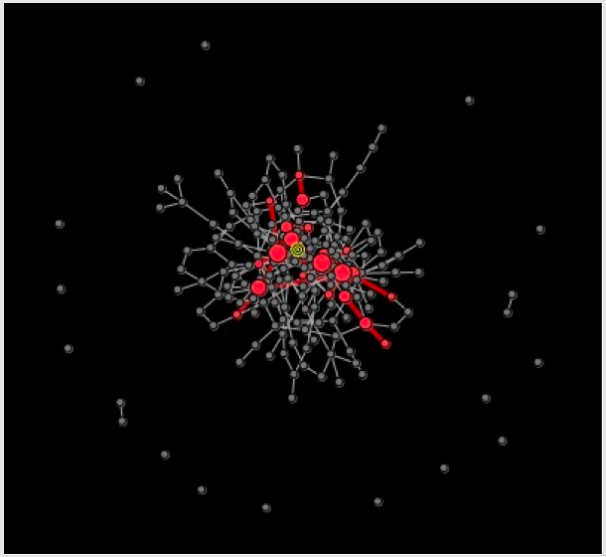
`http://www.ladamic.com/netlearn/NetLogo501/ERDiffusion.html`

Parameters: number of nodes, average degree

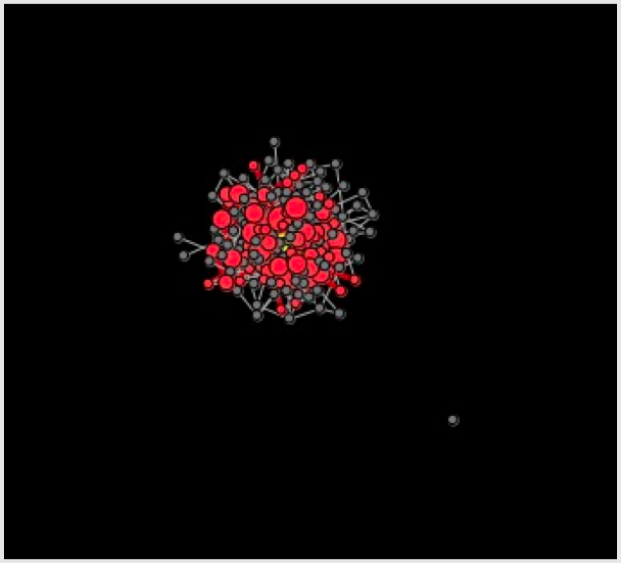
Erdös-Rényi graphs' connectivity and density vs. diffusion

Nodes infected after 10 steps, with *infection rate* = 1:

for average degree = 2.5



for average degree = 10



Quiz

When the density of the Erdös-Rényi network increases, the diffusion in the network is

- faster
- slower, or
- unaffected?

Answer

It is faster, since more nodes are infected in each step.

Quiz

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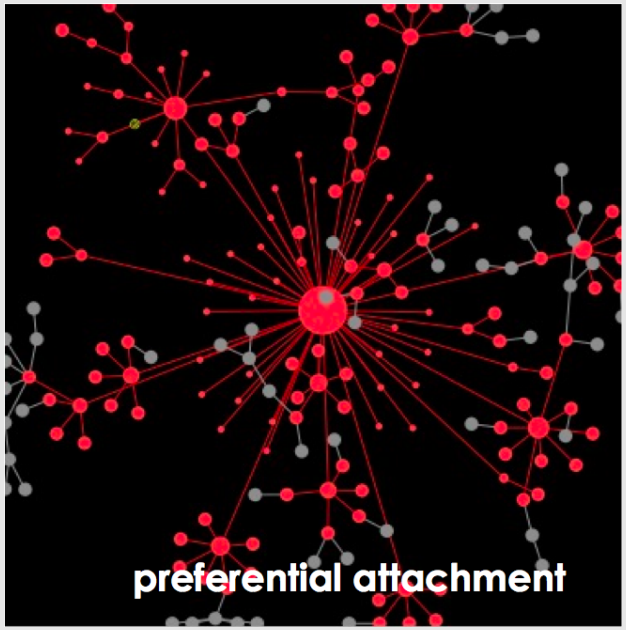
Live demo:

