Modeling Social Systems, Self-Organized Coordination, and the Emergence of Cooperation

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Auguste Comte (1798-1857) is often called the “father” of sociology. He proposed a rational (“positivistic”) approach to the study of society, based on observation and experiment. In the beginning, he called his approach “social physics”, but later he used the term “sociology” (meaning knowledge of society).

Auguste Comte considered sociology to be the queen of sciences. Comparing, for example, sociology with biology and physics, the systems it deals with are the most complex ones.
What Makes Quantitative Theoretical Progress Difficult

- Some of the reasons are:
  - the huge number of variables involved,
  - the relevant variables and parameters are often unknown,
  - empirical studies are limited by technical, financial, and ethical issues,
  - factors such as memory, anticipation, decision-making, communication, interpretation of intentions and meanings complicate the situation a lot.

- The non-linear dependence of many variables leads to complex dynamics and structures, and often paradoxical effects. Linear statistical methods do not reveal mechanisms of self-organization!

- Furthermore, heterogeneity (due to individuality, social difference and specialization), and the fact that the observer participates and modifies social reality, imply additional difficulties.

- Conclusion: It seems worth trying to start with simple, well measurable systems such as crowds or traffic, and only then proceed with more complex phenomena.
A Note on Simple Models

Geocentric Picture: Epicycles around the Earth

Heliocentric Picture: Elliptical paths around the sun
Can We Understand a System from Elementary Processes?
The Need of Simplification and Abstraction

Equations For A Falling Body

\[ t = \sqrt{\frac{2d}{g}} \]

\[ d = \frac{1}{2} gt^2 \]

\[ v_f^2 - v_i^2 = 2gd \]

\[ v = gt \]

"Y'know, Henry, I had no idea it would be so fun to go skydiving with a physicist."

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On Simple and Detailed Models

George Box: “All models are wrong. (But some are useful.)”

Josh Epstein: “If you didn’t grow it, you didn’t explain it.”

The more parameters a model has, the more difficult it is to fit them all exactly. This may affect the accuracy of predictions.

Many social systems are so complex, that the relevant variables and parameters involved are hard to identify and to measure. I will, therefore, study a few simple, measurable systems (leaving, for the time being, complex issues like meanings, values, historical aspects, and other behavioral dimensions aside), hoping that one can learn something more general from the principles observed in these examples.
Some Fundamental Phenomena in Social Systems

- **Homophily**: Interaction with similar people and social agglomeration
- **Social influence**: Collective decision making and behavior, voting behavior
- **Cooperation**: In social dilemma situations
- **Group identity**: Group formation, group and crowd dynamics, coalition formation, social movements, organizations
- **Social norms** and conventions, conformity, integration, social roles and socialization, social institutions, evolution of language and culture
- **Social differentiation**, inequality, and segregation
- **Social structure**, hierarchical organization, etc.
- **Deviance** and crime
- **Social exchange**, trading, market dynamics
- **Conflicts**, violence, and wars
Model Ingredients: Elementary Properties of Individuals

- Birth, death, and reproduction
- Individuals need resources (e.g. eat and drink)
- Competition, fighting ability
- Toolmaking ability, possibility to grow food, hunt etc.
- Perception
- Curiosity, exploration behavior, ability for innovation
- Emotions
- Memory
- Mobility and carrying capacity
- Communication
- Teaching ability
- Possibility of trading and exchange

Goal: Derive the fundamental phenomena from these elementary properties
Emergence of Coordination in Pedestrian Counterflows

Based on individual interactions, lanes of uniform walking directions emerge in pedestrian crowds by self-organization. This constitutes a "macroscopic" social structure. Nobody orchestrates this collective behavior, and most people are not even aware of it. A behavioral convention "institutionalizes" a side preference.
Breakdown of Coordination: Stop-and-Go and Turbulence Flow

The density times the variation in speeds constitutes the hazard! Pressure fluctuations cause turbulent motion and potentially the falling and trampling of people.

Increased driving forces occur in crowded areas when trying to gain space, particularly during “crowd panic.”
Evolutionary Game Theory:
How Spatial Interactions, Migration, Social Inequality, Globalization and Heterogeneous Preferences Can Change the World in Surprising Ways
What is Game Theory?

Game theory is a mathematical discipline providing a set of analytical tools and solutions concepts, which have explanatory and predictive power in interactive decision situations, when the goals and preferences of the participating players are potentially in conflict.

Self-Organization of A Behavioral Convention

The result of a social interaction between two individuals is characterized by the “payoff”

If \( p(1,t) \) denotes the probability of pedestrians to evade on the right and \( p(2,t) \) to the left, the expected payoff (“success”) is \( S(i,t) = Bp(i,t) \), when using strategy \( i \).

