Opinion Dynamics
Web Science (VU) (706.716)

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Repetition

- Agent-based Models
- Complex systems
- Example models

Opinion dynamics

Today

- We will learn how to mathematically assess how opinions evolve in a social network
- Microscopic interactions among individuals defined by set of rules (in line with social theories)
- Microscopic interactions help us understand macroscopic behavior (e.g. reaching consensus)
- Models for opinion dynamics: Voter Model, Sznajd model, Bounded Confidence Models
- Models for cultural dynamics: Axelrod model
- Models for language dynamics: Naming Game
- Case study: applying naming game to understand consensus building in online collaboration networks

Opinion dynamics

- Human behavior driven by opinions
- Opinions play crucial role in many global challenges: financial crisis, migration, climate change
- Formation of opinions is *social process* of collective intelligence
- Process can lead to consensus, fragmentation, polarization

Agent-based models and opinion dynamics

In practice, opinion dynamics often studied with agent-based models

- Agents: e.g., individuals, groups, institutions, that can feature attributes (e.g. social status)
- Social network: interactions between agents in which opinions are exchanged
- Update rules: agents' behavior can lead to change in their opinion state

Opinion dynamics

A typical research question would be:

How does a system evolve from an initially disordered state with multiple competing opinions to an ordered state (consensus, fragmentation, polarization) and what impacts this process?

Opinion dynamics

- We are looking for a mathematical approach to model and understand opinion dynamics
- The field of Physics provides mechanisms to quantitatively describe social and economic processes
- Statistical mechanics: study phenomena where relationship between microscopic properties and macroscopic behavior plays a role
- A major topic of interest in statistical mechanics (and in physics in general) is the understanding of phase transitions (e.g. freezing of water to form ice), which requires the study of interacting models.
- Do you remember a model from last lecture that can be used to study opinion dynamics?

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- Do you remember a model from last lecture that can be used to study opinion dynamics?
- Ising model

Recap: Ising model

- Models consists of spin variables s_i that can take the values up $(+1)$ or down (-1)
- Each spin interacts with its nearest neigbors in case of a 2 D representation with its 4 neighbors) as well as with an external magnetic field h
- The spins want to align with the direction of h - either ferromagnetic or paramagnetic
- If temperature is low, all spins align themselves - spontaneous magnetization
- If temperature is increased, spontaneous magnetization is destroyed, thermal fluctuation
- Critical temperature T_c below which spontaneous magnetization, above that, no magnetization
- How do we call that?

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- Phase transition

Ising model and opinion dynamics

- Spins: binary opinions
- An individual's opinion represented as individual spin state
- Consensus: modeled as ferromagnetic ordering in the Ising model

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- Driving forces of social dynamics are different from forces driving dynamics of interacting particles in physical systems
- Can you think of factors that govern social dynamics?

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- Driving forces of social dynamics are different from forces driving dynamics of interacting particles in physical systems
- Can you think of factors that govern social dynamics?
- Social influence, homophily, reciprocity, ...

Opinion dynamics - preliminaries

- Our goal: model and understand opinion dynamics in social networks
- We assume that each node in the network has an opinion state
- Opinion state can be discrete or continuous
- We study the system's evolution starting from an arbitrary opinion distribution
- A number of models exist to study opinion dynamics
- Many show the existence of a *tipping point*, i.e., a critical value of a model variable
- System behaves very differently above and below the tipping point
- Do you remember a dynamic model we discussed in one of our lectures that has a tipping point?

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- Threshold models

Voter Model: "Tell me what to think" (Sood & Redner, 2005)

- Each node in the system can take one of the two typical states $s = +1, -1$ (binary opinions)
- At each time step, pick a node i at random
- That node picks a random neighbor j and copies the opinion of this neighbor, i.e. $s_i = s_j$
- In other words, nodes imitate their neighbors
- In finite systems, at some point, consensus is always reached for this model
- Any ideas wrt runtime?

