Interactions in Complex Systems

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Global interactions

Chapter 1

Hyperbolic travelling waves in neolithic populations modelling

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Abstract

We give in this article some mathematical insights into archaeology models. We first introduce the wave of advance model developed by Ammerman and Cavalli-Sforza and an improvement by Mendez and Fort. Particular solutions of the underlying equations, called travelling waves by mathematicians and waves of advance by archaeologists, are good notions in order to describe the propagation of agriculture during the Neolithic period. We present existence results for such solutions and compute their propagation speed. The time-delayed model could indeed be viewed as a toy-model in order to investigate kinetic reaction-diffusion equations, which has recently been introduced in order to describe microscopic biological populations dynamics, and that were studied on their own with mathematical tools.

1.1 Reaction-diffusion models in archeology

1.1.1 The wave of advance model

The first use of reaction-diffusion equations in an archaeological framework is due to Ammerman and Cavalli-Sforza in their seminal work Ammerman-Cavalli-Sforza (1984), which investigated the spread of agriculture in Europe during the Neolithic transition. Using carbon 14 datations of archeological sites, they observed that the diffusion of agriculture starts from Middle-East in 7000 BC and then spreads in Europe at an approximate speed of 1 km/yr. In order to explain the existence of such a linear propagation speed, they used the classical Fisher-KPP equation

$$\partial_t u - D\Delta u = ru(1 - u/u_{max}). \tag{1.1}$$

This equation was first introduced in the 30's by Kolmogorov et al. (1937) and Fisher (1937), both in the framework of biological invasions. It has then been used in lots of models, related to genetics, chemistry, combustion, economics, ecology etc.

It relies on the hypothesis that the population is large enough to be modelled by a continuous density variable $u = u(t, x)$, and that the following interactions between individuals drive their evolution:

- the population disperses with a flux that is proportional to the gradient of density (Fick Law), at a rate D,
- at each time step dt, the population gives birth to a number $ru(t, x)dt$ of new individuals, where r is the reproduction rate,

- the environment is assumed to only contain a finite quantity of resources, which leads to a maximal density of population u_{max} and creates the nonlinear death term $-ru^2/u_{max}$.

Due to this nonlinear term, the equation cannot be explicitly solved. The trajectory followed by a given individual cannot be predicted. However, this model gives rise to deterministic asymptotic patterns at the population scale: the level lines of the population density behave like circle at large time $t >> 1$, containing a surface proportional to t^2. This is characteristic of a complex system.

A fundamental mathematical property of equation (1.1) is the existence of **travelling waves solutions**, that is, solutions of the form $u(t, x) = U(x - ct)$, where U is positive and smooth, $U(-\infty) = u_{max}$, $U(+\infty) = 0$. Here, U is called the profile of the travelling wave and $c \in \mathbb{R}$ is its speed. The shape of such solutions implies that if one shifts the time from t to $t + T$, then the solution keeps the same profile and is only translated by a lenght cT. It was proved in Kolmogorov et al. (1937) that there exists a travelling wave with speed c if and only if $c \geq c^* = 2\sqrt{Dr}$. Moreover, the travelling wave with minimal speed c^* attracts, in a sense, the solutions of the initial value problem (1.1) associated with compactly supported initial data. In other words, if one introduces a density of population in some given location of the space and lets it evolve through (1.1), then it will propagate in all directions with speed $c = c^*$ and will "look like" the wave with minimal speed c^* at large times. Note that the minimal speed $c^* = 2\sqrt{Dr}$ only depends on the linearization near the steady state $u = 0$ of the nonlinear equation (1.1), it does not depend on the saturation threshold u_{max}. This means that the waves is "pulled" by the edge of the invasion, where $U \simeq 0$.

Coming back to the Neolithic transition problem, Ammerman-Cavalli-Sforza (1984) identified travelling wave solutions as an appropriate mathematical equivalent of the **waves of advance** empirically observed. Using anthropological observations of preindustrial farmers, they estimated the parameters: $D \simeq 1100-2200$ km/gen, a generation time $\tau = 25$ years and $r \simeq 0.029 - 0.035$ per year. This gives a propagation speed $c^* = 2\sqrt{Dr}$ between 2.25 and 3.50 km/yr and a mean value of 2.86 km/yr, which has the same order of magnitude as the empirical speed 1 km/yr.

This validates this "wave of advance model" and gives a mechanism from which the linear spreading speed naturally arises, meaning in particular that this transition is not driven by some external force. This model has then been used in many works on the diffusion of technologies or languages in early populations. It was improved, in a way that we will describe in the next section, by Fort et al. (2004) in the Palaeolithic framework, in order to show that the speed of the wave of recolonization might not have been limited by the climate change but only by the intrinsic characteristics of the population.

1.1.2 The time-delayed model

The two physicists Fort-Mendez (1999) observed that the Fisher-KPP equation (1.1) relies on the Fick law. Namely, one assumes that the migration (flux) rate at time t is proportional to the gradient of the density of population at time t. This approximation is too rough for human populations, for which one expects the migrations to occur at a generation scale: the gradient of population at time t should give rise to a migration flux at time $t + \tau$, where τ is the generation time. This gives a delay term in the Fick

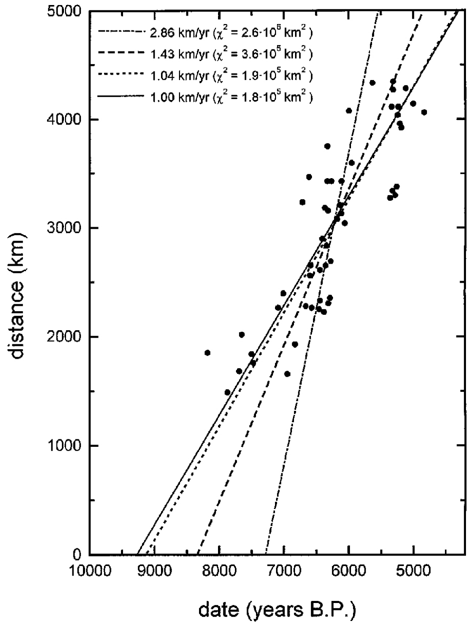


Figure 1.1: Figure from Fort-Mendez (1999): comparison between the wave-of-advance model and the time-delayed model. Each point was associated in Ammerman-Cavalli-Sforza (1984) with a dated archaeological sites where evidence of agricultural activities were found, distances being measured as great circle routes from Jericho (the presumed center of diffusion). Dates are conventional radiocarbon ages in years before present (BP). The solid line is the regression by Ammerman-Cavalli-Sforza (1984). The other three lines are least-squares fits with slopes calculated from the classical wave-of-advance model (dashed-dotted line), the time-delayed model (dotted line). We do not discuss here the dashed line, the interested readers being referred to Fort-Mendez (1999).

law, which leads to the new hyperbolic reaction-diffusion equation:

$$\frac{\tau}{2}\partial_{tt}u - D\Delta u + \big(1 - \frac{r\tau}{2} + \frac{2ru}{u_{max}}\big)\partial_t u = ru(1 - u/u_{max}). \tag{1.2}$$

The mechanism leading to this equation is very simple and indeed it is used in many fields such as forest fire modelling, epidemics, chemistry (see Fort-Mendez (1999) and the references therein).

Assuming that the propagation speed should be given by the leading edge of the invasion, where $u \simeq 0$, as for the classical Fisher-KPP equation (1.1), Fort and Mendez heuristically derived the following propagation speed for equation (1.2):

$$c^*_\tau = \frac{2\sqrt{rD}}{1 + \frac{r\tau}{2}}. \tag{1.3}$$

Evaluating r, τ and D as Ammerman-Cavalli-Sforza (1984), and noticing that the estimation of D should be divided by 4 since the population evolves on a $2d$ plane and not a $1d$ line, this gives a propagation speed between 0.84 and 1.24 km/yr, with a mean value 1.04 km/yr. This is much closer from the empirical speed 1 km/yr, validating this corrected delayed model. These results are displayed in Figure 1.1.

However, this computation of the speed c^*_τ relies on the approximation that only the leading edge of the invasion is important. Indeed, such an approximation is a bit risky from a mathematical point of view: the term $\partial_{tt}u$ changes the nature of the equation. There is a balance between the parabolic and the hyperbolic terms, and it is known that hyperbolic equations might give rise to singular solutions such as shocks instead of smooth travelling waves.

1.2 Mathematical investigation

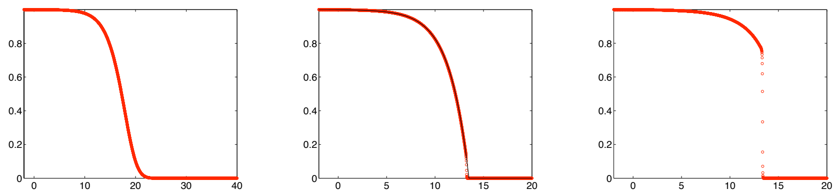
1.2.1 Computation of the propagation speed for hyperbolic reaction-diffusion equations

A mathematical study of equation (1.2) was recently provided by Bouin et al. (2014a), showing that one should distinguish two regimes.

If the delay is sufficiently small ($r\tau/2 < 1$), then the same behaviour as for the non-delayed Fisher-KPP equation occurs. Namely, there exists a smooth travelling waves solution of speed c for all $c \geq c^*_\tau$ and the one with minimal speed $c = c^*_\tau$ is stable, in a sense. We mention here that this framework was investigated mathematically in the older paper Hadeler (1988), using different techniques.

When the delay becomes larger ($r\tau/2 \geq 1$), typical hyperbolic phenomenon arise. Namely, there exists a travelling wave of speed c for all $c \geq \sqrt{2D/\tau} =: \widetilde{c}^*_\tau$, and the travelling wave with minimal speed $c = \widetilde{c}^*_\tau$ is discontinuous if $r\tau/2 > 1$, that is, it is a shock. This means that the propagation is not driven by the leading edge of the front. Indeed, as the migration time τ is large, the wave equation operator $\frac{\tau}{2}\partial_{tt}u - D\Delta u$ dominates equation (1.2) and the solution evolves with the associated speed $\widetilde{c}^*_\tau = \sqrt{2D/\tau}$. The shapes of travelling waves in these various regimes are displayed in Figure 2.

As a consequence, the approximation made in Fort-Mendez (1999) is not valid in general. Nevertheless, the parameters involved in Fort-Mendez (1999) satisfy $r\tau/2 < 1$, so that the computation of the minimal speed c^*_τ is correct in this particular setting. But if $r\tau/2 > 1$, then the propagation speed is $\widetilde{c}^*_\tau > c^*_\tau$.



(a) $\tau = 1/2$ (b) $\tau = 1$ (c) $\tau = 2$

Figure 1.2: $r = 2$, $D = 1$, $u_{max} = 1$. When $\tau < 1$, the wave-of-advance (i.e. travelling wave) is smooth and the speed is determined by the leading edge, where $u \simeq 0$. When $\tau \geq 1$, the wave is not smooth anymore: the density of population grows suddenly from $u = 0$ to $u = 3/4$ for $\tau = 2$.

1.2.2 Generalization: a kinetic approach to reaction-diffusion

As already mentioned, equation (1.2) is involved in other fields of applications. Apart from archaeology models, it arises for example in bacteria dynamics modelling, where it could be viewed as a simplification of a more general kinetic reaction-diffusion equations. Such equations are both interesting from a modelling point of view since it gives a microscopic interpretation to classical reaction-diffusion equations, and from a mathematical point of view. Let us briefly describe these promising prospects in order to conclude this paper.

Such a microscopic approach was initiated recently by Cuesta et al. (2012), who introduced Fisher-KPP equations with a kinetic distribution kernel:

$$\partial_t f + v \cdot \nabla_x f - M(v)\rho_f + f = r\rho_f\big(M(v) - f\big), \quad \text{for all } (t,x,v) \in (0,\infty) \times \mathbb{R}^N \times V, \tag{1.4}$$

$$\text{where } \rho_f(t,x) := \int_V f(t,x,v)dv, \quad V \subset \mathbb{R}^N \text{ is the space of admissible speeds,}$$

$$M(v) \geq 0, \ \int_V M(v)dv = 1.$$

Here, f is a density of populations parametrized by the time t, the space x and their speed v. The left hand-side is associated with the movement of the population with speed v and its random changes of speed with probability $M(v)dv$. The right hand-side modelizes the births and deaths of the population. Such models might be well-fitted in order to investigate microscopic populations dynamics such as bacteria (see the mathematical biological papers cited in Bouin et al. (2014b)).

If the kernel M is a combination of Dirac masses $M = \frac{1}{2}(\delta_{v_0} + \delta_{-v_0})$, then simple computations show that (1.4) turns into (1.2) under appropriate changes of variables. Equation (1.2) was thus first investigated in Bouin et al. (2014a) as a toy-model in order to understand the more general equation (1.4).

In the asymptotic regimes where the change of speeds occurs very frequently, it could be proved that the solutions of equations (1.4) converge to solutions of the classical Fisher-KPP equation (1.1) under an appropriate rescaling. Cuesta et al. (2012) used this observation in order to construct travelling waves solutions of equation (1.4) in a perturbative regime when the set of speeds V is bounded.