`http://www.ladamic.com/netlearn/NetLogo501/BADiffusion.html`

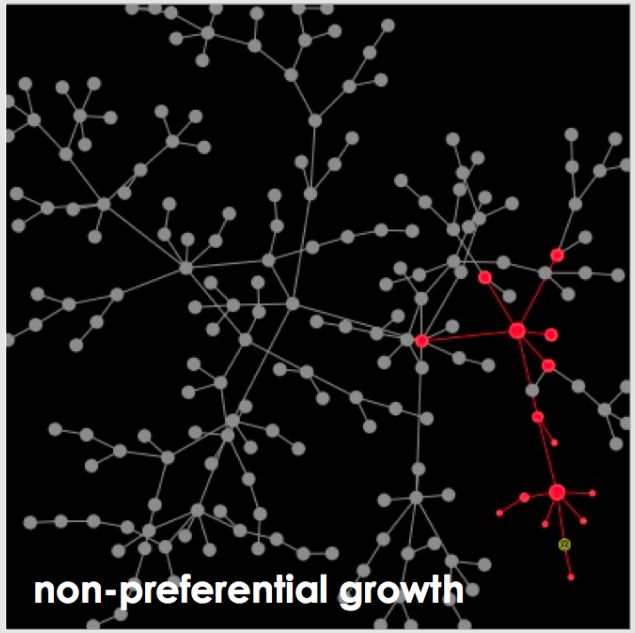
Diffusion due to Preferential Attachment/ Non-preferential growth

Nodes infected after 4 steps, with *infection rate* = 1:

Preferential Attachment



Non-preferential growth



Quiz

When nodes preferentially attach to high-degree nodes, the diffusion over the network is

- faster
- slower, or
- unaffected?

Answer

It is faster, since more nodes are infected in each step.

Quiz

When nodes preferentially attach to high-degree nodes, the diffusion over the network is

- faster
- slower, or
- unaffected?

Answer

It is faster, since more nodes are infected in each step.

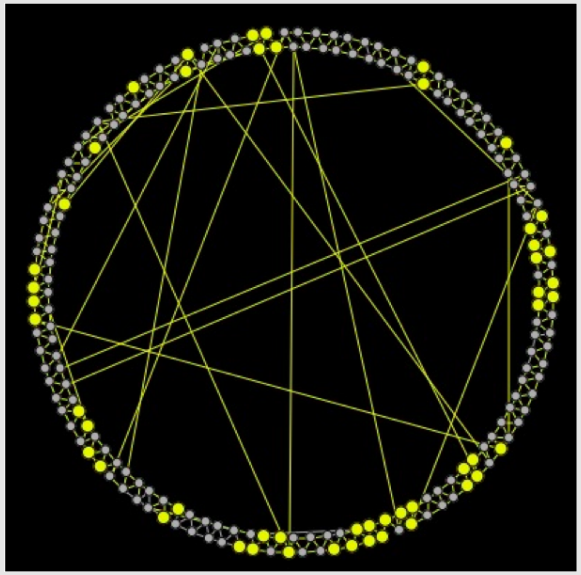
Information diffusion in Small-world graphs

Live demo: `http:`

`//www.ladamic.com/netlearn/NetLogo4/SmallWorldDiffusionSIS.html`

Diffusion due to Rewiring

What is the role of the long-range links in diffusion over small world topologies?



Quiz

As the probability of rewiring increases, the speed with which the infection spreads

- increases
- decreases, or
- remains the same?

Answer

It increases, since distant nodes are reached faster.

Quiz

As the probability of rewiring increases, the speed with which the infection spreads

- increases
- decreases, or
- remains the same?

Answer

It increases, since distant nodes are reached faster.

Simple vs. Complex Contagion

How does contagion occur in a society?