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- Time to reach consensus scales linearly with system size

Voter Model

Simulation: https://math.berkeley.edu/~bgillesp/apps/voter

Voter Model and impact of network topologies

- Regular networks: the order is irrelevant in which a node and its neighbors is selected
- What happens in networks with heterogeneous degree distribution?

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- What happens in networks with heterogeneous degree distribution?
- Who wins - high or low degree nodes?
- High degree nodes win - why?
- Typically, only few high degree nodes, picked rarely - change rarely
- Low degree nodes picked often, adopt opinions often

Variants of the Voter Model

- Presence of “zealots”: individuals that do not change its opinion (“committed agents”)
- Constraint voter model: agents can be in three states (leftists, rightists, centrists) but interactions can only involve centrists. Extremists do not talk to each other
- Majority rule model

Majority rule model: Social Imitation (Galam, 2002)

- In population of N agents with binary opinions, fraction of $p+$ agents has opinion $+1$, $p-$ agents have opinions -1
- Suppose all agents can communicate (complete graph)
- At each iteration, group of r agents selected as random ("discussion group")
- Group size r selected at each step from given distribution
- Odd r - majority is in favor of either opinion, r even: possibility of a tie ($r/2$ agents have either opinion)
- If tie: introduce bias so that opinion prevails in the group (e.g. $+1$)
- Inspired by social inertia: people are reluctant to accept a reform if no clear majority is in its favor (Friedman & Friedman, 1984)

Majority rule model (Galam, 2002)

- Assume an initial fraction of agents p_0^{+1} who have opinion $+1$
- If $p_0^{+1} > p_c(r)$ where $p_c(r)$ is a threshold, all agents will have opinion $+1$ and opinion -1 otherwise
- Time to reach consensus: log N (nr of updates per agent)
- Odd group sizes: $p_c(r) = 1/2$ due to symmetry of both opinions
- For groups with r even: $p_c < 1/2$, i.e., the favored opinion will eventually be the dominant one, even if it is initially shared by a minority of agents.

Sznajd model: "United we stand, divided we fall" (Stauffer, 2003)

- Impact a social group has on an individual increases with group size - remember the herding examples in this course!
- Convincing a person is easier for > 2 people than a single individual - basic principle behind Sznajd model
- Sznajd model relates to social validation phenomenon, extends the Ising model

Sznajd model (Stauffer, 2003)

- Agents occupy the sites of a linear chain
- Binary opinions (on (+1) and off (-1) like Ising spin variables)
- A pair of neighboring agents i and $i+1$ determine the opinions of their two nearest neighbors $i-1$ and $i+2$ according to these rules:
  - if $s_i = s_{t+1}$ then $s_{i-1} = s_i = s_{i+1} = s_{i+2}$
  - if $s_i \neq s_{t+1}$ then $s_{i-1} = s_{i+1}$ and $s_{i+2} = s_i$

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- Thus: if agents of the pair have the same opinion, they impose their opinion on their neighbors. Social validation: If two people share the same opinion, their neighbors will start to agree with them and change their opinion.

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- Thus: if agents of the pair have the same opinion, they impose their opinion on their neighbors. Social validation: If two people share the same opinion, their neighbors will start to agree with them and change their opinion.
- If they disagree, each agent imposes its opinion on the other agent's neighbor. Discord destroys: If a block of adjacent persons disagree, their neighbors start to argue with them. Intuitively: If the given pair of people disagrees, both adopt the opinion of their other neighbor.

Sznajd model (Stauffer, 2003)

- At start: random initial configuration, both opinions are equally distribution
- Opinions are updated in random sequential order
- In 1D, we reach two steady states: either consensus (with all spins up or down, "ferromagnetic state") or stalemate
- Stalemate? Because: if $s_i \; 6 \; s_{t+1}$ then $s_{i-1} = s_{i+1}$ and $s_{i+2} = s_i$
- Alternating on and off spin values unrealistic: would mean that complete population uniformly change their opinions at each time step. Unsufficient to represent behavior of a community.

