vrije Universiteit amsterdam

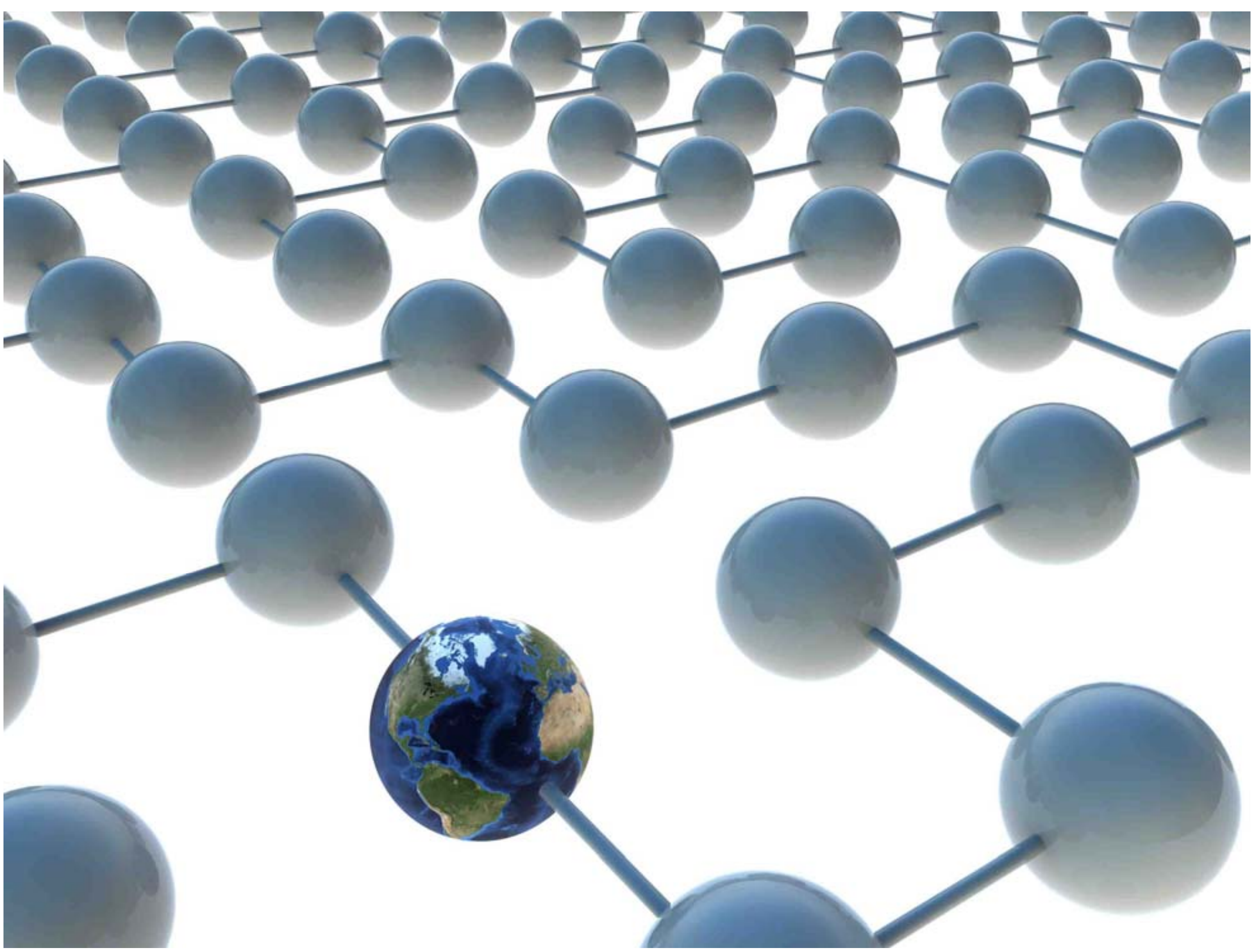
University of Amsterdam

Cascade Dynamics on Interaction Networks

PhD Project

in cooperation with

VU University Amsterdam and *University of Amsterdam*



Abstract: The aim of this project is to improve existing theories on the emergence and stability of collective behavior by explicitly modeling the development of *hidden* forces of action (sentiments). Towards congregation, the individual actors influence the other's preferential attachment through their social network position. The two main research questions are: (I) What kind of networks tend to display higher volatility in collective action than others? In particular, can we explain outbreak of collective action as an endogenous property of system dynamics? (II) How can we control or at least influence collective action given a particular network architecture? Applications are numerous and range from models of innovation, spread of rumours and diseases, marketing, sentiment dynamics in financial markets to crowd and riot behavior.

