Cooperation, Norms and Conflict: Towards Simulating the Foundations of Society

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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

\[ t = \sqrt{\frac{2d}{g}} \]
\[ d = \frac{1}{2} gt^2 \]
\[ v = gt \]
\[ v_i = \sqrt{2gy} \]
\[ v_f = gt \]

"You 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.
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. Acts like Adam Smith’s “invisible hand”
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, and Heterogeneous Preferences Can Change the World in Surprising Ways
Self-Organization of A Behavioral Convention

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

\[
\begin{array}{c|c|c}
\text{Pedestrian 2} & \text{right} \\
\text{left} & B & 0 & 0 \\
\text{right} & 0 & 0 & B \\
\end{array}
\]

\(B = \text{benefit of evading on the same side} = \text{time saved compared to one pedestrian evading to the right and the other one to the left}\)

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: 
\[
dp(i,t)/dt = r [S(i,t) - A(t)]p(i,t)
\]

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).
Nowak and May (1992) have extended the prisoner’s dilemma to simultaneous spatial interactions in an LxL grid involving L² 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.


blue = cooperator, red = defector, yellow = turned to defection, green = turned to cooperation
Spatio-Temporal Pattern Formation Due to Success-Driven Migration

- **Attractive Agglomeration** ("Clustering")
- **Repulsive Agglomeration** ("Ghetto Formation")
- **Segregation** ("Lane Formation")

Diagrams showing the distribution of entities over time and space, indicating different patterns of agglomeration and segregation.
Imitation and Success-Driven Motion, Separately and Together

- $P = 0$
- $R = 1$
- $S = 0$
- $T = 1.4$

**Imitation only**

**Migration only**

**Imitation & migration**

```
blue = C
red = D
```
The Breakdown and Outbreak of Cooperation

Red, yellow: defectors (cheaters)
Blue, green: cooperators
Time-Dependence of Transition of Predominant Cooperation

$R = 1$, $T = 1.3$, $P = 0.1$, $S = 0$, $r = q = 0.05$, $M = 5$
Intermediate Summary

A simple model considering strategy and location changes and noise can reproduce various stylized facts of social systems:

1. **Individuals like to agglomerate** (form cities, groups, etc.)
2. **Individuals with different behavioral strategies tend to segregate** (--> see also Schelling)
3. **Levels of cooperation** in the prisoner’s dilemma and in public goods games are *higher than expected*; they tend to break down, but may grow, if people can leave bad environments and choose more favorable ones
4. **Individual behaviors are partially determined by the social environment** they are contributing to (--> norms)
5. **Social environments persist** much longer than an average individual contributes to it (--> social institutions)
6. **Social systems perform well by continuous adaptation**
Possible Outcomes in the Two-Population Norms Game

\[ \varepsilon = 0.01, \text{Interaction Partner} = 1, \ p_0 = p_1 = 0.5 \]

**Proportional Imitation**

- **Red** = individuals preferring behavior 1
- **Yellow** = individuals adjusting to behavior 1
- **Blue** = individuals preferring behavior 2
- **Green** = individuals adjusting to behavior 2

Computer simulations:

Everyone tends to show the own preferred behavior

Population 1 sets the norm

Population 2 sets the norm

Reward of showing preferred behavior / Reward of conforming
History/Path Dependence - The Initial Condition Matters

Population 1 sets the norm
Population 2 sets the norm

Everyone tends to show the own preferred behavior

Reward of showing preferred behavior / Reward of conforming
Possible Outcomes in the Norms Game with Local Interactions

Population 1 sets the norm

Everyone tends to show the own preferred behavior

Local cultures are forming

Population 2 sets the norm

Reward of showing preferred behavior / Reward of conforming

Computer simulation:

Red = individuals preferring behavior 1
Yellow = individuals adjusting to behavior 1
Blue = individuals preferring behavior 2
Green = individuals adjusting to behavior 2

$\epsilon = 0.01$, $M = 2$, Proportional Imitation, $p_0 = p_1 = 0.5$
Two Populations with Incompatible Interests

Only in the stag hunt game we find that both populations tend to use the same behavioral strategy, i.e. a behavioral norm evolves! The norm-creating mechanism is also important for the evolution of language.
Summary of System Dynamics in Multi-Population Games

with interactions and self-interactions

MSH = multi-population stag hunt game
MPD = multi-population prisoner’s dilemma
MHG = multi-population harmony game
MSD = multi-population snowdrift game

without interactions

without self-interactions
Relevance of the Payoff Parameters and Power

With Interactions
Multi-Population Snowdrift Game
B = 2.0, C = -8.0, f = 0.8

multi-population stag hunt game

multi-population snowdrift game
Intermediate Summary II

- Simple models can produce complex behavior and promise to gain surprisingly interesting insights into the mechanisms underlying socio-economic systems.
- Linear models do not allow to explain emergent self-organization phenomena.
- The representative agent (mean field) approach is misleading.
- Considering time-dependence, spatial interactions, and heterogeneity lead to different conclusions regarding the behavior of socio-economic systems.
- Puzzles such as the occurrence of cooperation among selfish individuals (the victory of cooperators over free-riders) or the establishment of costly punishment (or the disappearance of second-order free-riders) are naturally resolved.
- Mobility is essential for the co-evolution of social environment and social behavior.
- It seems possible to formulate a unified model describing (1) the breakdown of cooperation, (2) the coexistence of different behaviors (subcultures), (3) the evolution of commonly shared behaviors (norms), and (4) the occurrence of social polarization or of revolutions.
- Globalization seems to endanger social cooperation. Are we on the way to a punishment society or to a reputation society?
Challenges to Address

- Social and economic systems are rapidly changing, are in a transformation process, not in equilibrium.
- Scientists need to be put in a better position to address the increasing number of socio-economic problems.