Simple contagion: **each** *friend* infects you *with some probability* for each unit of time (e.g., news)

Complex contagion: you will only take action if **a certain number** *or fraction* of your neighbors do (e.g., fashion)

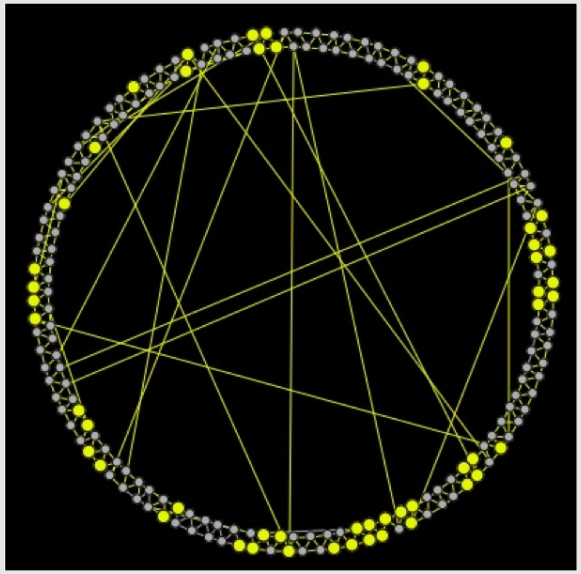
Complex contagion is a threshold model.

Shortcuts in Complex Contagion

Assumption (rule): A node adopts the new behavior iff at least two of its friends have done it already.

Complex Contagion due to Rewiring

Long range links are unlikely to coincide in influence



Shortcuts in Complex Contagion

Quiz

Relative to the simple contagion process, the complex contagion process:

- is better able to use shortcuts?
- advances more rapidly through the network?
- infects a greater number of nodes?

Answer

None of the above happens.

Quiz

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- is better able to use shortcuts?
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Answer

None of the above happens.

Game Theory (Economics' discipline)

Game theory studies situations of interaction among two or more *selfish* entities with *dependent payoffs*, called *games*.

Game definition

A game consists of:

- a *set of players*
- a *set of strategies* for each player
- a *payoff function*, that computes the payoff of each player given a strategy profile of the game (i.e., a set of strategies, one for each player).

Object of Game Theory

In a game, every player acts selfishly and chooses the strategy that maximizes her payoff, given the strategies of the rest players.
Game theory studies the solutions (stable states) of such settings.

Main solution concept: Nash equilibrium

Nash equilibria are called the states in which no player can increase her payoff by switching to another strategy unilaterally.

Opinion formation under social influence

How are the opinions of a set of individuals formed, given the influence in a social environment?

The model: Basic notions

We use:

a variation of the **DeGroot** model due to Friedkin and Johnsen [**?**] and the corresponding *game* of [**?**].

Each user i maintains:

An *intrinsic* belief s_i

Remains constant

An *expressed* opinion z_i

Updated iteratively through averaging

The cost a user suffers emanates from:

Suppressing her intrinsic belief

Disagreeing with her friends

Repeated Averaging

At each time step user i updates z_i to *minimize* her cost:

$$z_i = \frac{s_i + \sum_{j \in N(i)} w_{ij} z_j}{1 + \sum_{j \in N(i)} w_{ij}}$$

$N(i)$: the set of nodes that i follows

w_{ij}: the *strength* of the influence of j on i

The averaging process terminates when z converges to the unique Nash equilibrium, where the social cost is minimized.

A networked coordination game

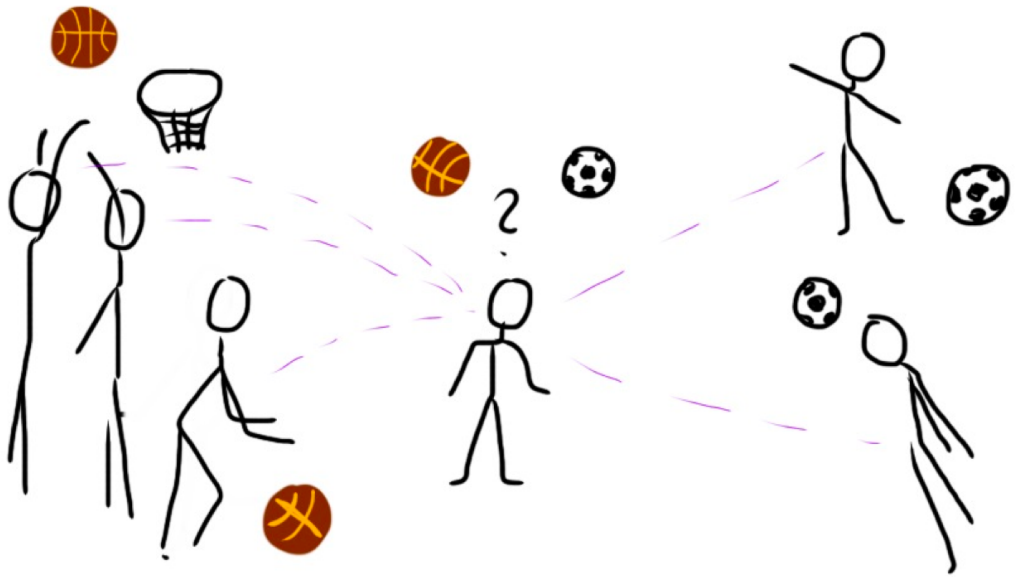
Consider a number of friends, each one having to choose between two things, A and B (e.g. basketball and soccer), simultaneously.