While the project is especially relevant to economics and social sciences, its methodological tools are borrowed from different disciplines. First of all the modelling is inspired by mathematical social science, in particular mass mobilization and social choice, and combined with mathematical models of biology and economics. Secondly, the corresponding system dynamics is studied using standard techniques and ideas in the field of nonlinear dynamic systems.

Keywords: Mathematical decision making, Nonlinear dynamic systems, Networks, Game theory, Multiple or simultaneous equation models, Mathematical and quantitative methods

Funding: This PhD position is financed by the Netherlands Organization for Scientific Research (NWO) whose objective is the advancement of innovative and high-quality scientific research in the social sciences. The project belongs to the 6 percent of project applications which have been awarded funding in 2011[1]. It was granted based on expert's reports assessing `significant theoretical impact' and the expectation `to lead to international top publications'. Moreover, the proposed interdisciplinary approach at the intersection of economics, biology, mathematics, sociology and political sciences suggests `that the prospective insights might not be confined to the field of economics alone'. The experts assert that `working on this topic could be a strong start in an academic career for a PhD student'.

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[1] *Free Competition* round for Social Sciences in 2011

Job description: The candidate prepares a PhD thesis of within the scope of the research project *Cascade Dynamics on Interaction Networks* and writes scientific articles in cooperation with the supervision team or under his or her own name. The candidate is offered to follow training programmes of our institutes (for details see Section 4 `PhD education' of this document).

Position: The position is a full-time vacancy for 4 years with very limited teaching duties (estimated 4 hours of working classes for 6 weeks in one academic year). Non-Dutch students can profit from the favourable 30% ruling which allows expatriate employees to The Netherlands to earn up to 30% of their compensation tax free (for details see Section 5 ` The 30% ruling').

Candidate Profile: The candidate should have a background in applied mathematics, ideally in dynamic systems or network theory, and should have some experience in programming. Further needed skills will be acquired during the PhD programme of our institutes. For further details see Section 4 `PhD education'.

Starting date: The latest October 2011.

Location: The office of the candidate will be at the VU University Amsterdam with the opportunity to profit from classes and supervision of the University of Amsterdam, as well as the associated Tinbergen Institute which is one of Europe's top graduate schools and research establishment. All institutes are knowledge centres conduct innovative research of international standing and take special care to ensure optimal support for and supervision of its students. The universities are autonomous pluralist institutions which are committed to the enhancement of an open, democratic and multicultural society. It actively pursues an equal opportunities policy.

Application address: Please send all hard copy applications to Dr. Ines Lindner, VU University Amsterdam, Department of Econometrics and Operations Research, De Boelelaan 1105, 1081HV Amsterdam, The Netherlands. For electronic applications please use the e-mail address ilindner@feweb.vu.nl . The receipt of all applications will be confirmed by e-mail. Deadline of applications is 15 May 2011.

1. Project description

Collective action sometimes seems to appear from nowhere, e.g., large protests against a particular regime suddenly bring onto the streets thousands and thousands of people as happened in Eastern Europe in 1989. Although the synchronization of action and the outburst as such might come as a surprise, it is not uncommon in such situations that a "mood" against the regime has already been building up under the surface for quite some time. How do these moods work and in what way does the architecture of interaction between people – the social network – influence sudden outbreaks?

More generally, the systemic phenomena of collective behavior have, according to the mathematical sociologist Coleman (see his 1990 book, chapter 9), several elements in common:

- They involve a large number of people carrying out the same or similar actions at the same time.
- The system is dynamic and might eventually reach an equilibrium state.
- There is some kind of synchronization of action; individuals do not act independently.
- There is some degree of unpredictability, sometimes leading to “explosive” results.

This class of phenomena is broad, including riot behavior, innovation and rumor diffusion, strikes, consumption network externalities, spread of fashions, applauding in a theater, migration, runs on banks, etc.

A particular action alternative will only be adopted on a large scale if it achieves some critical mass of support. Kuran (1989, 1991) suggests for the example of revolutions that the early mobilization problems will only be resolved through a catalytic event, a “spark”, that reveals the *hidden* unpopularity of the present regime. On the outbreak of the revolutions in Eastern Europe and the French Revolution he notes, however, that this spark is often difficult to discern, explaining why these occurrences seem to "appear out of nowhere". Where does this exogenous spark come from?