As president of New York’s Columbia University, Lee C. Bollinger formulated the issue as follows: “The forces affecting societies around the world ... are powerful and novel. The spread of global market systems ... are ... reshaping our world ..., raising profound questions. These questions call for the kinds of analyses and understandings that academic institutions are uniquely capable of providing. Too many policy failures are fundamentally failures of knowledge.”

- We must close the gap between existing socio-economic problems and solutions, and get into a position to come up with solutions before a problem occurs.
- The goal is to support politicians and business people in addressing practical problems.
10 Grand Socio-Economic Challenges

1. Demographic change of the population structure (change of birth rate, migration)
2. Financial and economic stability (trust, consumption and investments; government debts, taxation, and inflation/deflation; sustainability of social benefit systems...)
3. Social, economic and political inclusion (people of different gender, age, education, income, religion, culture, language, preferences,...; unemployment)
4. Public health (spreading of epidemics [flu, HIV], obesity, smoking, or healthy diets; incentives supporting food safety)
5. Balance of power (in a multi-polar world; also between individual and collective rights, political and company power; protection of pluralisms, individual freedom, and minorities...)
6. Conflict (terrorism, independence movements, social unrest, organized crime, war)
7. Sustainability of communication and information systems (education and inheritance of culture; cyber risks, violation of privacy, misuse of sensitive data, data deluge, spam, ...)
8. Collective behavior and opinion dynamics (social contagion, breakdown of trust, extremism, changing values, breakdown of cooperation, compliance, or solidarity)
9. Institutional design (over-regulation, compliance, corruption, balance between global and local, central and decentral, intellectual property rights,...)
10. Sustainable use of resources and environment (travel behavior, consumption habits, efficient use of energy and other resources, participation in recycling efforts)
The Need of Integrative Systems Design + Complex Systems Science

We envision to create a socio-economic knowledge accelerator - a multi-disciplinary Apollo project for the social sciences, involving natural scientists and engineers.
Visioneer - Our Chance for the Future of Complexity Science

**WP1: Socio-Economic Data Mining**
- Identifying a sufficient number of leading scientists
- Organization of think tank sessions and offline discussions
- Elaboration of ethical standards regarding the processing, evaluation and publication of social and economic data
- New strategies for data processing
- Proposition of plans for creation of centers for risk analysis and crisis forecasting

**WP2: Social Simulation**
- Development of strategies how to build up social simulation capacities
- Derivation of strategies for integrative system design
- Suggesting ways how to build up community that aims at simulating real and alternative societies by means of supercomputers

**WP3: Innovation Accelerator**
- Identification of new ways how to:
  * publish, evaluate and report scientific progress,
  * increase awareness of new emerging trends,
  * ensure sustainability of a technological future,
  * reach societal benefits and reach industrial needs using ICT

**WP4: Grand Challenges**
- Motivation of new research avenues from global perspective
- Analysis of expected impacts on the society, technology and science
- Formulation of future FET research topics

Your contributions are welcome and essential!
Socio-Economic Systems Imply Major Risks

- **Conflicts:** World War I (more than 15,000,000 victims); World War II (60,000,000 fatalities; cost of 1,000,000,000,000 1944 US$; destruction of 1710 cities, 70,000 villages, 31,850 industrial establishments, 40,000 miles of railroad; 40,000 hospitals 84,000 schools); Vietnam, Korea, former Yugoslavia, Afghanistan, Irak, Darfur…

- **Financial and Economic Crises:** estimated loss of 4-20 Trillion US$

- **Climate Change** will cause natural disasters conflicts for water, food, land; migration; social and political instability (estimated reduction of world gross domestic product by 0.6-12 Trillion US$ per year)

- **Epidemics:** Spanish Flu (20-40 Mio. Deaths), SARS (ca. 800 victims, 100 Billion US$ losses)
Decentralized Concept of Self-Organized Traffic Light Control

Inspiration: Self-organized oscillations at bottlenecks

Optimal compromise between coordination and local flexibility

Published in JSTAT (2008)
The switching sequence adapts to the arrival patterns. We reach flexible switching with a maximum red time duration. Due to the flexibility, we observe a reduction in both, the total waiting time and its variance. Stabilization mechanism avoids “social dilemmas” based on local optimization.
The Measurement and Control Area

Disturbances by public transport
Comparison of Current and Self-Organized Traffic Light Control
Gain in Performance

- Public transport: 2.02 vh, -56%
- Motorized traffic: 63.9 vh, -9%
- Pedestrians and Cyclists: 59 s, -36%

Total delay

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Centralized Control and Its Limits

- Advantage of centralized control is large-scale coordination
- Disadvantages are due to
  - vulnerability of the network
  - information overload
  - wrong selection of control parameters
  - delays in adaptive feedback control
- Decentralized control can perform better in complex systems with heterogeneous elements, large degree of fluctuations, and short-term predictability, because of greater flexibility to local conditions and greater robustness to perturbations

(Windt, Böse, Philipp, 2006)
ETH Zurich‘s Competence Center
Coping with Crises in Complex Socio-
Economic Systems

Kay Axhausen, Lars-Erik Cederman,
Dirk Helbing, Hans Herrmann,
Frank Schweitzer, Didier Sornette