- If friends choose A, each one gets payoff a.
- If friends choose B, each one gets payoff b.
- If they are just two and one chooses A while the other chooses B, their payoff is 0.

Coordinating with one's friends

When does coordination take place in a social environment?

Consider now the following generalization of the game, and let A be basketball and B soccer. Which one should you learn to play?



A fraction $p = \frac{3}{5}$ of the friends play basketball; the rest $\frac{2}{5}$ play soccer.

Coordinating with one's friends

According to Game Theory,
each player chooses the strategy that maximizes her payoff,
assuming that the strategies of the rest players are fixed.

Which choice yields higher payoff?

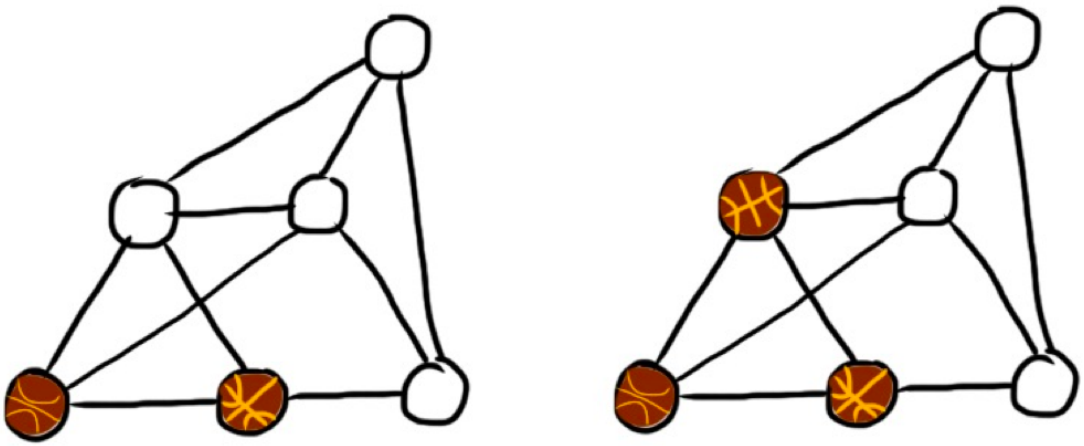
- d neighbors
- fraction p play basketball (A)
- fraction $(1-p)$ play soccer (B)
- if he chooses A, he gets payoff $p \cdot d \cdot a$
- if he chooses B, he gets payoff $(1-p) \cdot d \cdot b$

Therefore, he should choose A if $p \cdot d \cdot a \geq (1-p) \cdot d \cdot b$, i.e., $p \geq \frac{b}{(a+b)}$

How does a cascade occur?

How do cascades occur in a social environment?

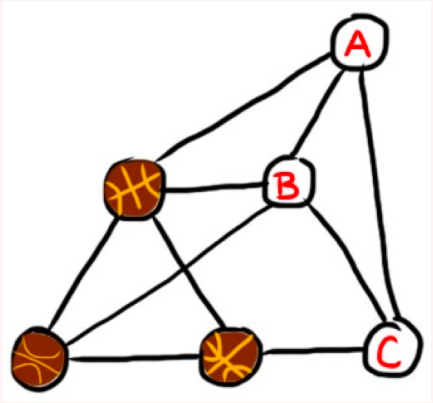
Suppose 2 nodes start playing basketball due to external factors (e.g. they are bribed with a free pair of shoes by some corporation).