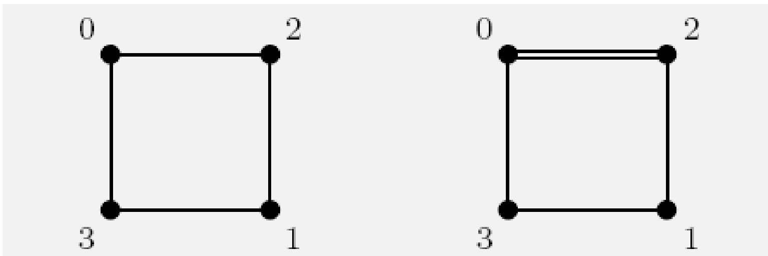
In their seminal work, Schelling (1978) and Granovetter (1978) developed models of collective behavior for situations where actors have two alternatives and the costs and/or benefits of each depend on how many actors choose which alternative. The key element in those models is a *threshold,* i.e. the number or proportion of others who must take action before a given actor does so, the point at which net benefits begin to exceed net costs for that particular actor. Allowing agents to have different thresholds, the models show how a frequency distribution of these may be used to calculate the equilibrium number of actors.

Example 1: Consider a population of 4 people and assume a threshold distribution of 0, 1, 2, 3. In this case, the instigator with threshold 0 stimulates action of the actor with threshold 1, etc. Hence the instigator sets off a domino-effect and everybody will follow.

Example 2: Now replace the individual with threshold 1 by one with threshold 2. Here, the riot ends with the instigator. This example, due to Granovetter (1978), demonstrates the particular value of threshold models in explaining unexpected outcomes: the difference between the two crowds is not observable from the outside, while the outcomes are completely different.

Now assume a non-homogenous society with a social structure. The agents are connected in a social network and take into account only the action of agents they are directly connected to (neighbors).

Example 3: Social networks **Example 4:** ….. with strength of ties



In Example 3, the instigator has no power to initiate action since he is not connected to the agent with threshold 1.

The outcome is again different if we consider *strength of ties* as in Example 4. Assume a strong link between the agents with threshold 0 and 2, say, as close friends their action counts double to each other. Here, the instigator triggers action of the agents with threshold 2 who in turn triggers the agent with threshold 1.

Example 5: Granovetter (1978) analyses cascades of action of large populations by assuming that thresholds are less likely the more they deviate from a certain mean (normal frequency distribution). In his setting, this regular variation about some central tendency leads to two stable equilibria. One equilibrium represents a low level of collective action (e.g. a small group of hardcore revolutionaries or a small group working with Macintosh instead of Microsoft), the other one situated on a high level of collective action (e.g. representing a revolution). Here, the system of collective dynamics needs an exogenous catalytic event – a spark - to lift it over the critical mass in order to move from one to the other stable equilibrium.

There are two drawbacks of these threshold models: First, the dynamics depends in such a strong manner on small changes in the parameters that formulating testable predictions from these models is difficult. Second, once the cascade of action is completed the present threshold models cannot explain further changes. In particular, it doesn't explain *sudden* outbreaks or *change* of collective action.[2]

Our approach is based on the insight that agents who interact in a social network have similar values and are important references to each other. Not only the action is observed but the degree and intensity of feeling or conviction is also communicated. To use an example of riot behavior, assume someone moves to Iraq today and might not want to join riot behavior due to a high threshold against violence. However, after an amount of time this person might be sufficiently "charged" by a hate wave in his social network. As an effect his threshold decreases and he joins riot action. This is what we call moods/sentiments: the thresholds are influenced by the mood in the network by a process of *mutual charging*. We hence remove the limitation to *static* thresholds and introduce *dynamic* thresholds exposed to diffusion of sentiments in the network.

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[2] The key concept of a threshold implies myopic behavior of the agents which suggests the application of evolutionary game theory. However, note that this theory works with the concept of mutations in order to explain changes in behavior. We refrain from working with this concept since (1) it is an exogenous phenomenon to the collective system (2) it does not help to explain the necessity of a critical mass.

In precisely those situations in which we mainly observe behavior and not *moods*/*sentiments* as e.g. the hidden unpopularity of the standing regime or the enthusiasm about an innovation, the limitation to static thresholds might explain why we do not understand, and thus not foresee, sudden actions of groups. Valente (2005) notes in the context of diffusion of innovation "Verbal accounts on how people make decisions and adopt behavior usually reveal .... *whims* (moods/sentiments) that are not independent of networks, but not easily captured in social influence models." (p.113). The state-of-the-art literature is not capable of explaining sudden collective action as an *endogenous* property of collective dynamics.