Indeed, Bouin et al. (2014b) showed that such travelling waves exist in general, not only in perturbative regimes, as soon as the set of speeds V is bounded, that is, the speed of each individual cannot be too large. Moreover, one can show that the associated propagation speed is given by the leading edge of the front. The difference with equation (1.2) is that this speed is not explicit anymore but is given by some integral equation involving the kernel $M(v)$. When V is unbounded, that is, when each individual could take arbitrarily large speeds, then travelling waves do not exist anymore Bouin et al. (2014b). Indeed, in this case the propagation is superlinear. For exemple when $V = \mathbb{R}$ and $M(v) = e^{-v^2}/\sqrt{2\pi}$, the leading edge of the front is located approximately at $x \simeq t^{3/2}$. The unerstanding and the rigorous proofs of these phenomenon is the subject of works in progress.

Conclusion

We first described in this article mathematical models involved in archaelogy. The classical model introduced by Ammerman-Cavalli-Sforza (1984) gives a mechanistical interpretation to the emergence of "waves of advance", observed for example in the neolithic colonization of Europe, showing that such propagation phenomenon is not driven by any external force. These waves are associated with travelling waves solutions of the Fisher-KPP equation. The order of magnitude of the propagation speed derived from this model could be improved by introducing a time-delay in the equation, as suggested by Fort-Mendez (1999), giving rise to a hyperbolic reaction-diffusion equation. This equation was rigorously investigated by Bouin et al. (2014a), who identified two different regimes: if the delay becomes too large, then the approximation made by Fort-Mendez (1999) is not valid anymore and shocks, that is, non-smooth travelling waves, arise. Hyperbolic reaction-diffusion equations are indeed simplifications of more general kinetic reaction-diffusion equations, which are involved for example in bacteria dynamics models. The investigation of these equations is more involved and might give rise to contrasting phenomena, such as superlinear propagation, which are still not completely understood (see Bouin et al. (2014b)).

Aknowledgements:

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Bibliography

Ammerman A. J., L. L. Cavalli-Sforza, 1984, *The Neolithic Transition and the Genetics of Populations in Europe*, Princeton University Press.

Bouin E. , V. Calvez, G. Nadin, 2014a, Hyperbolic traveling waves driven by growth, *Math. Models Methods Appl. Sci.*, 24.

Bouin E. , V. Calvez, and G. Nadin, 2014b, Front propagation in a kinetic reaction-transport equation, *Accepted for publication in Archive for Rational Mechanics and Analysis*.

Cuesta C. , S. Hittmeir, C. Schmeiser, 2012, Traveling waves of a kinetic transport model for the KPP-Fisher equation, *SIAM J. Math. Anal.*, 44, 4128–4146.

Fisher R. A., 1937, The advance of advantageous genes, *Ann. Eugenics*, 7, 335–369.

Fort J., V. Méndez, 1999, Time-Delayed Theory of the Neolithic Transition in Europe, *Phys. Rev. Let.*, 82(4).

Fort J., T. Pujol, L. L. Cavalli-Sforza, 2004, Palaeolithic populations and waves of advance, *Cambridge Archaeol. J.*, 14, 53-61.

Hadeler K.P., 1988, Hyperbolic travelling fronts, *Proc. Edinburgh Math. Soc.* 31, 89–97.

Kolmogorov A.N., I.G. Petrovsky, N.S. Piskunov, 1937, Etude de l équation de la diffusion avec croissance de la quantité de matière et son application à un problème biologique, *Bulletin Université d'Etat à Moscou (Bjul. Moskowskogo Gos. Univ.)*, 1–26.

Chapter 2

The Urban project, complex system in search of coherence

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Abstract

Urban project is a complex object resulting from interaction of several operations in progress on the Territory. The systemic approach developed here investigates the modelling of urban system as a possibility to go over contemporary fragmentation and complexity which assign strongly Planning of the Territory and Urban-Planning disciplines. These cope with the necessity for renewal of traditional modes of action in favour of reflexive approaches reflecting the experiment applied here. The modelling of urban system realized by the setting-up of interactive tool of map making is the indicator of the interactions between the various elements of the urban project. This tool is a part of experiments led on the urban observatories contributing to give a new vision of projects management, more flexible and adjustable to the context of uncertainty which is our, and attentive to the unexpected and interactions.

2.1 Introduction

This contribution is based on a town-planning research, related to the coherence of the urban project in a context of uncertainty and complexity, applied to the case of the City of Saint-Etienne in France. Urban-Planning and Planning of the Territory are guided by a structuring principle of territorial coherence (Zepf & Andrés, 2012 ; Zepf & Novarina, 2009; Jourdan, 2012; Faludi & Peyrony, 2011). However, complexity and fragmentation inherent in contemporary conditions of the urban development questions very strongly this objective (Ascher, 2001; Chalas, 2004; Kokoreff and Rodriguez, 2004). In the first time, we will demonstrate how the urban project can be broached as a complex system resulting from interaction of several planning operations taking place on the territory. After underlining this systemic character, we will develop stakes related to the modelling of urban system. The methodology developed for this research is based on the experiment of interactive tool realized with the city of Saint-Etienne, and revealing interactions between different projects of the territory. The research represent an attempt to go over uncertainty which assigns nowadays urban-planning and planning of the territory. It investigates the systemic approach and the modeling of urban project as a tool for decision support and city projects management, in quest for territorial coherence.

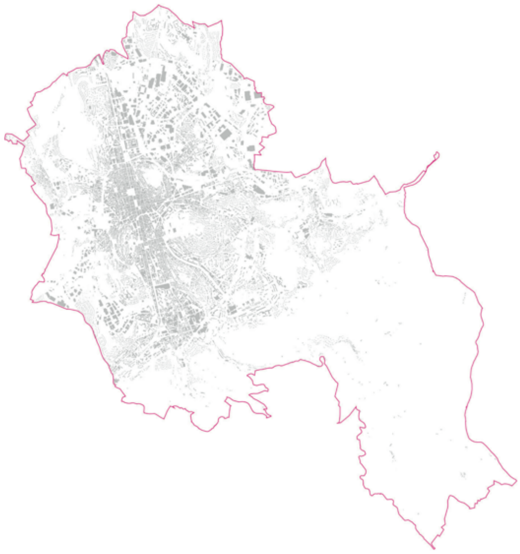

Figure 2.1: The municipal territory of Saint Etienne
Source: Chemin-Le Piolet

2.2 The urban project as a complex system

The urban project is a polysemous and multi scale concept (Bourdin & Prost, 2009 ; Genestrier, 1993 ; Panerai & Mangin, 1999 ; Rey et al., 1998; Tsiomis & Ziegler, 2007), that can be understood at different levels, alluding to, at the same time, a project of several architectural buildings, an operation of complex planning at district level, a city or urban area project (Merlin & Choay, 2005). The urban project also takes many dimensions: technical, political, economic and social (Ingallina, 2003). It will be understood here in its spatial dimension, as the combination of various planning actions or projects carried out at the city of Saint-Etienne. In this publication we will tackle the urban project, not as the compilation of the various projects of the territory, but as the combination in which projects come into interaction reinforcing, weakening, etc. The urban project is consequently seen as a complex system resulting from many interactions between projects (Toussaint and Zimmermann, 1998).

2.2.1 The major spatial components of the city urban project

The research topic is the project of the city of Saint-Etienne. On Figure 2.1, the municipal boundary of Saint-Etienne is represented by the pink outline, and buildings are in grey. We used these base maps to identify different project areas according to their natures , ladders, etc.

The dominant and general public view of city projects comes mainly through an approach to large projects represented by hatching roses (Figure 2.2). The perimeters of these complex and emblematic urban projects represent exceptional territories in which public actors take part heavily to accelerate the development of economic hubs, the replacement of precarious districts, the design of new districts, etc. This outstanding intervention is motivated by its strategic specificity at the global territory level.

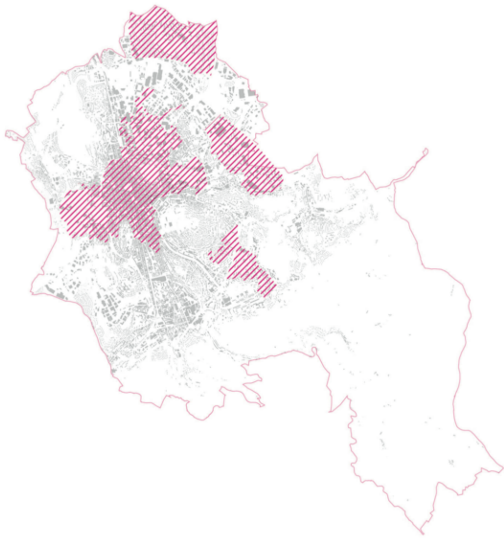

Figure 2.2: The perimeter of major projects
Source: Chemin-Le Piolet

The territories are excluded from the common law, and are subject to operational arrangements (public-private partnerships, global urban planning procedures, etc.) and distinctive monitorings (the setting of a specific organization in project mode for example). These are areas in which local actors have great knowledge and about which they communicate a lot in a territorial marketing logic.

This vision, synthesizing the city project through major projects, seems reductive in a systemic approach. Our approach advocates an expanded vision of the city project, that encompasses a multitude of actions, taking major projects but also actions, more common and anonymous, that move the territory into consideration. The challenge in this systemic approach, is to include the diversity of projects that make up the territory, to develop an all-embracing vision, and to exceed focus generally carried on major urban planning projects. It is integrating ordinary city in the thought of global urban project. The city so-called common, represents 80 % of the territory but is not the subject of cultural, residential, or commercial emblematic major public programs, and yet, this city is also changing, according to the operations in more common districts, private interventions of limited replacement in the plot, etc. These projects involved in the evolution dynamics of the territory, and therefore of the overall urban project.

In this way, the overall urban project of the city of Saint-Etienne, represents a system in which multiple emblematic operations involve such major projects, or more anonymous actions dealing with the common city. It therefore appears as a system combining varied elements such as major projects, cross functional projects such as transport infrastructures, equipment and utilities projects, and the varied operations encompassed in what we will call the `"diffuse"`.

- The “Diffuse” (Figure 2.3) provides the most expanded possible vision on the dynamics of the territory. Areas not covered by complex operations, contain however varied dynamics regarding private operations and/or public local actions. They are consequently squarely included in the overall dynamics of the

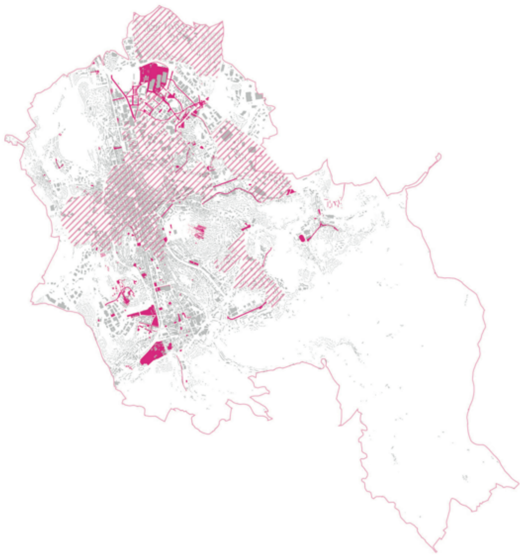

Figure 2.3: “Diffuse projects”
Source: Chemin-Le Piolet

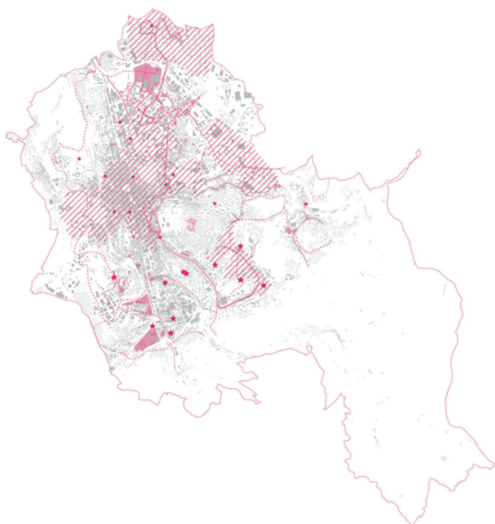

Figure 2.4: List of municipal kindergartens
Source: Chemin-Le Piolet

urban project, without requiring a strong action of the public actor in term of project. These projects are of a smaller scale and of one-off nature, as shown in Figure 2.3. It may be the renewal of a square in a district, a small public garden, the creation of a block of flats, the setting-up of faćade restoration, etc.

- Equipment and utilities projects raise the question of territorial balance, through the implementation of various public policies. They embrace projects of equipment and services to the people such as kindergartens, shown in Figure 2.4, schools, associations, etc. It is to develop a balanced offer, in terms of equipment and services, to the population in the different districts.

- Cross-functional projects whose transport infrastructures are emblematic, strongly impact the territories they cross. High structuring stakes of the municipality surround them. Examples of the public transport (Figure 2.5) and Green lane projects (Figure 2.6) in Saint-Etienne are representative of these particular character projects.

2.2.2 The combination of many projects at municipal level

Resulting from this use of the urban project as a system, we are interested by the interactions between these various elements. It is to identify how these elements work in synergy, comforting or not the projects amongst themselves and the overall project. Thus, the urban project cannot be reduced to the sum of the different projects developed in the area, but rather their combination in which some of them will weaken, strengthen, annihilate themselves or each other etc.