How does a cascade occur?

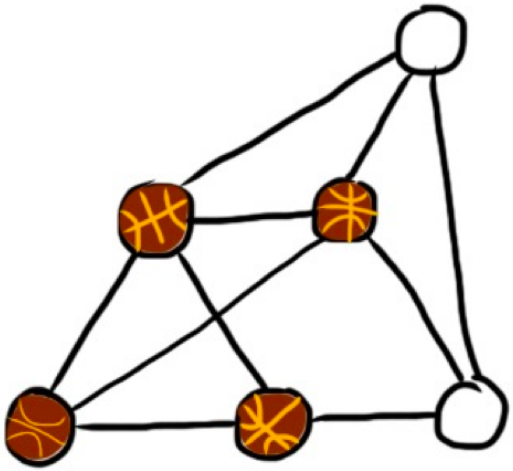
Quiz

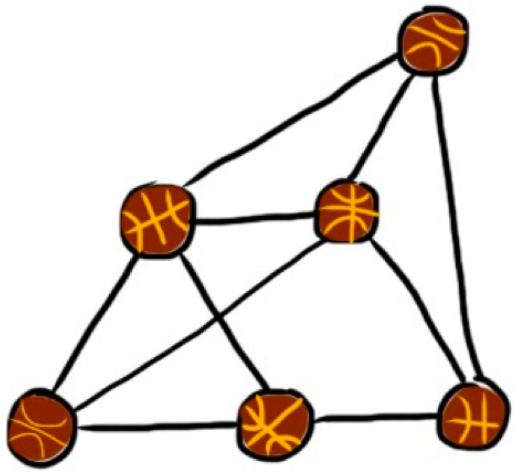
Which node(s) will switch to playing basketball in the next step?



How does a cascade occur?

The complete cascade:

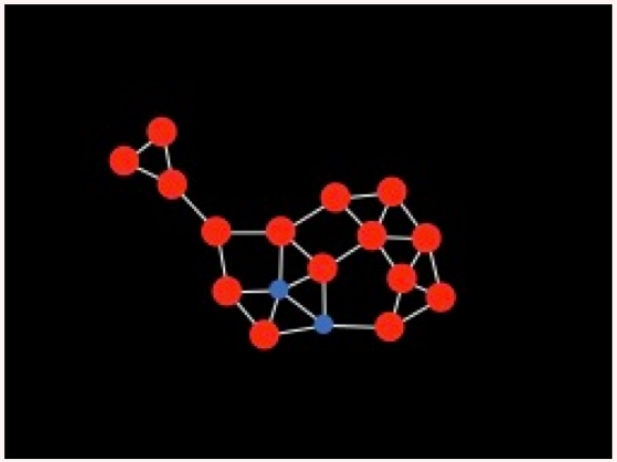




How does a cascade occur?

A larger example: from Easley/Kleinberg book, Chapter 19

We pick the initial 2 nodes that switch. Does the cascade spread throughout the network?



Live demo:

`http://www.ladamic.com/netlearn/NetLogo412/CascadeModel.html`

How does a cascade occur?

Implications for viral marketing

If you could pay a small number of individuals to use your product, e.g., a new smartphone model, which individuals would you pick?

Communities in complex contagion

Quiz

What is the role of communities in complex contagion?

- enabling ideas to spread in the presence of thresholds
- creating isolated pockets impervious to outside ideas
- allowing different opinions to take hold in different parts of the network

Answer

All the above are true.

Communities in complex contagion

Quiz

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- allowing different opinions to take hold in different parts of the network

Answer

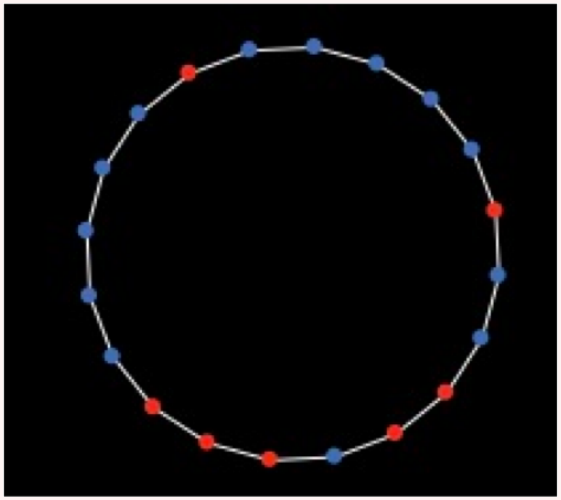
All the above are true.