This project aims to improve existing models by introducing sentiments (endogenous thresholds) so that sparks and sudden actions can be explained by synchronization effects based on mutual "charging". Putting it differently, the static threshold approach of Granovetter is replaced by a dynamic approach of *threshold contagion*. We believe that these moods/sentiments are the unobservable missing link between why some collective action events occur and others don't.

Moreover, on a micro level, the question is how do we measure the *power* of groups of actors to initiate mass-mobilization in a structured society. E.g. nowadays in Iraq, with the endeavor of the international community in vain, (just) a small number of actors is credited for accomplishing a self-sustaining basis of support for the insurgency, large enough to be able to disrupt completely the early beginnings of what is supposed to be a democratic process. This example shows that there is a strong need of understanding the powers of these destructive forces and the *scale* at which they occur. Also in other applications, as reactions to fire alarms, strikes, voting, migration, or diffusion of innovation, it can be instructive to know the most influential individuals. With some information on the social network and threshold distribution, a social planner, a political party, or a firm's management may be able to actively address the most powerful individuals and thus help to prevent or to stimulate action in a given context.

In social network theory, there are measures quantifying the importance of an actor in a network. (For an overview see e.g. Laslier 1997.) However, the major drawback of these measures is that they depend only on the architecture of the network without taking the distribution and development of thresholds into account. Recall Example 3: due to the symmetry of the network, measures solely based on the network itself would suggest a symmetric measure. However, we have seen that the power to initiate action depends crucially on the distribution of the thresholds.

These examples demonstrate that social structure and the distribution of thresholds are crucial for different *levels* of collective action. In Example 1, the instigator has the power to initiate 100% of collective action. In Example 2 and 3, this power is zero since he doesn't trigger any other action. In Example 4, he has some power to initiate action, however, not 100% since the agent with threshold 3 remains inactive.

Measures of voting power can quantify the *extent* to which a voter or a group of voters is able to *control* the outcome of a vote (Felsenthal and Machover, 1998). Here, the collective choice is determined by a decision rule (say, simple majority). In a broad sense, mass mobilization can be seen as a process of dynamic voting where the static aggregation *rule* is replaced by a dynamic aggregation *process*. In his well known 1971 paper Coleman proposed three measures of voting power with direct appeal for our specific context as elaborated in Goal 2. This project aims to extend these existing measures of influence by considering a dynamic process within networks as the aggregation rule to determine collective choice/action.

RESEARCH GOALS AND QUESTIONS

This project has two goals, each with two different levels of abstraction.

1. **Goal:** Generalizing existing models of collective action by including the private dynamic component, that of the hidden dimension of *sentiments.* Next, can we understand herding effects and volatility as *endogenous* effects of collective dynamics.
   Main research question: What is the relationship between network architecture and volatility in collective dynamics? Can we explain collective action that seems to appear out of nowhere by means of the volatility of the dynamic system?

2. **Goal:** Understanding and *measuring* the effect of actions of individuals ("sparks") on the *likelihood* of starting an outburst depending on their network position and individual characteristics.
   Main research question: How can we control or at least influence collective action given a certain network architecture and dynamics of threshold contagion?

Each goal comprises general as well as more applied research. Combined with extended computer simulation runs the latter refines the general model and confirms theoretical results by introducing specific network structures that differ significantly with respect to their structural characteristics (density, centrality, transitivity, scale free). Examples include telephone call graphs, co-authorship and citation networks of scientists, the quintessential "old-boy" network, the overlapping boards of directors of the largest companies in the United States, insurgent networks, the World Wide Web, firms' cross-licensing agreements. Databases of many network architectures are now easily accessible, by courtesy of the internet (see Strogatz 2001 for an overview). Figure 1 gives some examples of stylized network topologies.