Thus, cross-functional projects can represent a boosting or nuisance vector for other operations in progress, and challenge their progress and future. For example, the passing of a public transport in a district can be an opening up factor for the revitalization project of the district. Or the setting-up of a green lane to a smooth inter-district connection, can enhance operation of housing nearby. The setting-up of a highway, can both connect spaces, while representing a nuisance and urban split for crossed areas. Similarly, several 'diffuse' actions matched together, may impact a large project by producing competing projects such as a new housing offer with a similar target and quality, office areas, etc.

All these actions or projects developed and produced by various actors, come into interaction with each other, and impact the overall system. In the field of urban planning, each planning of public areas, any renovation or construction of equipment or various housing impact the district not only where the operation is taking place but also in the city in its entirety. It is actually appropriate to speak of congruence, rather than impact between projects, because in this complex system, it becomes very difficult to assess which element has an impact on any other. Each project coming into resonance with the other actions on the territory can influence the overall strategies of the city project and change the balance of the urban project, notably in terms of equipment distribution, public utilities access, etc.

The challenge, in this systemic approach of the urban project, therefore lies in the consideration of many projects which component it. This task falls to the public actor, who is responsible for the development of the territory, and whose role is to coordinate projects together, in order to promote synergy, rather than a weakening of urban dynamics, and to reduce the inequalities which might occur. These projects under the action of a multitude of actors, the stake of the coherence of these actors and their actions represent, in our opinion, the current major challenge for city planners.

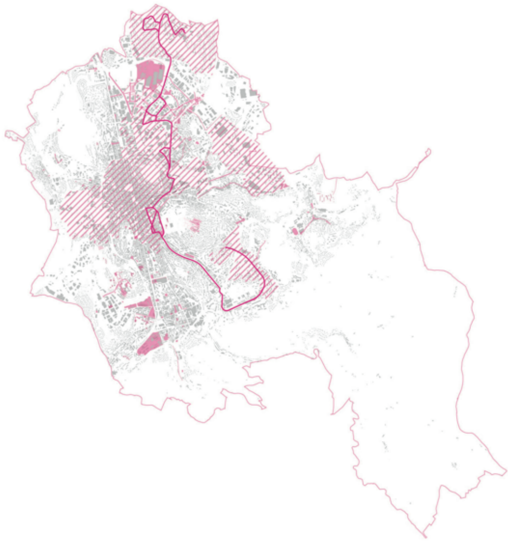

Figure 2.5: Possible drawing for the public transport in Saint Etienne
Source: Chemin-Le Piolet

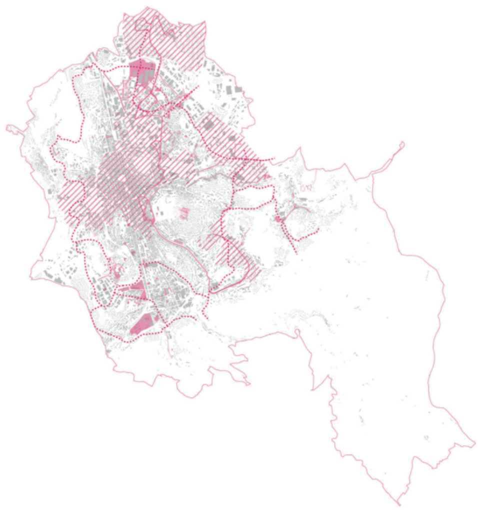

Figure 2.6: Possible drawing for green lane, inter-districts link
Source: Chemin-Le Piolet

2.3 The quest for coherence of the urban project

2.3.1 Coherence and complex system

The system is broached by E. Morin as "different elements combinatorial association"[2] (Morin, 2005, p. 28). The sociologist and philosopher also points out: "systemic virtue is to have placed at the centre of the theory, with the notion of system, not a discrete elementary unit, but a complex unit, a "set" that cannot be reduced to the "sum" of its constituent parts "[3] (Morin, 2005, p. 29). Several versions of the system concept alludes to the logic and organization as resultant of its structure. The system appears as “a set of equipments or not, mutually dependent on each other to form an organized whole”[4] (Lalande, 2006, p. 1096). Thus, the concept of "coherence" is implicitly included in the internal working of the system.

When it is complex, system working doesn't appear much decryptable even intertwined and therefore its logic and coherence escape. It is the complexity that takes us away from the coherence concept as many parameters become intertwined in interaction. Complexity prevents from assessing the future state of the system and its various parameters. The complexity is the "characteristic of a system which, due to the heterogeneity of processes that take place, has the ability to evolve in different directions, which makes this dynamic difficult to predict from present conditions".[5] (Levy and Lussault, 2003, p. 188).

Thus, taking an interest in the coherence of the urban project as a complex system, reflects a certain paradox which would be similar to breaking through the logic which leads the system and clearing up its complexity. This paradox particularly impacts the land settlement and town-planning disciplines, of which the projection of the "urban system" in the time is one of the founding principles. Thus, the urban action collides with the complexity of the system on which it must operate.

2.3.2 Incertitude and fragmentation of urban systems

It must be noted that the land settlement is now occurring in a context of increasing complexity and uncertainty. Urban transformations, changing territories and projects appear extremely unpredictable and question the land settlement practices. Contemporary dynamics such as globalization and metropolitanization have caused a loss of intelligibility figures of the cities, confusing the keys of reading and action on the territories (Chalas, 2009). Multiple uncertainties impact the town-planning such as economic, environmental and social instability of the territories, the future consequences of innovations in the mobility and new communication technologies, etc. The uncertainty and complexity are the paradigms of contemporaneity. In this sense, they radically transform the way we think about territories and actions to lead taken on them.

Moreover, the framework for developing and implementing various land settlement projects is becoming increasingly fragmented. We are in particular witnessing a fragmentation of public actors competences through the "institutional millefeuille" resulting from the French decentralization. The financial framework constrains public actors and the involvement increasingly significant of private actors and people in the production of the city increase tenfold the partnership aspect of these projects.

[2] Personal translation from the text of the author
[3] Personal translation from the text of the author
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In this way, the urban project results from the combination of actions led by multiple public and private actors. It appears fragmented as a result of a multitude of projects and actors interacting amongst themselves, and it becomes extremely complex to predict the future effects. These projects are so numerous that it seems to be impossible to assess how the global urban system will evolve. Especially, within each project, economic, sociological, economical, political and environmental parameters influence their own progress, success, impact, etc.

And yet, the particularity of the discipline is to take part on the territories. Town planning is a "science of action" (Merlin, 2009) based on the principle of beneficial response to the current or future working of the territory. The approach developed here is based on the consideration of the territory as a system. Therefore, taking into account the interactions that drive our complex urban systems emerges as one of the major challenges in the discipline but also becomes the way to expand our thinking of the "coherence" of the urban project.

The analysis of the systems traditionally operated through the black box principle (Wiener, 1948), listing the incoming and outgoing and by deduction the production of the system, does not seem adapted to the land settlement disciplines. Indeed, the challenge for these disciplines is to influence trends deemed not desirable before that they do not produce too many undesirable effects. The aim is therefore to take into account the in progress dynamics and not once they have produced irreversible effects.

The complexity of operating urban systems and the inability of land settlement actors to predict their evolution have been highlighted above. The challenge of the urban project coherence is therefore in the broadest possible knowledge of ongoing and future projects in order to "re-act" knowingly. This approach of the urban project distanced itself from the traditional planner vision of the land settlement. The integration of contemporary complexity and uncertainty inherent in urban systems reduce long-term urban anticipation in favour of an informed and reflexive management of the urban project.

This sense of the urban project cannot be only limited to sloppiness and emergency logics. It is vital to manage the urban project, not to undergo urban developments. This management is based on 3 elements of the urban project: the expected vision for the future of the territory, strategies deployed to work towards this vision and the fulfilment of these strategies through projects. In our opinion, the coherence of the urban project lies in the articulation between these elements. This articulation is based on a strong principle of reflexivity in which it is no more a question of stating an action plan in a linear way, but re-examine the current action based on the first effects produced and new parameters used in interaction (Ascher, 2004).

In this changing and fragmented context, the job of the public actor appears as the conductor of the general meaning of the action. He guarantees in this way, the coherence of the urban project across the entire city. It is a matter of overcoming the breaking up of actions and actors of the system by giving a comprehensive and shared vision of the territory. The main challenge for the public actor lies therefore in the broadest possible knowledge of ongoing projects in the area and in the implementation of a readable global urban project.

2.4 Modelling of complex system: The urban project atlas of Saint-Etienne

2.4.1 To a "global" and "informed" management of the urban project

Faced with challenges of readability and reflexive management of the urban project, this reflection has led to the modelling of complex urban system of Saint-

Etienne. This experiment was managed by the town-planning services of the city of Saint-Etienne and a tool for readability and coherence of the urban project called Atlas of the urban project in Saint-Etienne has been created.

In 2010, the fragmentation of the urban project in Saint-Etienne is marked daily by the lack of a common representation among the planning actors. Each of them developing its own communication media on his own projects (large projects, thematic cross-functional projects such as the public transport, etc.). The lack of support to represent all projects, including in particular diffuse and private projects, does not enable to take the evolution of the ordinary city and the territory into account as a whole. So, the urban project is the subject of multiple partial representations reflecting the fragmented governance that implements it. The complex urban system is therefore broached in a divided and partial way by each of these actors. From this perception of the system results a partial management and vision of the urban project that will have to be exceeded by the experiment of the modelling of complex urban system as a whole.

For the modelling of the urban project such as complex system, the support used is the map. It allows to represent each project in its spatial form to reveal possible future interactions through a temporal slicing. It is therefore to develop a partnership tool representing all projects, regardless of the project ownership. The partnership dimension is here very important because each actor has his own data of his project and it is necessary to group them in order for the tool to work.

The modelling of the complex urban system, The Urban Project Atlas, works as:

- An element-resource: a database, a filing of town-planning studies, a reporting and monitoring of projects
- A tool for decision support and production analysis that informs us about urban form, the progress of projects, and makes the connection with strategic planning documents and public policies.

2.4.2 The temporal map revealing interactions

The core of the tool is a temporal map. This map is the indicator of the interactions between the various elements of the system. This is the modelling of different projects in their urban form at the city scale, according to a common programmatic legend and a temporal slicing of actions, concerning the short-term (current year), the medium-term (end of the mandate), and the long-term (beyond the mandate). The major challenge lies in the completeness and responsiveness of modelling projects, large and small, private and public. Thus, it is by the support of the community database (building permits, housing services, displacements, prospective, etc.) to input private operations, public areas, emblematic town-planning operations and diffuse actions, all project ownerships. The base map is the cadastral plan of the territory with buildings in grey and

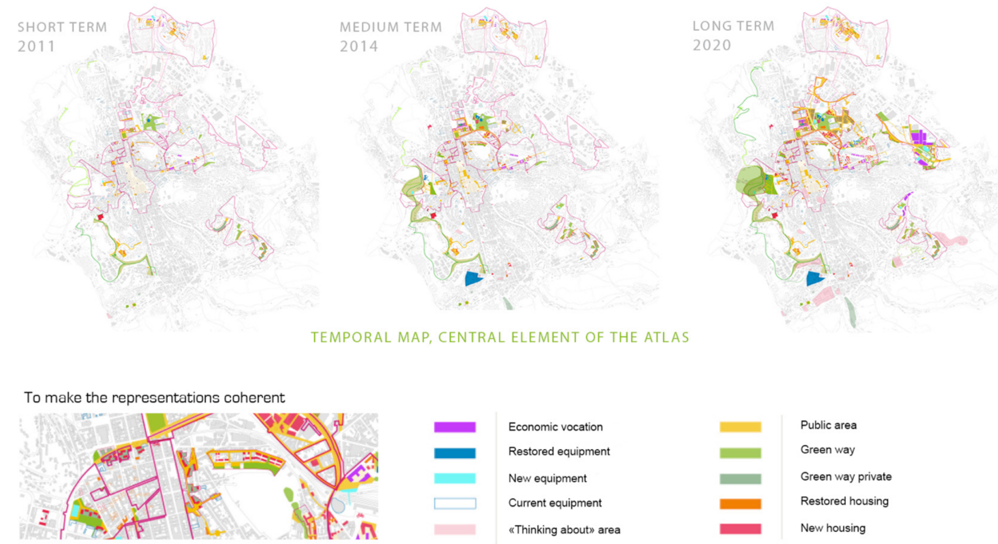

Figure 2.7: Extracts of the temporal map and legend. Source: City of Saint-Etienne

highways. The outline of the municipality delimits the study area. In a homogenized corporate identity and style guide, all projects of the territory are represented according to the categories of programs: public areas, housing restoration, new equipments, etc. A particular colour corresponds to each program category.

Thus, knowledge and modelling of each project become strategic because they will be the "indicator" of the "possible" future interactions. This map reveals the interactions between projects at several levels. At first, the mere fact of represent many projects of the territory on the same map is indicative of the potential interactions between operations previously considered separately. Thus, such a support opens up new perspectives in terms of synergies to strengthen or competitions to regulate between the various ongoing operations. The production of this map making allows to develop a global vision of the territory and its dynamics, and to examine the equilibrium distribution of the various programs on the territory, for example.