Bilingual nodes

So far nodes could only choose between A and B.
What if you can play both A and B, but pay an additional cost c?

Cascade with bilingual nodes

- Increase the cost of being bilingual so that no node chooses to do so. Let the cascade run.
- Now lower the cost. What happens?



Cascade with bilingual nodes

Quiz

The presence of bilingual nodes

- helps the superior solution to spread throughout the network
- helps inferior options to persist in the network
- causes everyone in the network to become bilingual

Answer

The bilingual nodes help the inferior options to persist in the network.

Cascade with bilingual nodes

Quiz

The presence of bilingual nodes

- helps the superior solution to spread throughout the network
- helps inferior options to persist in the network
- causes everyone in the network to become bilingual

Answer

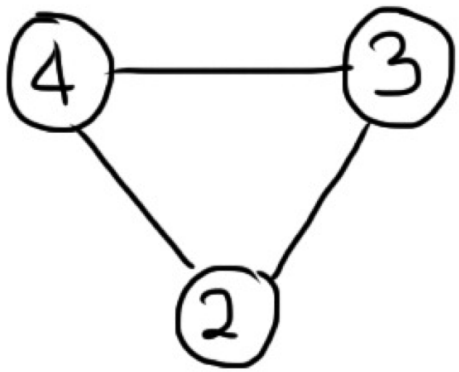
The bilingual nodes help the inferior options to persist in the network.

Knowledge, thresholds, and collective action

Nodes need to coordinate across a network, but have limited horizons.

Can individuals coordinate?

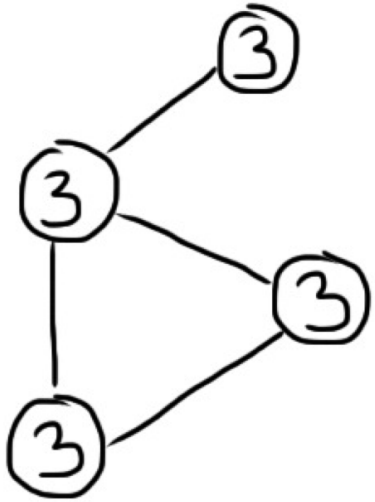
Condition: Each node will act if at least x people (including itself) mobilize.



Here the nodes will not mobilize.

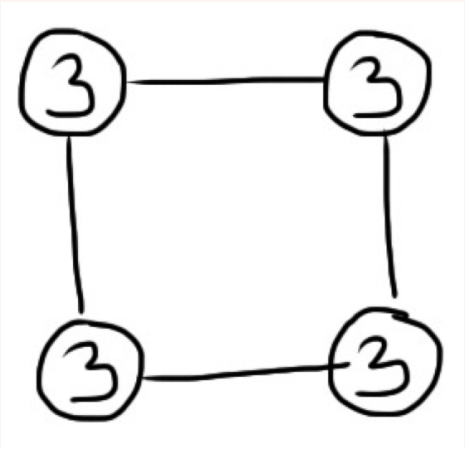
Mobilization

There will be some turnout.



Quiz

Will this network mobilize (at least some fraction of the nodes will protest)?

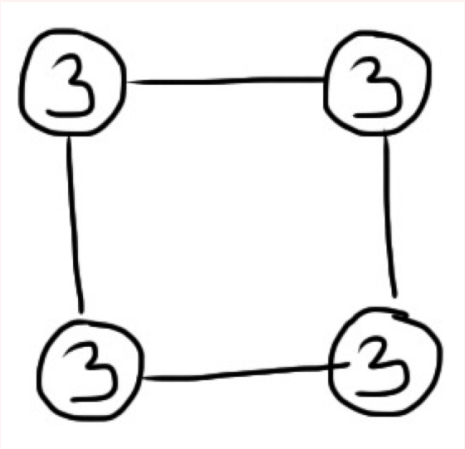


Answer

Yes, because for each individual it suffices if 2 friends of her mobilize.