The average success of pedestrians is \( A(t) = p(1,t)Bp(1,t) + p(2,t)Bp(2,t) \), where \( p(2,t) = 1 - p(1,t) \). Due to strategy changes (success-driven imitation), the proportion of strategy \( i \) grows proportionally to the difference between the expected success and the average expected success:

\[
\frac{dp(i,t)}{dt} = r [S(i,t) - A(t)]p(i,t)
\]

Only the stationary solutions \( P(i,t)=0 \) or \( 1 \) are stable, i.e. one evading side will become a behavioral convention (Helbing, 1990, 1991, 1992; Young 1993).
The prisoner's dilemma game has served as prime example of strategic conflict among individuals. It assumes that, when two individuals cooperate, both get the "reward" $R$, while both receive the "punishment" $P < R$, if they defect. If one of them cooperates ("C") and the other one defects ("D"), the cooperator suffers the "sucker's payoff" $S < P$, while the payoff $T > R$ for the second individual reflects the "temptation" to defect. Additionally, one typically assumes $S + T < 2R$.

Many "social dilemmas" are of a similar kind (see public goods game)
Peer to Peer Systems and BitTorrent

- Techno-social systems where resources available to all result from resources contributed by the users (storage, bandwidth, contents, ...)

- Most commonly used for content sharing and distribution
  - But also for Internet telephony, computation, ...

- Distributing from a computer to many others is costly
  - Capacity must grow linearly with number of users

- In BitTorrent, downloaders cooperate, sending data to their peers while downloading
  - Scalability: Capacity of the system grows with users
Client Server Systems vs. BitTorrent

Client - Server

BitTorrent

Source
BitTorrent as a Public Goods Problem

- **Torrent**: Group of people downloading and distributing a file

- Torrents depend on cooperation:
  - Users downloading provide bandwidth for each other
  - Users can provide extra capacity (i.e. download speed) once they have finished downloading
  - If users do not share after downloading, the torrent can die

Users provide:
- Storage capacity
- Bandwidth
- Content
Enhancing Cooperation: Theoretical Mechanisms

+ costly punishment, group pressure, community formation...

(Nowak, 2006)
Enhancing Cooperation: Applying Tit for Tat

- Tit-for-tat application to BitTorrent
  - Each downloading peer must choose whom to allocate its upload capacity to
  - Higher contributors are prioritized
  - Quite successful
Users that like the same files group together in online communities with identities, forums, rules and norms.
On-Going Work in QLectives

Main goals:

- Provide tools for decentralized and zero-cost community creation with Tribler (www.tribler.org)

- Implement new cooperation mechanisms for these communities
  - Imitation, tit for tat
  - Community identity
  - Indirect reciprocity/reputation
Indirect reciprocity relies on third-party information ("gossip") about other agents’ behavior (reputation)
- But behavior is hard to verify and some agents lie...

Approach: BarterCast
- Each agent builds a network representing all interactions it knows about
- The reputation of a node P depends on the reputation of other nodes in the path between an agent and P
Combining Game Theoretical Interactions with Success-Driven Motion (Migration)
Nowak and May (1992) have extended the prisoner’s dilemma to simultaneous spatial interactions in an L \times L grid involving \( L^2 \) players, assuming that each player would have binary interactions with \( m=8 \) nearest neighbors, and would afterwards imitate the strategy C or D of the most successful neighbor, if he or she performed better. Computer simulations for \( R=1 \) and \( P=S=0 \) show “chaotic” pattern formation phenomena in a certain parameter range of \( T \).

For \( R=1 \) and \( P=S=0 \) Nowak and May have found that big clusters of defection shrink for \( T<1.8 \), while for \( T>2 \), cooperative clusters do not grow, and in between, both cooperative and defective clusters would expand, collide, and fragment.

Marrying Models of Motion with Game Theory

- What will happen when integrating game-theoretical models and models of mobility?
- Will the resulting individual-based models produce new kinds of self-organization?
- Why are group, class, and niche formation, agglomeration, segregation etc. so widespread in social, economic, and biological systems, although one often tries to counteract these phenomena?
- What is the role of mobility for social cooperation?
- Is migration a “bad thing”?
- Does leaving the birth place necessarily reduce cooperation by cutting social ties, as one may think?
... and Extend It, Considering Success-Driven Migration

- We will now combine strategic interaction, as described by game theory, with a special, success-driven kind of motion. Individuals are assumed to have a preference for a favorable neighborhood. A higher expected payoff, i.e. a higher level of cooperation, makes a neighborhood more attractive.

- We generalize the spatial prisoner's dilemma by adding a success-driven motion step before the interaction and imitation steps. We assume that $N < L^2$ grid locations are occupied, and individuals can move to empty sites.

- To keep things simple, for each empty site within a certain mobility radius $M$, each individual is assumed perform a “test interaction” to determine the fictitious total payoff that would result when moving to this location (“neighborhood exploration”). The individual would then move to the location with the highest payoff, and in case of several equivalent locations, to the closest of them. We assume a random sequential update and periodic boundary conditions.

- Restricting migration to empty sites resembles relocations (e.g. between apartments) and reflects that individuals tend to occupy a certain territory.
Spatio-Temporal Pattern Formation Due to Success-Driven Migration

- Attractive Agglomeration ("Clustering")
- Repulsive Agglomeration ("Ghetto Formation")
- Segregation ("Lane Formation")
Agglomeration in the Prisoner’s Dilemma and Snow Drift Game

Snow-drift game (SD)
Prisoner's Dilemma (PD)

no pattern formation
... to be continued with the Lecture on Cooperation, Norms, and Conflict