Secondly, the most revealing element of these interactions is the temporal slicing done with this map making (Figure 2.7). In fact, each project is assigned a specific temporality, short-term (current year), medium-term (end of the mandate, 2014) and long-term (beyond the mandate). This temporal slicing can render map making dynamic and therefore refine the interaction between projects. It is this dynamic vision of the fulfillment of "scheduled" projects that will reveal possible interactions and may cause a re-orientation in terms of programming. Seeing that similar projects are planned nearby could, for example, make a project initiator postpone the phasing or develop another type of products, etc.

The Urban Project Atlas is an indicator of ongoing urban dynamics in the territory and a tool for decision support and production analysis. Through interactivity it connects the "representation of projects" in terms of urban form, content (program, planning, etc.) and progress, with the strategic planning documents and major public policies (Figure 2.8).

This interactive tool based on the principle of articulation scale, allows to include a global vision of the urban project from the strategy to details of operations. It is now

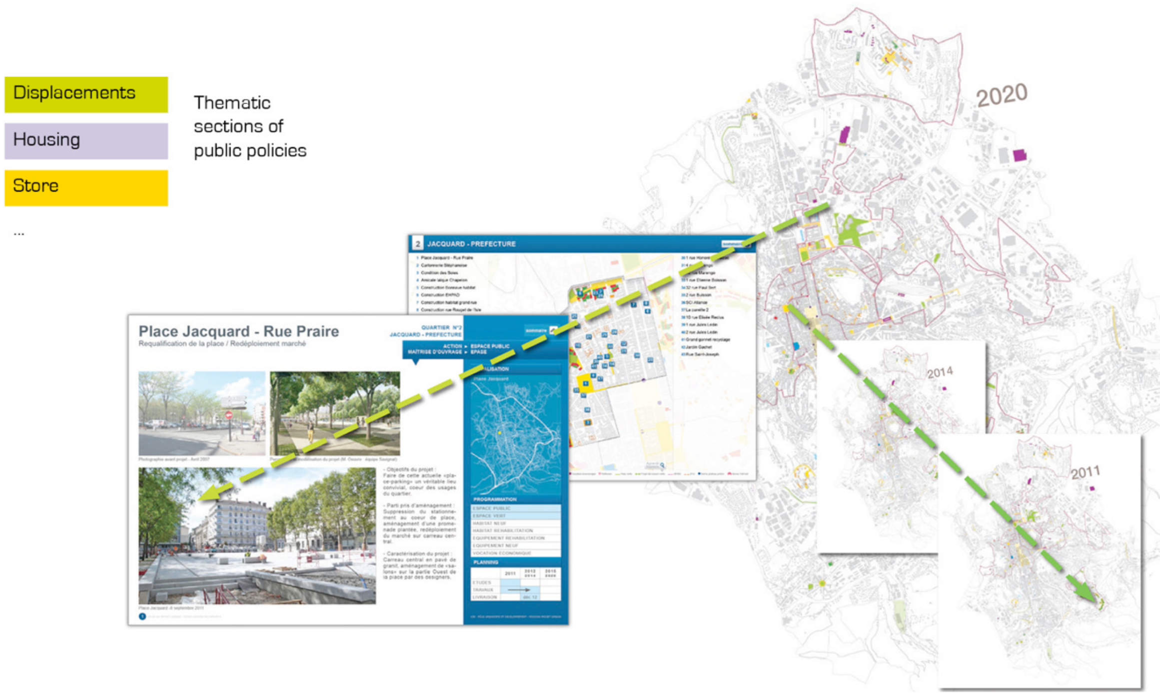

Figure 2.8: The urban project Atlas scales articulation principle and interactivity. Source: City of Saint Etienne

accessible to various officers of the City of Saint-Etienne and their privileged partners as the urban conglomeration Saint-Etienne Metropolis in particular.

2.5 Conclusions

This action-research led on the interactions in complex systems allowed us to demonstrate the essential sign of the concept in the field of town-planning and land settlement.

The territory is in essence an extremely complex object, - resulting from the combination of multiple geographic, economic, social parameters, - and thus generating a "situation" or context whenever new. André Corboz describes it as a combination of " factors as diverse as the geology, the topography, the hydrography, the climate, the forest cover and crops, populations, the technical infrastructure, the productive capacity, the judiciary, the administrative zoning, the national accounting, service networks, policy stakes and so on, not only in all of their interferences, but dynamically, in virtue of an intervention project"[6] (Corboz, 2001, p. 10). The town planning and the land settlement are complex disciplines by definition since they involve in working on these areas in order to improve their functioning, reduce inequalities, etc. It is in this sense an art of synthesis, the consideration of many factors that have to be reconciled, or at least to reconcile the greatest possible number.

In this way, this contribution dealt with the urban project, the territory project of the city of Saint-Etienne, as system confronted with complexity, uncertainty and breaking

[6] Personal translation from the text of the author.

up of urban areas. And, whose the quest for coherence, has resulted in a reflection on interactions between multiple projects constituent of the global urban project. The necessity for renewal of traditional modes of action of the land settlement in favour of reflexive approaches has been highlighted by this reflection.

As a consequence, the experiment based on this analysis was led through the modelling of complex urban system of Saint-Etienne represented by The Urban Project Atlas. This interactive tool, whose the core is a temporal map making of projects, acts as the indicator of interactions between the various elements of the urban system.

This experimental and innovative tool is part of multiple investigations led on the theme of "the watching of territories." These tools, which can be grouped into the "urban observatories" category are a way to "enter" the interactions of complex urban systems, in the sense of their understanding but also representation. The current rise of these functions of observatory reflects the challenge of taking into account the interactions and complexity of urban systems for territorial sciences.

Bibliography

Ascher F., 2001, *Ces événements nous dépassent feignons d'en être les organisateurs*, l'Aube.

Ascher F., 2004, *Les nouveaux principes de l'urbanisme*, l'Aube.

Bourdin A., R. Prost, 2009, *Projets et stratégies urbaines : regards comparatifs*, Parenthèses, La ville en train de se faire.

Chalas Y., 2004, L'urbanisme dans la société d'incertitude, in : *L'imaginaire aménageur en mutation*. L'Harmattan, 231-269.

Chalas Y., C. Gilbert, D. Vinck, 2009, *Comment les acteurs s'arrangent avec l'incertitude*, Paris, Editions des archives contemporaines.

Corboz A., 2001, *Le territoire comme Palimpseste*, Les Editions de l'imprimeur.

Faludi A., J. Peyrony, 2011, *Cohesion Policy Contributing to Territorial Cohesion - Future Scenarios*, in: European Journal of Spatial Development, 43, 2-17.

Genestier P., 1993, *Que vaut la notion de projet urbain?*, in : *L'architecture d'aujourd'hui*, 288, 40-46.

Ingallina P., 2003, *Le projet urbain,* Presses Universitaires de France.

Jourdan G., 2012, *La planification face au défi de la cohérence territoriale*, in : *Enjeux de la planification territoriale en Europe*, Presses polytechniques et Universitaires Romandes, 163-180

Kokoreff M., J. Rodriguez, 2004, *La France en mutations, quand l'incertitude fait société*, Editions Payot.

Lalande A., 2006, *Vocabulaire technique et critique de la philosophie*, Presses Universitaires de France.

Levy, J., M. Lussault, 2003, *Dictionnaire de la géographie et de l'espace des sociétés*, Belin.

Merlin P., F. Choay, 2005, *Dictionnaire de l'urbanisme et de l'aménagement*, Presses Universitaires de France.

Merlin P., 2009, *L'urbanisme, que sais-je?*, 8^{th} Ed., Presses Universitaires de France, 3-4.

Morin E., 2005, *Introduction à la pensée complexe*, Seuil.

Panerai P., D. Mangin, 1999, *Projet Urbain*. Parenthèses.

Rey J., F. Thomas, JY. Toussaint, M. Zimmermann, 1998, *Projet urbain: ménager les gens, aménager la ville*, Mardaga.

Rochette D., 1999, *Image et identité urbaines de Saint-Étienne*.

Toussaint JY., M. Zimmermann, 1998, *un enseignement de la complexité*, in : *Projet urbain : ménager les gens, aménager la ville*, Mardaga, 163-173.

Tsiomis Y., V. Ziegler, 2007, *Anatomie de projets urbains : Bordeaux, Lyon, Rennes, Strasbourg,* Editions La Villette.

Ville De Saint-Etienne, 2012, *Atlas du projet urbain : Cahier de méthodologie*.

Ville De Saint-Etienne, 2013, *Saint-Étienne, construire le projet urbain horizon 2020*.

Wiener R., 1948, *Cybernetics; or, Control and communication in the animal and the machine*, Paris, Technology Press.

Zepf M., G. Novarina ,2009, Territorial Planning in Europe : New concepts, New experiences, in : *DISP, The Planning Review,* 179, 18-27.

Zepf M., L. Andres, 2012, *Enjeux de la planification territoriale en Europe*, Presses Polytechniques et Universitaires Romandes.

Chapter 3

A PDE-like toy-model of territory working[1]

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Abstract

In this paper we build a Toy-Model based on Partial Differential Equations (PDE) that embeds several aspects of Territory Working. In a first place we describe Territory Working using a Systemic Approach involving compartments, action-reaction loops and feedback loops. Then density functions are associated to each compartment and we write a PDE for each density translating action-reaction loops and feedback loops into coefficients or source terms in this PDE. We then obtain a system of four PDEs that we use for a numerical simulation. The interpretation of the result of this simulation shows that some aspects of the Toy-Model behavior are consistant with the working of a real territory.

3.1 Introduction

In this paper, by Territory, we mean a Country or a Town or a set of Towns and Countries having a coherence and being administrated by a common local government.

As explained in Cullingworth and Nadin (2006), town and country planning needs an understanding of the interactions occurring within a Territory, at various scales. With the perspective of providing a solution for this need, our long term goal is to build a software tool that behaves like a Territory, and in particular that incorporates its multi-scale-in-time-and-space nature, in order to make simulations, to explore scenarios, to foresee policy impacts, to help to make a decision when facing a change in the environment or in cultural behavior, *etc.*.

Models of Territory that do not take into account space (see Moriarty and Adams 1976) exist. Now, many questions in town and country planning are related to people displacement: for instance, daily displacements are linked with decision making concerning transport network and population migration has consequences on construction policies. Hence, these models are a little limited to help decision making. On another hand, space models exist for a long time in Spatial Economics (see for instance Vickerman 1980, Beckmann and Puu 1985, Meardon 2001) but do not seem to be much used for the purpose of town and country planning.

A Territory is clearly a Complex System that involves, among others, a geographic area, people, local government actions and enterprises. It also consumes energy and produces wealth, goods, services and culture. Comprehend Territory Working globally is certainly a very difficult task and possessing a rich enough mental picture of it without using modeling may be impossible.

Hence, As we want to begin the process of understanding Territory Working, we face with the following issue: we need to build a model of something that we do essentially not understand. For doing this, the usual analytic modeling method, that describes precisely the working of every detail of a system and that assembles those details into a global mathematical model is ineffective.

We need to turn to the Systemic Approach that starts from the global and that offers the possibility to consider only a part of a Complex System or to consider several parts that are not modeled with the same level of details. For doing this, the Systemic Approach considers a Complex System as several compartments that act on each other via action/reaction loops and on themselves via feedback loops. Building a first occurrence of the Systemic Model of a given Complex System consists in isolating a few parts of the System and to assign them the status of compartment. Then, we have to describe how the parts (or compartments) act on each other and on themselves to define the action/reaction and feedback loops.
If this task is properly achieved, it is possible to associate with each compartment a mathematical object and with every loop a mathematical operator acting on one of those objets. Hence, we finally obtain a mathematical model that can be analyzed or simulated using usual mathematical tools.

Once the first occurrence of the Systemic Model of a given Complex System is built, it is possible to add a part in it. That is to say that a new compartment and new loops are added in the Systemic Model and that a mathematical object and mathematical operators are added in the mathematical model. It is also possible to go into the details of one part. This consists in replacing one compartment by several ones and in re-defining the loops.

In this paper we build a mathematical model, that we call Toy-Model, following the way described above that embeds several aspects of Territory Working. In a first step a Systemic Approach leads a Systemic Model. Then, we translate this Systemic Model into the mathematical one. For that we use density functions as mathematical objects and PDEs (see Farlow 1993) as mathematical operators. More precisely, the action/reaction and feedback loops are translated into coefficients and source terms of the PDEs that give the time evolution of the considered densities.

For the building of the Systemic Model we make choices concerning the parts to take under consideration. In those choices, there is arbitrariness. Yet, we find clever to consider that the working of a territory is essentially the consequence of actions of people living on it and on the economic activity standing on it. Hence we choose to use a "People" and an "Enterprises" compartments. Then, we want to put our work into the perspective of the long term goal describe in the beginning of this Introduction. Hence we choose to introduce an "Energy" compartment as energy is, on the one hand, used for displacement of people and, on the other hand, is something that burns the wealth that economy produces. Besides, we choose to embed our Model into a geographical area because of our long term goal and because, if space is not modeled, no displacement can be taken into account, and so, no related energy consumption estimated.