Quiz

Will this network mobilize (at least some fraction of the nodes will protest)?



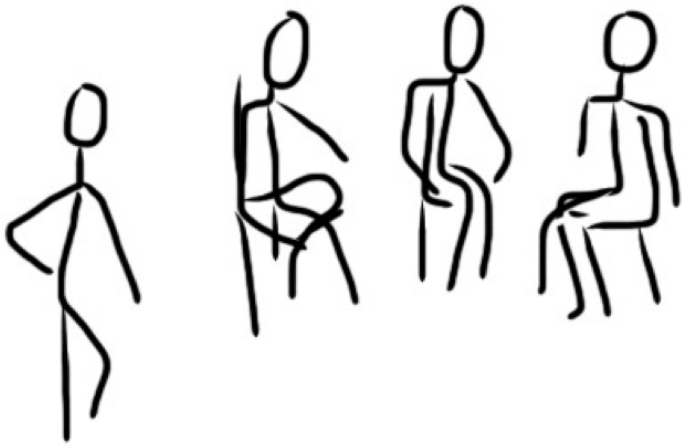
Answer

Yes, because for each individual it suffices if 2 friends of her mobilize.

Innovation in networks

- Network topology influences who talks to whom
- Who talks to whom has important implications for innovation and learning

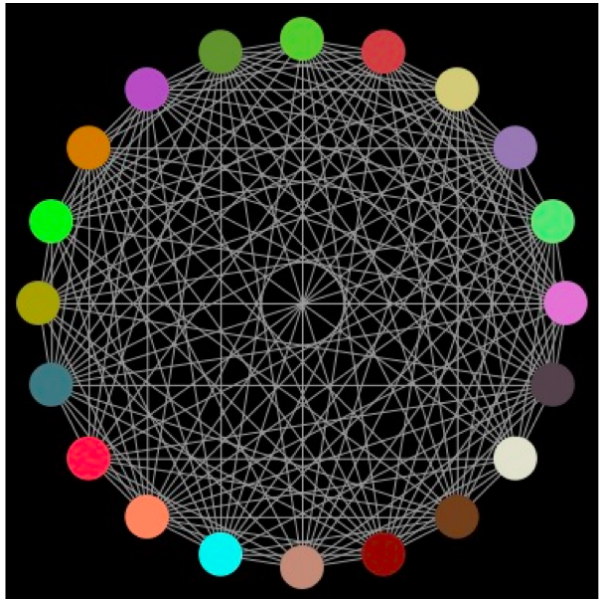
Is it better to *innovate* or *imitate*?

