Opinion Dynamics

Computational Social Systems I (VU) (706.616)

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Repetition

- Agent-based Models: agents, environment, rules
- Rule define microscopic interactions between agents
- Help us understand macroscopic behavior (e.g. reaching consensus)

Today

- Opinion dynamics:
  - Voter Model, Sznajd model, Bounded Confidence Models
- Cultural dynamics:
  - Axelrod model
- 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 crisis
- Formation of opinions is *social process* of collective intelligence
- Process can lead to consensus, fragmentation, polarization

Agent-based models and opinion dynamics

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: Research Question

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

- Statistical Physics: study of phenomena where relationship between microscopic properties and macroscopic behavior plays a role
  - E.g., phase transitions
  - Freezing of water to form ice
- Do you remember a model that can be used to study opinion dynamics?

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  - Ising model

Repetition: Ising model

- Spin variables s_i: up $(+1)$ or down (-1)
- Each spin interacts with nearest neigbors and external magnetic field h
- Spins align with direction of h
- If temperature low, all spins align - magnetization
- If temperature increases, magnetization destroyed, thermal fluctuation
- Critical temperature T_c below which magnetization, above that, no magnetization
- How do we call that?

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Ising model and opinion dynamics

- Spins: binary opinions
- Individual's opinion represented as individual spin state
- Consensus: ferromagnetic ordering

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- Can you think of factors that govern social dynamics?
  - Social influence, homophily, reciprocity, ...

Opinion dynamics

- Assume each node in the network has an opinion
- Opinion can be discrete or continuous
- Start with arbitrary opinion distribution
- Study evolution of system

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

- Each node in the system can take one of two states $s = +1, -1$
- At each time step, pick node i at random
- That node picks random neighbor j and copies 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

Voter Model

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

Impact of network topology

- Regular networks: irrelevant in which order node and neighbors selected
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Impact of network topology

- Regular networks: irrelevant in which order node and neighbors selected
- What if degree distribution heterogeneous?
  - Few high degree nodes, rarely selected - change rarely
  - Low degree nodes often selected, 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
  - Interactions can only involve centrists
  - Extremists do not talk to each other
- Majority rule model

Majority rule model: Social Imitation (Galam, 2002)

- Assume 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
- All take the majority opinion within the group

Majority rule model: Social Imitation (Galam, 2002)

- Group size r can be fixed or selected at each time step from 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)

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

- Variant of Ising spin model
- Impact a social group has on an individual increases with group size - remember herding!
- Basic principle: convincing person easier for > 2 people

Sznajd model (Stauffer, 2003)

- Agents occupy sides of a linear chain
- Binary opinions $+1; -1$
- Pair of neighboring agents i and $i+1$ determine opinions of their two nearest neighbors $i-1$ and $i+2$:
  - if $s_i = s_{i+1}$ then $s_{i-1} = s_i$ and $s_{i+2} = s_i$
  - if $s_i \neq s_{i+1}$ then $s_{i-1} = s_{i+1}$ and $s_{i+2} = s_i$

Sznajd model (Stauffer, 2003)

- Intuition: group of individuals with the same opinion can influence their neighbours more
- If they disagree, each agent imposes its opinion on the other agent's neighbor
- Discord destroys: if given pair of people disagrees, both adopt opinion of their other neighbor
- Can lead to consensus or stalemate
- Applied in politics to describe voting behavior in elections

Sznajd model: alternative dynamics rule

- Second rule modified:
  - if $s_i = s_{i+1}$ then $s_{i-1} = s_i = s_{i+1} = s_{i+2}$
  - if $s_i \neq s_{i+1}$ then $s_{i-1} = s$ and $s_{i+2} = s_{i+1}$

Discrete vs continuous opinions

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

Bounded Confidence Models

- Opinions: real numbers within some interval
- All agents start with different opinions
- 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 sufficiently close to each other

Deffuant model (Deffuant et al., 2000)

- Describes pattern for social interaction
- Two neighboring agents randomly meet
- Share opinions if difference between their opinions below given threshold ϵ

Deffuant model: How does it work

- Assume population of N agents
- Initially, each agent i has opinion x_i chosen randomly from interval $[0, 1]$
- At each time step, 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 threshold ϵ - each agent keeps 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 constructive debate, opinions 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

Culture dynamics

Culture dynamics

Definition

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

Culture dynamics

- Culture dynamics similar to opinion dynamics
- Difference: opinions are scalar variables but culture is faceted
- Therefore: modeled as vector of variables, whose dynamics are coupled
- Example research 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: 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

Axelrod model

- Social scientists expected that those homophily and social influence will eventually lead to global convergence to a single culture
- Do you think that this is realistic?

Axelrod model

- Social scientists expected that those homophily and social influence will eventually lead to global convergence to a single culture
- Do you think that this is realistic?
- No. In some cases, diversity persists
- 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
- Each cell inhabited by an individual of certain culture
- Culture: list of features f (e.g. language, religion, style of music, ...)
- Features: integer values $\sigma_1, ..., \sigma_f)$, can assume q traits $\sigma_f = 0, 1, ...q - 1$
- Traits q correspond to number of possible traits 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, active agent k selected at random
- One of k's neighbors j selected at random
- k and j interact based on their cultural similarity $n_{k,j}/f$ with $n_{k,j}$ is the number of cultural features for which both have the same trait and f is the nr of cultural features overall
- 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

Axelrod model - dynamics

What is the outcome?

- Each pair of neigbors has either identical cultures or completely different cultures
- Parameters f (features) and q (traits) 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
- No interaction when no same trait
- 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

- Emergence, evolution, interaction, 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 own vocabulary at random
- 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

Naming Game - How it works

- Assume a population of N agent
- Goal: bootstrap a common name for a given object on a fully connected network
- Each agent has an inventory of word-object associations it knows
- At each time step, 2 agents are randomly selected: one is 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

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

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 speaker and s_l of listener and β is a stratification factor

Findings

- Social status impacts consensus building
- Hubs are key to reaching consensus

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?