Thanks to those choices, the simulations made with the resulting mathematical model allow to visualize the dynamics of people going to work, the energy and wealth consumptions those displacements induce and the fact that people working in enterprises generates wealth. It also helps to comprehend the result of the way this wealth is split into the part used to improve enterprises' efficiency, the part allocated to increase their size and the part that goes to people.

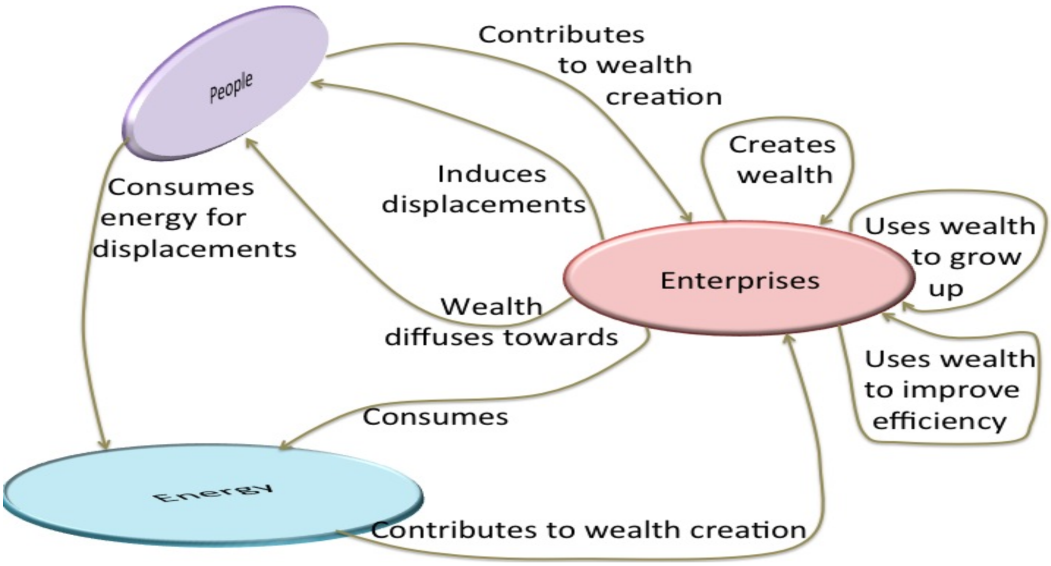


Figure 3.1: Systemic approach of territory working

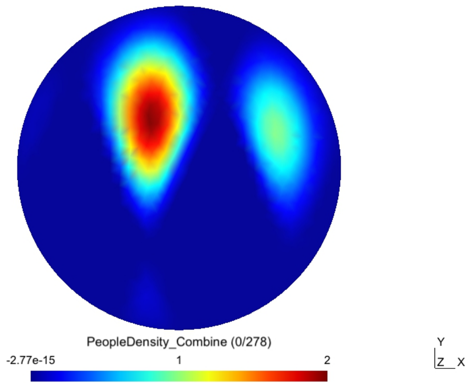
3.2 Systemic approach of territory working

We consider that the Working of a Territory results from the interactions between people and enterprises on a geographic area and that this interaction consumes energy. Integrating this within a Systemic Approach results in a Systemic Model which representation is given in Figure 3.1. Three compartments are considered. The first one ("People") concerns the population, the second one ("Energy") concerns the energy questions and the last one ("Enterprises") concerns the world of enterprises. We have, at this level, a non restrictive definition of what is an enterprise. It can be any organization producing goods or services and in which people work.

Then, the compartments influence each other or themselves. This fact is symbolized by the arrows. For instance, the arrow which is the more at the top of the figure translates that when people are at work, they contribute to the production of wealth. In return, the arrow just below means that displacements are induced by enterprise locations and the arrow in the left translates that an energy consumption is induced by those displacements. The three arrows that point on the "Enterprises" compartment from itself symbolize that enterprises create wealth and that this created wealth is used by the enterprises for growing up and for their efficiency improvement. The two last arrows, in the bottom, express that enterprises consume energy to create wealth.

3.3 The toy – model

From the Systemic Model of the previous section, we now build the Toy-Model. In this Toy-Model, all quantities are dimensionless, meaning that they have no unit and that their order of magnitude is 1.
In order to provide the reader, as fast as possible, with an interpretation of the equations that are introduced, we make simulations during the model writing. They are done us-



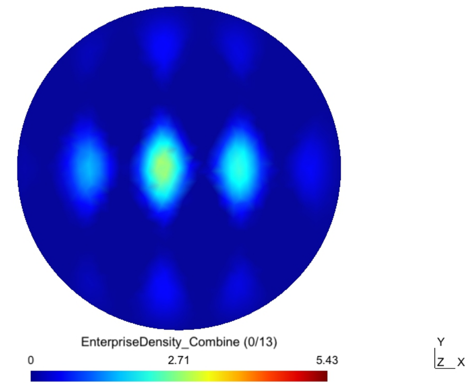


Figure 3.2: Initial population density $\mathcal{P}_0$ (left) and job-station density $\mathcal{E}_0$ (right)

ing Freefem++ which is a Finite Element software tool. All the simulations are done over the same time interval $[0, T)$, defined for a real number $T > 0$, which is driven by variable t.

The geographic model of the Toy-Model is a disk $\mathtt{D}$, provided with coordinates x, with a boundary $\partial\mathtt{D}$. The vector of norm 1, orthogonal to $\partial\mathtt{D}$ and pointing outside $\mathtt{D}$ is denoted μ.

On this disk, several densities, which depend on time, are defined:

- $\mathcal{P} = \mathcal{P}(t, x)$ is the Population Density.
- $\mathcal{E} = \mathcal{E}(t, x)$ is the Job-station Density.
- $\mathcal{W} = \mathcal{W}(t, x)$ is the Wealth-that-goes-to-people Density.

For those densities, initial values are defined: $\mathcal{P}_0 = \mathcal{P}_0(x)$ which is the Population Density when everybody is at home at night, $\mathcal{E}_0 = \mathcal{E}_0(x)$ and $\mathcal{W}_0 = \mathcal{W}_0(x) = 1$.
An example of initial density $\mathcal{P}_0(x)$ is drawn on the left of Figure 3.2 and an example

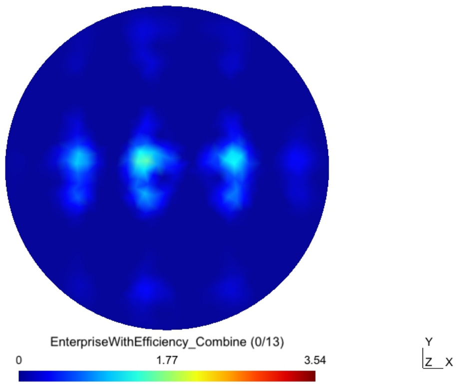


Figure 3.3: job-station density $\mathcal{E}_0$ times efficiency indicator $\mathfrak{i}_0$

of $\mathcal{E}_0(x)$ is drawn on the right of Figure 3.2. The simulation to come will be done with those initial conditions.

An Efficiency Indicator $\mathfrak{i} = \mathfrak{i}(t, x)$ is also defined on the disk. It ranges in $[0, 1]$ and measures the efficiency of the enterprises at transforming people working into wealth at every point of the disk; it is initialized at $\mathfrak{i}_0$.
The product of the initial Job-station Density $\mathcal{E}_0$ of Figure 3.2 by the initial Efficiency Indicator $\mathfrak{i}_0$ that will be used in the simulation to come is given in Figure 3.3.

From initial Population Density $\mathcal{P}_0$ and Job-station Density $\mathcal{E}$, two attractors are built. The first one $\mathcal{A}_\mathcal{E} = \mathcal{A}_\mathcal{E}(t, x)$ attracts the Population Density towards Job-stations. It is defined as

$$\mathcal{A}_\mathcal{E}(t, x) = \frac{\displaystyle\int_{\mathtt{D}} \mathcal{P}_0(x)\,dx}{\displaystyle\int_{\mathtt{D}} \mathcal{P}_0(x)\,dx + \alpha \int_{\mathtt{D}} \mathcal{E}(t, x)\,dx} \left(\mathcal{P}_0(x) + \alpha \mathcal{E}(t, x)\right), \tag{3.1}$$

where α is a constant larger than 1. The second one $\mathcal{A}_\mathcal{P} = \mathcal{A}_\mathcal{P}(x)$ makes the population to go back home. It is defined as

$$\mathcal{A}_\mathcal{P}(x) = \mathcal{P}_0(x). \tag{3.2}$$

With those two attractors, we can simulate the daily motion of the population. For this, we firstly adopt the convention that day length is 1. Then, we define two functions $\mathfrak{t}_m = \mathfrak{t}_m(t)$ and $\mathfrak{t}_e = \mathfrak{t}_e(t)$ depending only on time and periodic of period 1. $\mathfrak{t}_m(t) > 0$ for instants corresponding to the morning displacements, when people goes to work and is 0 otherwise; and, $\mathfrak{t}_e(t) > 0$ for instants corresponding to the evening displacements, when people goes back home and is 0 otherwise. Secondly we write the equation meaning that in the morning the Population Density is attracted by the Job-station

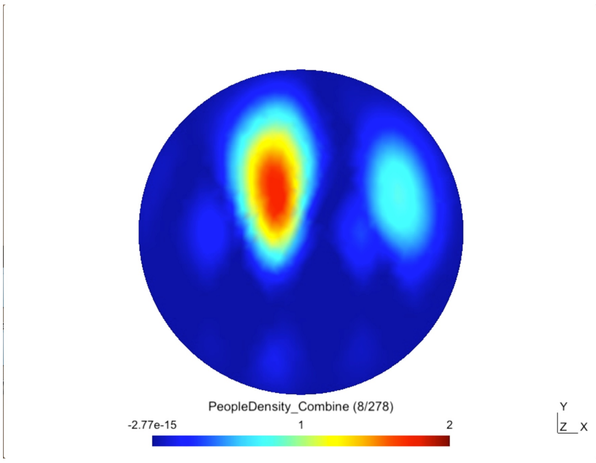


Figure 3.4: Displacements from home to work and back (Animation available on YouTube: http://youtu.be/LkPlVT-a4pg.)

Attractor and in the evening by the Home Attractor:

$$\frac{\partial \mathcal{P}}{\partial t}(t,x) = \mathtt{t}_m(t)\left(\mathcal{A}_{\mathcal{E}}(t,x) - \mathcal{P}(t,x)\right) \\ + \mathtt{t}_e(t)\left(\mathcal{A}_{\mathcal{P}}(x) - \mathcal{P}(t,x)\right), \ \forall x \in \mathtt{D}, \forall t \in (0,+\infty), \quad (3.3)$$

and describing the daily people motion.

An example of the evolution of $\mathcal{P}$ is given by the movie in Figure 3.4. In this example, the initial densities $\mathcal{P}_0(x)$ and $\mathcal{E}_0(x)$ are the ones of Figure 3.2.
In this movie, we can see the alternation of people displacements to their work (in the morning) and to their home (in the evening). Because of the Job-station distribution chosen for this example, most of people converges everyday to work in a small region located near the center of the disk.

This motion generates an energy consumption. It is modeled by a time density $\phi = \phi(t)$, which is constant per day and which value at any given day is the double integral over the disk of the distances from home locations to Job-station locations weighted by the locations where Population Density $\mathcal{P}$ increases and where it decreases.
In other words, ϕ is a constant over every interval $[n, n+1], n \in \mathbb{N}$ and its value on $[n, n+1]$ is computed as follows

$$\phi^n = \int_{\mathtt{D}} \int_{\mathtt{D}} |x-y| \, \mathcal{P}^n_{\text{Incr}}(x) \mathcal{P}^n_{\text{Decr}}(y) \, dx dy, \quad (3.4)$$

where $\mathcal{P}^n_{\text{Incr}}$ is the density of increasing population, where population increases, when comparing the Population Density in the morning (before people go to work) and in the middle of the day (when workers are at their job-station). It is defined by

$$\mathcal{P}^n_{\text{Incr}}(x) = \max(\mathcal{P}(n+\frac{1}{2}, x) - \mathcal{P}(n,x), 0). \quad (3.5)$$

In a similar way, $\mathcal{P}^n_{\text{Decr}}$ is the density of decreasing population, where population decreases, when comparing the Population Density in the morning and in the middle of

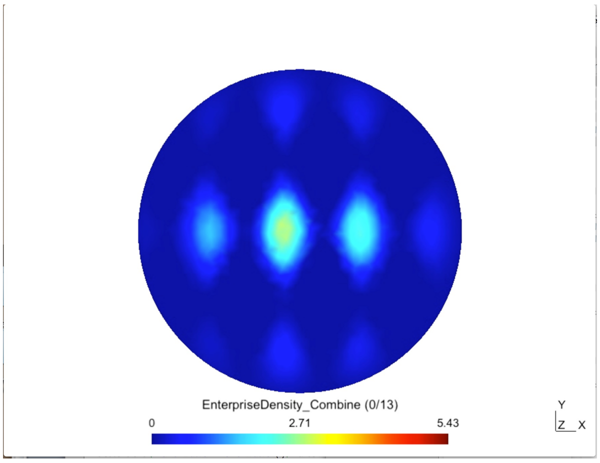


Figure 3.5: Evolution of job-station density $\mathcal{E}$. (Animation available on YouTube: http://youtu.be/PorgK4q5Ds0.)

the day and is defined by

$$\mathcal{P}^n_{\text{Decr}}(x) = \max(-\mathcal{P}(n + \frac{1}{2}, x) + \mathcal{P}(n, x), 0). \tag{3.6}$$

We consider that the fact that people is at work produces Wealth with a rate which depends on the product of the Population Density $\mathcal{P}$ by the Job-station Density $\mathcal{E}$ times the Efficiency Indicator $\mathtt{i}$. To take this into account, we introduce now a wealth production rate density $\omega = \omega(t, x)$ which is constant per day. Its value at any given day (represented by interval $[n, n+1], n \in \mathbb{N}$) is in proportion with the product of the Population Density $\mathcal{P}$ by the Job-station Density $\mathcal{E}$ times the Efficiency Indicator $\mathtt{i}$ at the middle of the day:

$$\omega^n(x) = \beta_0 \, \mathcal{P}(n + \frac{1}{2}, x) \, \mathcal{E}(n + \frac{1}{2}, x) \, \mathtt{i}(n + \frac{1}{2}, x). \tag{3.7}$$

In this equation, β_0 is a coefficient much smaller than 1, meaning that the time scale of Wealth variation is large when compared to a day.