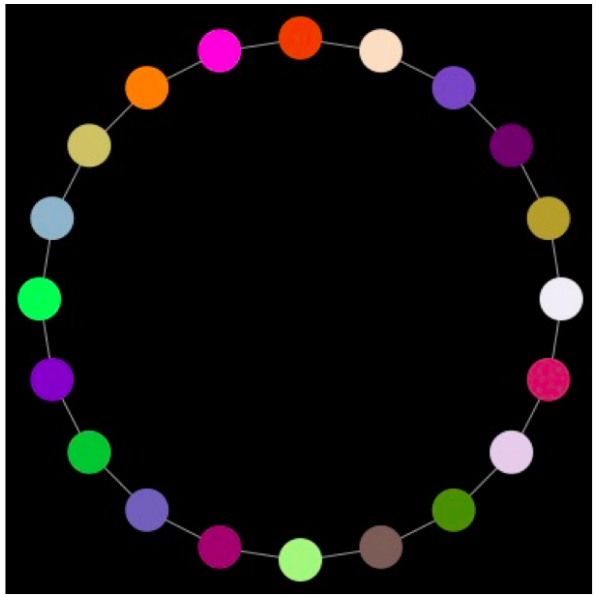


brainstorming:
pro: more minds together
con: danger of groupthink

working in isolation:
more independence
slower progress

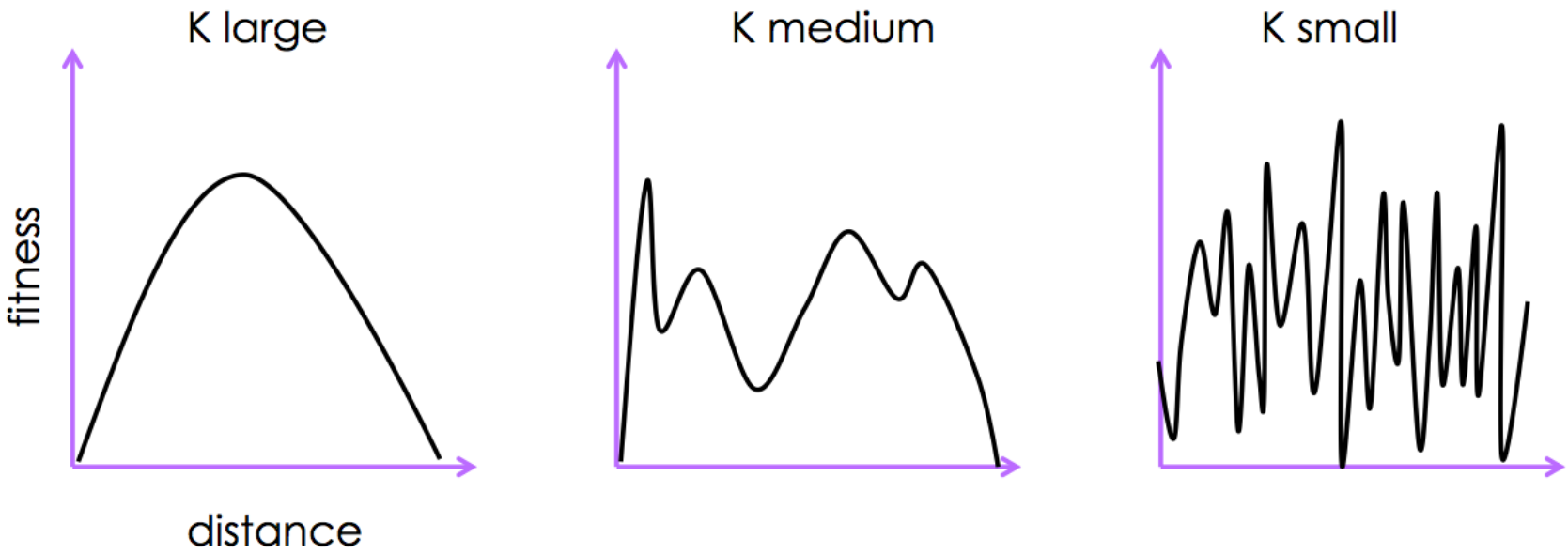
Modeling in a network context





Modeling the problem space

- We employ Kauffman's NK model
- We assume a N-dimensional problem space (N bits, each can be 0 or 1)
- K describes the smoothness of the fitness landscape (how similar is the fitness of sequences with only 1-2 bits flipped). For $K = 0$ we have no similarity, for large K smooth fitness.



Update rules

- As a node, you start out with a random bit string
- At each iteration
  - If one of your neighbors has a solution that is more fit than yours, *imitate* (copy their solution)
  - Otherwise *innovate* by flipping one of your bits

The role of random connections

Quiz

Relative to the regular lattice, the network with many additional, random connections has on average:

- slower convergence to a local optimum
- smaller improvement in the best solution relative to the initial maximum
- more oscillations between solutions

Answer

We converge faster to some solution, but on average the improvement in the best solution is smaller relative to the initial maximum.

The role of random connections

Quiz

Relative to the regular lattice, the network with many additional, random connections has on average:

- slower convergence to a local optimum
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Answer

We converge faster to some solution, but on average the improvement in the best solution is smaller relative to the initial maximum.

Coordination: graph coloring

Application of coordination: coloring a map

limited set of colors

no two adjacent countries should have the same color

Recap

1. The network topology influences the processes occurring on networks
   - what state the nodes converge to
   - how quickly they get there
2. The process mechanism matters:
   - simple vs. complex contagion
   - coordination
   - learning

Unit 4: Recap

We discussed the following aspects:

- Information diffusion
- Contagion
- Opinion formation
- Coordination and cooperation
- Cascades
- Mobilization
- Innovation