Sznajd model: alternative dynamics rule

- Social validation unchanged but second rule modified:
  - if $s_i = s_{t+1}$ then $s_{i-1} = s_i = s_{i+1} = s_{i+2}$
  - if $s_i = -s_{t+1}$ then $s_{i-1} = s$ and $s_{i+2} = s_{i+1}$

Sznajd model (Stauffer, 2003)

- Model very useful to describe how opinions spread in a society as it models how information flows outward
- Applied in politics to describe voting behavior in elections

Discrete vs continuous opinions

- So far, we treated opinions as discrete variable
- Reasonable in several scenarios (pro and contra opinions)
- However: opinion of individuals can vary smoothly from one extrem to the other
- Ex: political orientation is typically not restricted to extreme choices but to all options in between
- This requires a different modeling framework

Bounded Confidence Models

- Initial state typically a population of N agents with randomly assigned opinions
- Opinions can be represented by real numbers within some interval
- All agents start with different opinions
- Opinion clusters may emerge in final stationary stage: consensus (one opinion), polarization (two), fragmentation (more)
- In principle: all agents can interact with each other regardless of the nature of their opinion
- In real life: real discussions often only if opinions of the involved agents are sufficiently close to each other
- This is called bounded confidence

Bounded Confidence Models

Basic intuition: agents adjust their opinion gradually towards opinions of others when distance in opinion is within their bound of confidence.

Deffuant model (Deffuant et al., 2000)

- Describes pattern for social interaction
- Two neighboring individuals randomly meet and share their opinions on a certain topic, if the difference between their opinions is not beyond a given threshold

Deffuant model: How does it work

- We consider a population of N agents
- Each agent i initially has an opinion x_i - opinions are chosen randomly from the interval $[0, 1]$
- At each time step, a randomly selected agent i interacts with one of its neighbors j (also chosen randomly)
- Both have opinions $x_i(t)$ and $x_j(t)$
- If difference of opinions $x_i(t)$ and $x_j(t)$ exceeds a threshold ϵ - each agent keep their original opinion
- If $|x_i(t) - x_j(t)| < \epsilon$, then:
  - $x_i(t+1) = x_i(t) + \mu[x_j(t) - x_i(t)]$
  - $x_j(t+1) = x_j(t) + \mu[x_i(t) - x_j(t)]$
  - where μ is the *convergence parameter*, lies in interval $[0, 1/2]$

Deffuant model (Deffuant et al., 2000)

- Compromise strategy: after a constructive debate, the positions of agents get closer to each other by relative amount μ
- If $\mu = 1/2$, the two agents converge to the average of their opinions before discussion
- For any value of ϵ and μ, the average opinion of the agents' pair is the same before and after the interaction
- In other words: the global average opinion $(1/2)$ of the population is an invariant of Deffuant dynamics

Bounded Confidence Models

Netlogo model: Download from
http://ccl.northwestern.edu/netlogo/models/community/bc
Implements another bounded confidence model: Hegselman and Krause (2002)

Culture dynamics

Culture dynamics

Culture: *"the set of individual attributes that are subject to social influence"* ... *"something people learn from each other"* (Axelrod 1997)

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- Culture dynamics similar to opinion dynamics
- In opinion dynamics, opinions are considered as scalar variables
- The culture of an individual is considered as being more faceted
- Therefore: modeled as vector of variables, whose dynamics are coupled
- Typical questions: e.g. what are the microscopic mechanisms that drive formation of cultural domains?
- Or, what is the role of diversity - will it persist or will all differences eventually disappear in the long run?

Axelrod model (Axelrod, 1997)

Basic intuition: people become similar through interaction

- Includes two mechanisms that are believed to be fundamental when modeling and understanding dynamics of cultural assimilation / diversity: social influence & homophily
- Social influence: tendency of individuals to become more similar when they interact - increases number of cultural attributes they share
- Homophily: similar people tend to interact more frequently - people more likely to interact with others who share many of their cultural attributes

Axelrod model

- Example: people are more likely to talk to someone who speaks a similar language than to someone, who speaks a dissimilar language. Through their communication their future patterns of speech tend to become even more similar (Axelrod, 1997)

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- Do you think that this is realistic?