It seems pertinent to consider that this Wealth is split into three parts. The first one is allocated to enterprises' growth. It accounts for the fact that when an enterprise works well, it increases its workforce. This first part is a source term in the following Ordinary Differential Equation (ODE) driving the Job-station Density $\mathcal{E}$ evolution:

$$\frac{\partial \mathcal{E}}{\partial t}(t, x) = \beta_1 \, \omega(t, x), \ \forall x \in \mathtt{D}, \forall t \in (0, +\infty). \tag{3.8}$$

In this ODE, which is set in every point of the disk, β_1 is a coefficient belonging to a triplet $(\beta_1, \beta_2, \beta_3)$ of positive coefficients such that $\beta_1 + \beta_2 + \beta_3 = 1$. This ODE means that the growth speed of the Job-station Density is in proportion with produced Wealth.

The second part ($\beta_2\,\omega(t,x)$) contributes to improve enterprises' efficiency. This accounts for that enterprises invest to increase their productivity. This second part contributes as a source term in the ODE, set in every point of the disk and which is such that its solution $\mathfrak{i}$ always ranges in $[0,1]$:

$$\frac{\partial \mathfrak{i}}{\partial t}(t,x) = \mathfrak{i}(t,x)(1-\mathfrak{i}(t,x))\left(\beta_2\,\omega(t,x) - \beta_1\,\omega(t,x)\right),\ \forall x \in \mathtt{D}, \forall t \in (0,+\infty). \tag{3.9}$$

The term $\beta_1\,\omega(t,x)$ in this equation models that when organization grows, if nothing is done, its efficiency decreases.

The result of the influence of Wealth on the Job-station Density $\mathcal{E}$ and on the product of the Job-station Density $\mathcal{E}$ times the Efficiency Indicator $\mathfrak{i}$ are given in the movies of Figures 3.5 and 3.6 for the same example as in the previous figures.

We see in those movies that, around the small region where most of people converges everyday to work, there is a strong increase of Job-station Density $\mathcal{E}$ and of enterprises' Efficiency $\mathfrak{i}$.

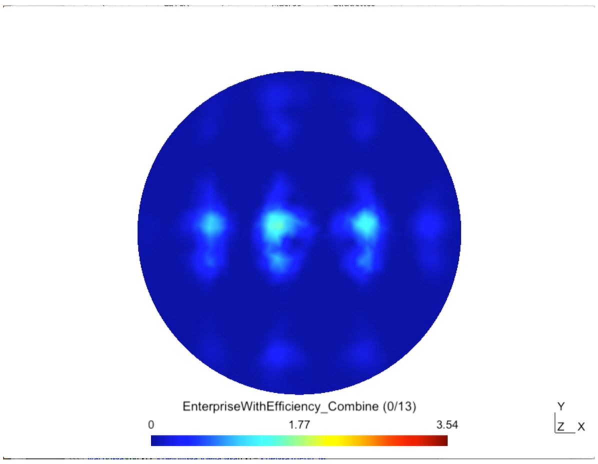


Figure 3.6: Evolution of job-station density $\mathcal{E}$ times efficiency indicator $\mathfrak{i}$. (Animation available on YouTube: http://youtu.be/B7gjmu7q8IU.)

The third part of Wealth production will diffuse inside the population. It is then a source term in the diffusion equation $\mathcal{W}$ is solution to:

$$\frac{\partial \mathcal{W}}{\partial t}(t,x) - \nu\Delta\mathcal{W}(t,x) = \beta_3\omega(t,x) - \kappa\phi(t),\ \forall x \in \mathtt{D}, \forall t \in (0,+\infty), \tag{3.10}$$

$$\frac{\partial \mathcal{W}}{\partial \mu} = \mathcal{F}_{\mathcal{W}},\ \forall x \in \partial\mathtt{D}, \forall t \in (0,+\infty), \tag{3.11}$$

where ν is the diffusion coefficient of Wealth within the population on the territory. In this PDE, the energy consumption time density ϕ is also a source term but with an opposite action than that of the Wealth production. This is because ϕ induces a consumption of Wealth. In this PDE there is also a boundary condition on the disk border, translating the fact that there is a little wealth that enters or leaves the Territory through its border.

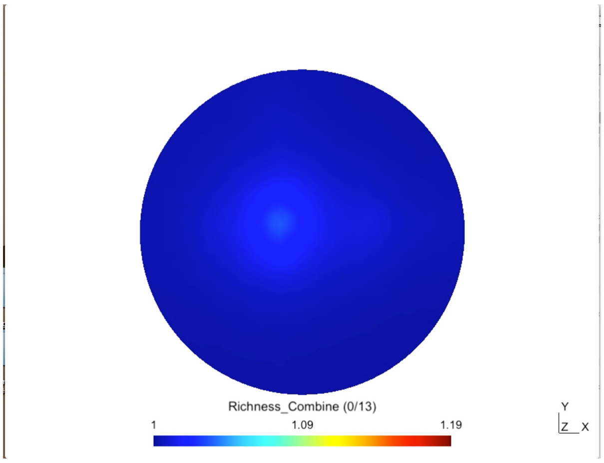


Figure 3.7: Evolution of wealth density $\mathcal{W}$. (Animation available on YouTube: `http://youtu.be/05JNyznPxvw`.)

The evolution of Wealth-that-goes-to-people Density is given by the movie in Figure 3.7, still for the same example as before. We can see the diffusion of the Wealth-that-goes-to-people from the small region where most of people converges everyday to work towards the other parts of the Territory.

3.4 Interpretation

Clearly, the simulation made using the Toy-Model does not pretend to be realistic. Nonetheless, it illustrates that the proposed approach brings a way to couple several aspects of Territory Working.

For instance, it can handle non-linearities. This is illustrated by the two pictures of Figure 3.8. The one on the left is the Population Density at midday of the first day and the one on the right is the Population Density at midday of the last day. We can see that, in the small region close to the center of the disk, the density is higher in the right picture than in the left picture. This can be explained as follow: Since many people works their, wealth is produced, which induces Job-station number to increase. As a consequence, day after day, more and more people is coming to work in this small region.

The scales (regarding time and space) have no realistic meaning. Nevertheless, we can see the capability of this kind of models to account for a wide variety of scales. For instance, regarding the space scales, in the Toy-model, there is the size of the Territory (the disk) and there are the characteristic sizes of variation of Population-at-home Density, of Job-station Density and Enterprise Efficiency.

Besides, this way of modeling allows us to connect several Territories through their common boundaries and then to consider a large number of connected Territories.
Regarding the time scales, in the Toy-Model there are the characteristic time of Population motion, the characteristic time of wealth production and the one of wealth diffu-

sion.

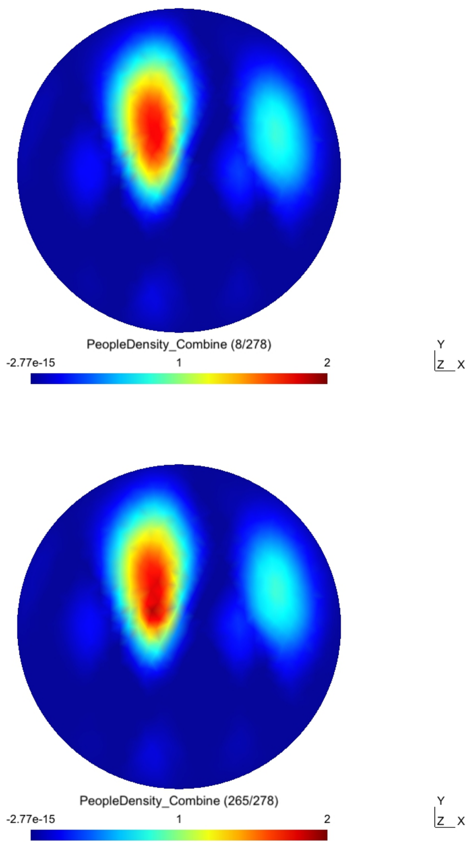


Figure 3.8: Population density at midday of the first day (left) and of the last day (right)

3.5 Conclusions

In this paper, we proved that building a mathematical model, based on PDEs, starting from the Systemic Approach of Complex System, of Territory Working is possible. Moreover we saw that this Toy-Model can be used to make simulations of the working of a territory. Clearly this work is modest and far from the long term goal evoked in the Introduction. Nevertheless, it is a convincing proof of concept and gives confidence in the fact that it can be achieve.

At this stage, we already can test the various results of various ways to split the produced wealth between enterprises' efficiency improvement, enterprises' size increase and people.

Once the long term project will be more advanced, we will be able to provide decision makers with a software tool that somehow behaves like a territory. Hence they will be able to use this tool to simulate their planned actions and consequently see the impact of their decisions. They will also be able to use it to chose between several scenarios or to optimize a given scenario.

Bibliography

Beckmann M., Puu T., 1985, Spatial Economics: Density, Potential and Flow, Studies in Regional Science and Urban Economics, 14, North-Holland, Amsterdam.

Cullingworth B., V. Nadin, 2006, Town and Country Planning in the UK, Taylor & Francis, London.

Farlow, S. J., 1993, Partial Differential Equations for Scientists and Engineers, Dover, New-York.

Meardon S. J., 2001, Modeling Agglomeration and Dispersion in City and Country: Gunnar Myrdal, Franćois Perroux, and the New Economic Geography, *American Journal of Economics and Sociology*, 60, 25-57.

Moriarty M., A. Adams, 1976, Issues in Sales Territory Modeling and Forecasting Using Box-Jenkins Analysis, *Journal of Marketing Research*, 16, 221-232.

Vickerman R., 1980, Spatial Economic Behaviour. The Microeconomic Foundations of Urban and Transport Economics, Macmillan Press, Limited, London.

Chapter 4

Decision-making and interacting neuron populations

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Abstract

In this article we present the modeling of bi-stability view problems described by the activity or firing rates of two interacting population of neurons. Starting from the study of a complex system, the system of stochastic differential equations describing the time evolution of the activity of the two populations of neurons, we point out the strength and weakness of this model and consider its associated partial differential equation, which resolution gives statistical information on the firing rates distributions. The slow-fast characterization of the solutions finally leads us to a complexity reduction of the model by the definition of a one-dimensional stochastic differential equation and its associated one-dimensional partial differential equation. This last model turns out to be well adapted to the resolution of the problem giving access, in particular, to reaction times and performance, two macroscopic variables describing the decision-making in the view problem.

4.1 Introduction

Decision-making problems in social and natural sciences are often described by means of complex systems governed by differential equations giving the time variation of some quantities. We can represent the two choices decision making situation like a set of particles evolving in double wells potentials (potential functions with two minima or stable equilibrium points and one maximum or unstable equilibrium point) and submitted to interactions. Each well represents one of the decision states and corresponds to one attractor of the system. The function describing the double well potential is usually a fourth order polynomial (like in the Van der Pool equation), and the problem can be explicitly solved, see for example the book by Galam (2012) for an application to social sciences. The decision-making process may also be described by the evolution of the reaction times and performance, two macroscopic variables representing the mean minimal time a subject needs to make a decision (or a particle needs to exit a potential well), and the amount of subjects having choosen a particular decision state (or the sum of all particles being in a potential well) at a given time.