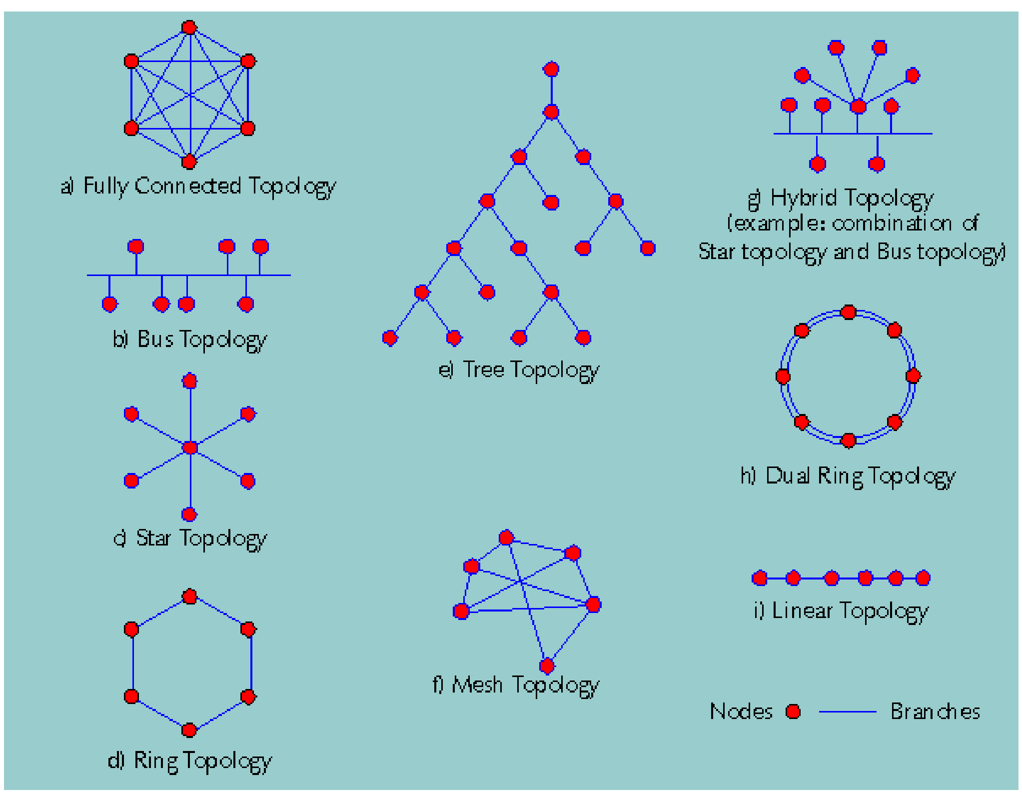

Figure 1: Stylized topologies of networks

3. Embedding in game theoretic literature

In a nutshell, local interaction games are about scenarios where players only interact with small subsets of the overall population rather with society as a whole (for an overview see e.g. Weidenholzer 2009). In the setting of our proposal, these small subsets can be seen as the direct links in a networks. On the other hand, the key concept of a threshold implies myopic behavior and imitation. This suggests to attribute our proposal to evolutionary game theory. Note, however, we do not aim to explain volatility of a collective system by means of (exogenous) mutation.

4. PhD education

The education of the PhD student will depend on his or her background. We suggest considering participation in the educational program of the Tinbergen Institute. This institute offers courses on game theory, individual decision making, social choice, strategic and cooperative decision making. Moreover, VU University and University of Amsterdam offer specialized courses on dynamic systems, stochastic processes, bifurcation theory and evolutionary game theory.

5. Salary and the 30% ruling

The following table indicates annual salaries in Euros. Note that non-Dutch citizens profit from the favorable 30 percent tax rule (see explanation below).

Year	**Annual gross salary**	**Annual net salary with 30 percent tax rule**	**Annual net salary without 30 percent tax rule**
First	**28920**	**23475**	**19977**
Second	**33693**	**26627**	**22230**
Third	**35294**	**27556**	**23009**
Fourth	**36993**	**28527**	**23882**

These numbers include 12 monthly payments plus two additional annual gross payments: (1) One in may („vacation payment“) and (2) one in december („end-of-the-year payment“). The net salary is gained by the gross salary substracting taxes, social security (unemployment insurance) and pension fees.

Health insurance is compulsary in the Netherlands and can range from 50 to 110 Euros per month, depending on the costs you want to be covered and your own risk. E.g. the cheapest insurance excludes dental costs and incorporates an annual own risk of 650 Euros (meaning that medical costs exceeding this amount will be covered by your insurance).

The favourable 30% ruling (or in Dutch "30% regeling") allows expatriate employees to The Netherlands to earn up to 30% of their compensation tax free. In addition, the 30% ruling also allows you, the expat, to opt for the partial non-residency status. With the partial non-residency status you are exempt from Dutch taxation on your investments (except investments in Dutch real estate). Americans with the partial non-residency status can also claim a deduction for employment income allocated to non-Dutch workdays. Finally, with the 30% ruling you and your partner are allowed to exchange your foreign driver's license for a Dutch driver's license without having to take time-consuming tests.

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