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- Social scientists expected that those two factors will eventually lead to global convergence to a single culture
- Do you think that this is realistic?
- In some cases, diversity persists regardless of self-reinforcing mechanism (more interaction means more similarity).
- The model proposed by Axelrod lets us study and predict that.

Axelrod model - How does it work?

- Individuals are located in a LxL lattice of cells (could also be nodes in a network)
- Each cell is inhabitated by an individual who is endowed with a certain culture
- This culture is described by a list of features f (e.g. language, religion, style of music, ...)
- Features are integer values $\sigma_1, ..., \sigma_f)$ that can assume q traits $\sigma_f = 0, 1, ...q - 1$
- Traits q correspond to the number of possible traits allowed per feature
- Culture of individual i can be represented by vector x_i of f variables and each variable takes an integer value in the range $[0, q - 1]$
- Intuition: model the different beliefs, attitudes and behaviors of individuals

Axelrod model - dynamics

- At each time step, an individual k is selected at random (active agent)
- One of k's neighbors j is selected at random (passive agent)
- k and j interact with a probability that is equal to their cultural similarity $n_{k,j}/f$ where $n_{k,j}$ corresponds to the number of cultural features for which both have the same trait
- Interaction: active agent k randomly selects one of the $f - n_{kr}$ features on which both agents differ and copies the trait of the passive agent j
- Thus, agent k approaches the cultural interests of j
- Continues until no more cultural changes can occur
- What is the outcome?

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- What is the outcome?
- Each pair of neigbors has either identical cultures or completely different cultures
- Parameters f and q influence probability with with system evolves to only one cultural region or to several multicultural regions

What does that mean?

- Dynamics of Axelrod's model tend to increase similarity of interacting individuals
- However: interaction is more likely for neighbors who share many traits (ergo, who have higher homophily)
- No interaction when no trait is the same
- This gives two stable configurations for pairs of neighbors: either they are exactly the same and thus belong to the same cultural region
- Or, they are completely different

Axelrod Model

Netlogo Simulation: download Axelrod model from
http://ccl.northwestern.edu/netlogo/models/community/Axelrod%20-%20Network

Language dynamics

Language dynamics

"Open minded individuals"

- Focus on processes related to emergence, change, evolution, interaction and extinction of languages
- Sociobiological approach: evolution is the main responsible both for the origin and the emergence of natural language in humans. Models based on natural selection
- Semiotic dynamics approach: language as evolving system. New words and grammatical constructions may be invented, new meanings may arise, the relation between language and meaning may shift,..

Naming Game model

- Originally main focus on the formation of vocabularies, i.e., a set of mappings between words and meanings (e.g. for physical objects)
- Each agent develops its own vocabulary in a random, private fashin
- However, agents must align their vocabularies
- Achieved by successive conversation between a certain number of agents, who exchange meanings - cooperation through communication
- Result: globally shared vocabulary (ideally!) as consequence of local adjustments of individual word-meaning associations

Minimal Naming Game (Dall'Asta et al (2006)

- We assume a population of N agent
- Goal: agents aim to bootstrap a common name for a given object on a fully connected network
- Each agent has an inventory of word-object associations it knows
- Initially, inventories of all agents are empty
- At each time step, 2 agents are randomly selected and one is assigned the role of speaker and the other is listener
- Rules of interaction: speaker transmits word to listener. If listener does not have the word in its inventory, it is added. If word is inventory of both agents, they agree on the word and delete all other words from the inventory.
- Thus: Naming Game describes agreement dynamics in a system

Naming Game variant: binary agreement model

- Number of possible words restricted to 2 (A or B)
- Goal: study two competing opinions
- Each noide can be either in one of the two competing states A and B or in an intermediate state AB
- Difference to voter model: individuals have some inertia to change their state (some internal belief)
- Impact on dynamics: time to reach consensus scales logarithmically with system size