In this paper we deal with bi-stability visual situations. The decision-making process in this context involve a huge number of interacting neurons and it is not possible to describe it by the knowledge of each single neuron. The synchronization of the neurons activity leads to an equilibrium representing the decision. We can briefly sketch the situation as follows. A subject is asked to choose between two possible views of a picture. His sight has to focus on one of these views, and this is done at a neuronal level. The decision is taken once the focus is done. Neuron-physicists are then interested in the two macroscopic quantities: the reaction times and the performance. Since neurons in the visual cortex have different skills and are connected, this problem can't be modeled by the description of a single neuron activity, but different populations of neurons in interaction must be considered. In computational neurosciences, the decision making of interacting population of neurons (excitatory and inhibitory ones) have been successfully described by a system of deterministic differential equations, called the Wilson-Cowan system, see the seminal work by Wilson and Cowan (1972). In this model, the unknowns are function of time only and represent the mean firing rate of each population of neurons, i.e. for each population, the mean frequency of the neuronal signal, hence its activity. Moreover, the underlying potential is not a fourth order polynomial function and can't be explicitly computed. More recently, noise has been added to the model, see Deco and Martì (2007), in order to account for the finite number of neurons in the mean field approximation used to derive the Wilson-Cowan model. The non-linearity in the model makes its mathematical analysis difficult. In particular, it is not possible to write the explicit solution of the stationary associated problem. Nevertheless, in Deco and Martì (2007) the authors numerically show, applying the moment analysis, that for the ranges of parameters they are interested in, the solutions are bi-modal, i.e. double peaked. This method works well, but no closure to the system of equation is provided. In order to write an approximation of the explicit stationary solution to the problem, knowing that the solutions must be bi-modal and applying Taylor expansion methods, it is also possible to define a fourth order polynomial V, passing from the equilibrium points, see for example Roxin and Ledberg (2008). This function V is then also used to compute reaction times (by means of Kramers formula) and performance (by means of the steady state). This approach, which is usually applied in computational neurosciences, gives results in agreement with experimental data, see Roxin and Ledberg (2008), but only holds locally.

In this paper, we will consider the partial differential equation associated to the stochastic system which describes the evolution of the probability distribution function in terms of the firing rates of the two neuron populations. We will see in the sequel how its mathematical analysis and numerical simulations can help to reduce the complexity of the problem leading to faster computations of the reaction times and the performance, and compare the results of the simplified model with the initial one. The presented complexity reduction method is a good way to overcome the difficulty of not knowing the explicit form of the underlying potential and the approximated solutions are defined on the whole domain we are interested in, and not only locally as usually done in computational neurosciences. The present work resumes the results of several papers done in collaborations with J. A. Carrillo (London), G. Deco (Barcelona) and S. Cordier (Orléans), see Carrillo et al. (2011), Carrillo et al. (2013a) and Carrillo et al. (2013b).

4.2 The mathematical model

Recently bi-stability visual problems have been investigated by considering systems of stochastic differential equations which describe the time evolution of the firing rates for two or more interacting populations of neurons (see for example Deco and Martì (2007) and Roxin and Ledberg (2008)). This kind of models, based on the deterministic Wilson-Cowan one (see Wilson and Cowan (1972)), permits to numerically evaluate the subject reaction times and the performance together with their variations with respect to the differences on the applied stimuli and/or the weight of the interactions.

For instance, reaction times correspond to the time needed for the subject to make a decision, and performance is the number of good responses taken by the subject without limitation on time. The model can be interpreted from a physical point of view as particles trapped in a double (or multiple) well potential, reaction times corresponding then to the exit time from a well and performance being given by the density contained in the well associated to the correct answer.

The model studied in Deco and Martì (2007) considers the time evolution of the firing rates $\nu_1 = \nu_1(t)$ and $\nu_2 = \nu_2(t)$ of two neuron populations. Their behavior satisfies the following system of stochastic differential equations:

$$\begin{cases} \mathrm{d}\nu_1 = \psi_1(\nu_1, \nu_2)\mathrm{dt} + d\xi \\ \mathrm{d}\nu_2 = \psi_2(\nu_1, \nu_2)\mathrm{dt} + d\xi, \end{cases} \tag{4.1}$$

where $d\xi$ is a white noise of standard deviation β and ψ_1, ψ_2 are the dynamical part of the equations and model the neuronal activity. They are defined by:

$$\psi_1 = -\nu_1 + \phi(\lambda_1 + w\,\nu_1 + \hat{w}\,\nu_2),$$

$$\psi_2 = -\nu_2 + \phi(\lambda_2 + \hat{w}\,\nu_1 + w\,\nu_2),$$

with $\phi(z)$ the so-called response function to the mean excitation z, defined by the sigmoid:

$$\phi(z) = \frac{\nu_c}{1 + \exp(-\alpha(z/\nu_c - 1))},$$

with ν_c and α parameters that are fixed by biology and where the mean excitation z is given by the sum of the applied stimuli (λ_1 or λ_2) and the internal activities given by a linear combination of the activity of each population weighted respectively by w and $\hat{w}$ depending if we are considering the same population or not. Note that, the weights being symmetric, if the applied stimuli are the same (i.e. $\lambda_1 = \lambda_2$), then the problem is symmetric and is defined as the unbiased case, whereas if one of the stimuli is larger than the other (say $\lambda_1 = \lambda_2 + \Delta\lambda$), the problem loses its symmetry and we define this situation as the biased case, with the bias given by $\Delta\lambda$. In the following numerical results, with the exeption of those in Figure 4.3 which consider a slightly different potential, $\nu_c = 20$, $\alpha = 4$, $w = 0.45$, $\hat{w} = 1.23$, $\beta = 0.3$, $\lambda_1 = \lambda_2 = 15$ and $\Delta\lambda = 0.01$.

It's well-know in literature that we can deduce a Fokker-Planck equation from system (4.1) applying Ito calculus or considering the forward Kolmogorov equation associated to (4.1): for $(t, \nu_1, \nu_2) \in (0, +\infty) \times \Omega$,

$$\partial_t p + \nabla \cdot \left(F\,p - \frac{\beta^2}{2} \nabla p \right) = 0, \tag{4.2}$$

where $p = p(t, \nu_1, \nu_2)$ is the probability distribution function representing the probability that at time $t \geq 0$ the firing rates are in $(\nu_1, \nu_2) \in \Omega \subset \mathbb{R}^2_+$, and with $F = F(\nu_1, \nu_2) = (f(\nu_1, \nu_2), g(\nu_1, \nu_2))$ the drift term. The domain Ω being bounded (the square $[0, \nu_m] \times [0, \nu_m]$, with ν_m the maximal firing rate value for the neuron populations), we complete equation (4.2) by the following Robin type (or no flux) boundary conditions: on $\partial\Omega$,

$$F\,p - \frac{\beta^2}{2} \nabla p = 0\,,$$

and we finally consider the normalized initial condition:

$$p(0, \nu_1, \nu_2) = p_0(\nu_1, \nu_2) \geq 0.$$

As proven in Carrillo et al. (2011), under the assumption of incoming flux, the problem is well posed and there exists a unique steady state solution of the stationary Fokker-Planck equation. Nevertheless, as explained in Carrillo et al. (2011) there is no potential function $V = V(\nu_1, \nu_2)$ such that $F = -\nabla V$. This fact implies that it is not possible to write explicitly the steady state associated to (4.2). Recall that the steady state and the potential V are essential for the computing of reaction times and performance.

The bi-dimensional behavior of the solution of (4.2) at a given time is shown in Figure 4.1: the solution is concentrated around the two stable equilibrium points and is aligned along the equilibrium manifold. The bi-modal aspect of the solution is well captured by the numerical simulations of the Fokker-Planck equation (left). When the situation is biased (i.e. one of the applied stimuli is bigger), then one of the wells is deeper than the other and the symmetry of the problem is lost. In this situation the solution at equilibrium (or for large times) is concentrated around the equilibrium point corresponding to the deeper well, (right). Note that in Deco and Martì (2007) the authors represented the solution by means of their marginals (i.e. the projections along each axis) and no bi-dimensional numerical result was obtained.

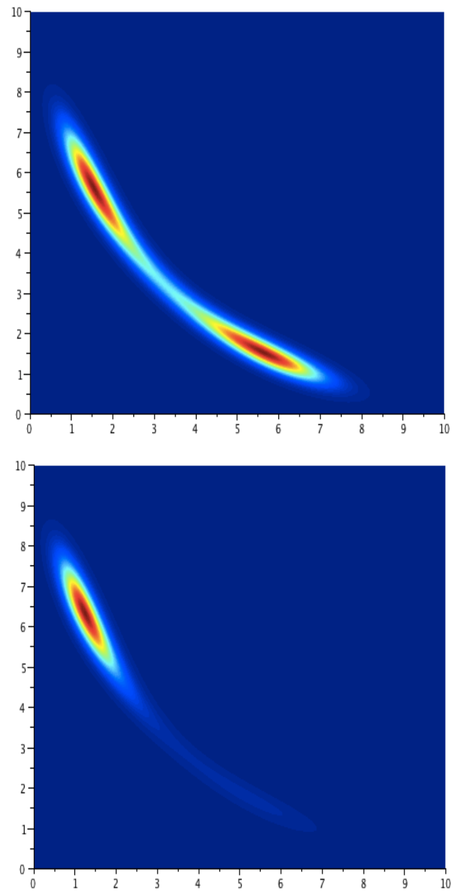

Figure 4.1: Solution to equation (4.2). Left : unbiased case. Right : biased case.

4.3 Complexity reduction

Although the behavior of the solution of equation (4.2) is in agreement with what is expected physically, the application to real problems of this equation, or the use of the associated numerical simulations, are not competitive, since nor the potential function V nor the steady state are known and to approximate them numerically requires very long CPU times.

Nevertheless, the study of problem (4.2) shows that its solution is characterized by a slow-fast behavior: rapid diffusion towards the equilibrium manifold and slow drift along the manifold towards the stable equilibrium points. In Carrillo et al. (2013a) we have proposed a complexity reduction of (4.3) based on this slow-fast characteristic of the problem and leads to a one-dimensional Fokker-Planck equation living on the equilibrium manifold (see Berglund and Gentz (2005)). The fast convergence being along a direction which is given by a linear combination of ν_1 and ν_2, we can define two new variables x and y respectively as the variable along which the fast convergence is done and the one corresponding to the slow direction (see Carrillo et al. (2013a) for more details). With this change of variables the stochastic system (4.1) transforms in:

$$\begin{cases} \mathrm{d}x = f(x,y)\mathrm{dt} + d\xi_x, \\ \mathrm{d}y = g(x,y)\mathrm{dt} + d\xi_y, \end{cases} \tag{4.3}$$

where $f(x, y)$, respectively $g(x, y)$, are the linear combination of the functions ψ_1 and ψ_2, and where $d\xi_x$ et $d\xi_y$ are two white noises of standard deviation β_x and β_y. Summarizing, we may say that f and g are the functions describing the activity of the combined firing rates x and y, respectively.

We can define the coefficient ε as the ratio of the two eigenvalues associated to the Jacobian matrix of F, in such a way that $\varepsilon \ll 1$. This coefficient represents then the time scaling between the fast and slow variables. It is then possible to write the deterministic part of (4.3) as follows:

$$\begin{cases} \varepsilon \mathrm{d}x = f(x,y)\mathrm{dt}, \\ \mathrm{d}y = g(x,y)\mathrm{dt}. \end{cases}$$

Considering the limit of ε going to zero, we can implicitly solve the first equation and define a curve $x^*(y)$ such that $f(x^*(y), y) = 0$. Replacing in the equation for the slow variable y, we get:

$$\dot{y} = g(x^*(y), y).$$

Considering now the stochastic term, we end up with the stochastic differential equation:

$$\dot{y} = g(x^*(y), y) + \beta d\xi. \tag{4.4}$$

We can then consider the associated partial differential equation on $[0, \infty] \times \Omega_y$, with $\Omega_y = [-y_m, y_m]$:

$$\partial_t q + \partial_y \left(g(x^*(y), y)q - \frac{\beta^2}{2}\partial_y q \right) = 0, \tag{4.5}$$

where $q = q(t, y)$ is the probability distribution function representing the probability that at time $t \geq 0$, the firing rate is in y. This is a one-dimensional Fokker-Planck equation, and we can endowed it by means of no flux boundary conditions, for $y = \{-y_m, y_m\}$:

$$g(y)q - \frac{\beta^2}{2}\partial_y q = 0,$$

and the normalized initial condition $q(0, y) = q_0(y)$, which is the projection of $p(t, \nu_1, \nu_2)$ only along the y variable. The slow behavior of the solution persists, since q lives on the equilibrium manifold along the slow direction. Nevertheless, computational time costs are reduced by using implicit in time numerical schemes. Moreover, we can compute an approximation of the potential function V and of the stable state. In fact, for a one-dimensional Fokker-Planck equation the stable state is given by:

$$q_s(y) = \exp\left(\frac{-2G(y)}{\beta^2}\right), \tag{4.6}$$

where $G(y)$ is the potential function associated to $g(x^*(y), y)$ and defined by:

$$G(y) = -\int g(x^*(z), z)\, dz.$$

As shown in Figure 4.2, the complexity reduced equation (4.5) of the initial Fokker-Planck model (4.2) gives very good results, both in the unbiased and biased cases.