Naming Game to study opinion formation (Baronchelli et al., 2007)

- Additional parameter β to mimick an irresolute attitude of agents in making decisions
- Probability to model the negotiation process that, in a successful interaction, both the speaker and the hearer update their memories erasing all opinions except the one involved in the interaction

Naming Game: Impact of social status, network structure, user similarity (Hasani-Mavriqi et al., 2018)

- In our own work, we found that social status can speed up consensus building in the Naming Game
- We found that in assortative networks, consensus is always reached
- We found that user similarity and social status are opposing forces with respect to consensus

Naming Game: Impact of social status, network structure, user similarity (Hasani-Mavriqi et al., 2018)

- Study online collaboration systems and consensus building in those systems: StackExchange, Reddit, Wikipedia,..
- RQ: Which factors govern consensus building in online collaboration systems?
- Factors social status, network structure, user similarity
- Approach: Adapting Naming Game to account for those factors

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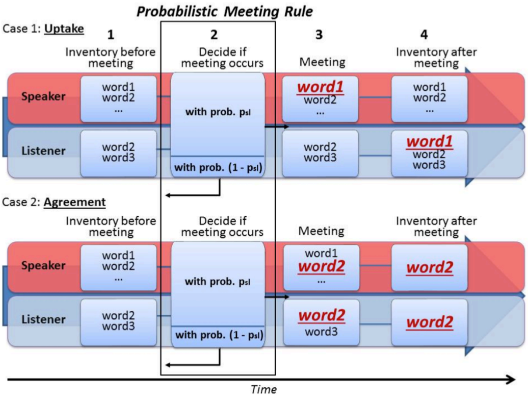
Adapting Naming Game



Naming Game Meeting

Probabilistic Meeting Rule: Social Status

- Idea: Social status how interactions turn into meetings
- Meeting rule to decide whether meeting takes place

$$p_{sl} = min(1, e^{\beta(s_s - s_l)}) \tag{1}$$

where s_s is the social status of the speaker and s_l of the listener and β is a stratification factor

The emergence of social classes

- Egalitarian society: any agent can exchange opinions regardless of status $(\beta = 0)$
- Ranked society: we can model any situation inbetween the extreme cases (e.g. opinions likely flow from high status agents to low status agents) $(\beta >>)$
- Stratified society: opinion flow in only one direction from higher status agents to lower status agents $(\beta >)$

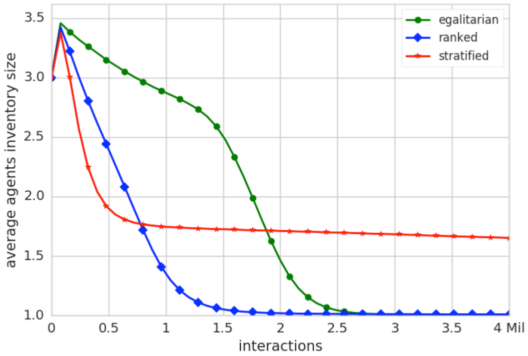
StackExchange

- Reputation scores as proxy for social status
- Social status correlates with node degree

Naming Game

- Initialize agents' inventories with opinions at random
- Create meeting sequences: pairs of agents selected at random, define nr of interactions (iterations)
- Calculate different values for β
- Report averaged simulation results per beta

Naming Game: Impact of Social Status



Findings

- Weakly stratified societies – fastest consensus
- Completely stratified societies – no consensus
- Special setting for each network – optimal social status influence

The role of network structure

- Hubs are key to reaching consensus
- External interventions facilitate consensus building in dissortative networks (where dissimilar agents are more likely connected)
- Any idea why?

More details can be found here:
https://computationalsocialnetworks.springeropen.com/articles/10.1186/s40649-018-0050-1

Summary

- Opinion dynamics
- Cultural dynamics
- Language dynamics

Take away

We can model complex social processes about opinion formation and consensus building using mathematical approaches and models (mostly from physics). Simplified models help us understand complex human behavior in online systems.

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Thanks for your attention - Questions?