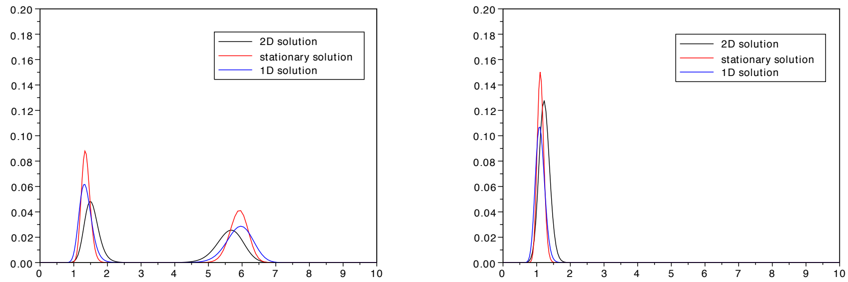

Figure 4.2: Comparison of the solutions along y for equations (4.2) and (4.5), and with the stable state (4.6). Left : unbiased. Right : biased.

Therefore, it is possible to compute the wanted macroscopic quantities: reaction times and performance, as done in Carrillo et al. (2013b).

4.4 Application to a three-well potential

The complexity reduction we have discussed for the double well potential is also useful for studying more complex situations like a three well potential. The main difference with what has been done previously is in a modified definition of the response function ϕ. This situation is more realistic of what happens in visual decision making. Before a decision is made neurons firing rates are all concentrated at around a certain frequency value (the middle well) and they do migrate towards the other values (external wells) when the decision is made. Reaction times in the three well potential case are given by the exit times from the middle well to get to one of the external wells (the deeper one in the biased case). Whereas performance is defined by the density being, at equilibrium or for large times, into one specific well. In Figure 4.3 we plot the computed reaction times (left) and performance (right) both with respect to the difference on the applied stimuli $\Delta\lambda$ and for different values of the coefficient w_+, which is one of connectivity coefficients used in the definition of the weights w and $\hat{w}$.

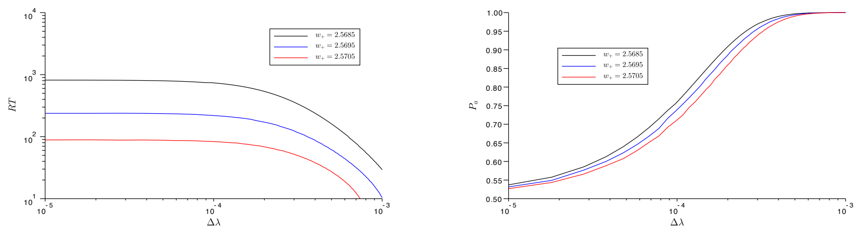

Figure 4.3: Left : Reaction times. Right : Performance.

The chosen values of the coefficient w_+ corresponds to a sub-critical bifurcation situation: the system passes form three minima to two minima. Indeed, for $w_+ = 2.5685$

the underlying potential has three stable equilibrium points and two unstable ones, for $w_+ = 2.5695$ the middle well gets flat (the system is at the bifurcation) and for $w_+ = 2.5705$ the underlying potential has two wells and separated by a maximum which has replaced the middle well. Concerning reaction times (left), the larger the bias is the faster firing rates move towards the deeper well, and when the middle well disappears it become easier to take take a decision. Concerning, performance (right), the larger is the bias the more the subjects will give the expected answer, but the disappearance of the middle point doesn't increase the density of the good decision since the bias also implies higher maximum values in the potential to overcome in order to get to the expected well. The same behavior was obtained in Roxin and Ledberg (2008) for a similar problem and in several experimental results. Nevertheless, the approach proposed in Roxin and Ledberg (2008) is valid only in a neighborhood of the spontaneous state (middle well), whereas the analysis and results presented here are valid on the whole domain of definition of the problem.

4.5 Conclusions

We have discussed here in the framework of bi-stability view problems and of computational neurosciences, how the study of the partial differential equation associated to stochastic differential system of equation, can give complementary informations and can lead to the computation of macroscopic quantities (as reaction times and performance) of interest in the modeling of interacting population of neurons. In particular, we have presented the complexity reduction method based on the slow-fast behavior of the solution of a given stochastic differential system and applied it to a three well potential case.

Bibliography

Berglund N., Gentz B., 2005, Noise-induced phenomena in slow-fast dynamical systems: a sample-paths approach. In: Probability and its applications. Springer, New York.

Carrillo J. A., Cordier S., Mancini S., 2011, A decision-making Fokker-Planck model in computational neuroscience, J. Math. Biol., 63, pp. 801-830. doi: 10.1007/s00285-010-0391-3

Carrillo J. A., Cordier S., Mancini S., 2013a, One dimensional Fokker-Planck reduced dynamics of decision making models in Computational Neuroscience, Commun. Math. Sci., 11(2), pp. 523-540.
doi: 10.4310/CMS.2013.v11.n2.a10

Carrillo J. A., Cordier S., Deco G., Mancini S., 2013b, General One-Dimensional Fokker-Planck Reduction of Rate-equations models for two-choice decision making, PLoS ONE 8(12): e80820. doi:10.1371/journal.pone.0080820.

Deco G., Mart ‘i D., 2007, Deterministic Analysis of Stochastic Bifurcations in Multi-stable Neurodynamical Systems, Biol. Cybern., 96(5), pp. 487-496. doi: 10.1007/s00422-007-0144-6

Galam S. 2012, Sociophysics : A Physicist’s Modeling of Psycho-political Phenomena. In: Understanding Complex Systems. Springer-Verlag,Berlin.

A. Roxin A., Ledberg A. 2008, Neurobiological models of two-choice decision making can be reduced to a one-dimensional nonlinear diffusion equation, PLoS Comput Biol 4(3): e1000046. doi:10.1371/journal.pcbi.1000046

Wilson, H. R., Cowan J. D., 1972, Excitatory and inhibitory interactions in localized populations of model neurons, Biophy. J., 12(1), pp. 1-24.

Part II

Network interactions

Chapter 5

Parallel versus sequential update and the evolution of cooperation with the assistance of emotional strategies

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Abstract

The large extent of cooperation among humans can be described as a complex adaptive system made up of interconnected individuals who update their strategy based on experience. When interactions are described as a single shot Prisoner's Dilemma (PD), then the events of cooperation are particularly puzzling. We construct a model in which individuals are connected with positive and negative ties. Some agents play sign-dependent strategies that use the sign of the relation as a shorthand for determining appropriate action toward the opponent. In the context of our model in which network topology, agent strategic types, and relational signs coevolve, the presence of sign-dependent strategies catalyzes the evolution of cooperation. We highlight how the success of cooperation depends on a crucial aspect of implementation: whether we apply parallel or sequential strategy update. Parallel updating, with averaging of payoffs across interactions in the social neighborhood, supports cooperation in a much wider set of parameter values than sequential updating. Our results cast doubts about the realism and generalizability of models that claim to explain the evolution of cooperation but implicitly assume parallel updating.

5.1 Introduction

The defining characteristics of Complex Adaptive Systems (CAS) is that they are made of a large number of interacting components that - together - generate results which are not observable at the level of each single element (Anderson et al. 1972). In such systems, even relatively simple local interaction rules can result in very complex behaviors of the aggregate system (Helbing 2012). Moreover, small variations in the local rules of interaction can result in large (non-linear) changes at the system scale. Thus, when studying complex systems, it is important to understand the impact of changes in the rules of interaction on the aggregate system properties.

One of the most elaborate complex system known is the human society. The human society is composed of individuals who are already complex in themselves and who interact with each other generating highly complex patterns. The results of these interactions are emerging structures, whose behavior can hardly fit simple or linear models (consider, for instance, financial markets and traffic in cities that are well studied examples).

What makes social systems uniquely complex is that their components are self-aware and, as such, act with some - limited - degree of intentionality. Game theory, that first attempted to model formally the complexity of *interdependent intentional* decisions (Von Neumann & Morgenstern 1944), made drastic assumptions initially that

(1) humans act rationally and (2) small scale interactions can be aggregated to the system level through simple extrapolation. These assumptions, however, have been relaxed progressively and now social systems are studied considering individuals that lack perfect foresight about the future consequences of their actions (March 1978, Simon 1982) and are affected by emotions and feelings (Camerer 2003, Gigerenzer 2008). In this context, an interesting approach to the problem of studying social interactions is provided by evolutionary game theory that tries to explain which strategies disappear, survive or thrive in the long run in a setup where strategies with higher payoffs tend to diffuse. This strain of literature allows to identify reasons and situations in which strategies that are rational in static games, are not the most successful ones in an evolutionary context. In evolutionary game theory, interactions are modelled in a very simple way when one compares them with the complexity of real-world social exchanges. Indeed, in these models agents are encoded with strategies that they are then bounded to follow when interacting with others. This simplification, however, allows to explore the mechanisms leading to the emergence or to the disappearance of specific behavioral patterns in social groups. One of the problems to which this literature has been applied is the theoretical justification of the continuing existence of selfless cooperative behavior in both nature and society.

The survival and extent of cooperative behavior in human society has for a long time been considered as one of the main and most difficult questions in the social sciences (Axelrod & Hamilton 1981, Axelrod 1997, 1984). Social dilemma games describe situations in which the self-interest of agents is in contrast with the one of their interaction partners. The most studied and puzzling among them is the Prisoner's Dilemma (PD). Individuals have two options in the PD: the dominant strategy - defection - guarantees a higher payoff regardless of what the partner does. The alternative strategy - cooperation - if played mutually, offers a payoff that is higher than the payoff from mutually playing the dominant strategy. This problem intensifies in a complex way when one passes from a 2-agent game played in isolation - where defection is always the winning strategy - to a game played by agents in a structured population of agents. It has been shown that unstructured populations with individuals interacting with randomly selected partners are unable to solve the puzzle of cooperation as natural selection generates uniform populations of defectors (Taylor & Jonker 1978, Hofbauer & Sigmund 1998). Recently, particular interest was devoted to the issue of evolutionary games in structured (networked) populations. On the one hand, studying interactions on networks increases significantly the realism of models, as this formalism allows to explicitly consider their inherent locality. On the other hand, limiting the possible interactions of agents (given the sparseness of interactions), proved to be able to increase cooperation in the population (Nakamaru et al. 1997, Nowak & May 1992).

The structure of interactions is important because many relevant mechanisms are channeled through network ties and because behavioral influence spreads differently in different structures (Phan 2003). Similarly, reputational mechanisms such as image scoring (Wedekind & Milinski 2000) also flow via network ties. It has been studied which network topologies are most efficient for the emergence and diffusion of cooperation (Hauert 2004, Santos & Pacheco 2005, Johnson et al. 2003). Having formal analytical proofs, however, is difficult in this context. Most contributions, therefore, use numerical simulations and agent-based models. This is especially true for the case in which the co-evolution of network topology and agent types (Santos et al. 2006, Yamagishi & Hayashi 1996, Yamagishi et al. 1994) is studied. Among the mechanisms that improve the conditions of cooperation in dynamic networks are the possibility of parter selection, exclusion of defecting agents, and exit from relationships (Schuessler

1989, Vanberg & Congleton 1992, Yamagishi & Hayashi 1996).

In Righi & Takács (2014*b*) we studied the conditions for the emergence of cooperation on dynamic signed networks. Virtually all co-evolutionary models of networks and cooperation before assumed the presence of positive relations only. We have relaxed this assumption and interpret signed ties as expressing the (positive or negative) emotional content of the social relationship between two individuals. This interpretation is consistent with evidence that emotions evolved in humans due to their function in social interactions (Darwin 1965, Frank 1988, Keltner et al. 2013, Trivers 1971). Signed relations help guaranteeing the diffusion of reputational information about the agent's past conduct, thus providing a guiding light for partners in choosing the correct behavioral response. While relational signs could be interpreted as a form of memory (Szolnoki et al. 2013), they constitute a cognitively much less costly mechanism, which can be used as a shorthanded tool that condenses the past history of a relationship. The sociological intuition behind why negative ties should also be considered for the evolution of cooperation is the relevance of altruistic punishment of defectors (Bowles & Gintis 2004, Dreber et al. 2008, Ernst & Gaechter 2005, Fowler 2005, Fowler et al. 2005, Rand & Nowak 2011) and the process of stigmatization and social exclusions of these individuals (Kerr & Levine 2008, Kurzban & Leary 2001). These mechanisms could result in negative interpersonal ties that in turn help the spread of cooperative behavior.

In Righi & Takács (2014*b*) we thus constructed an evolutionary Agent Based Model where agents played the Prisoner's Dilemma on signed networks (where links can be either positive or negative). We assumed that tense relationships can be resolved either by changing the sign or being erased and rewired. We analyzed a setup in which network topology co-evolves with relational signs and agent strategies. Our major conclusion was that the introduction of conditional strategies, that utilize the emotional content embedded in network signs, could act as catalysts and in general created favorable conditions for the spread of unconditional cooperation. We noticed, however, that the introduction of conditional strategies was successful in eliciting increased cooperation if the network was dynamic (i.e. if there was some positive probability of updating the network topology). Our results are summarized in Table 5.1.[3] In line with the literature, we found that the evolution of unconditional cooperation occured most likely in networks with relatively high chances of rewiring and low likelihood of strategy adoption (or strategy evolution). While some rewiring enhanced cooperation, too much rewiring limited its diffusion. Finally, we provided evidence that, unlike in networks with positive ties only, cooperation became more prevalent in denser networks.

Table 5.1: Summary of main findings in Righi & Takács (2014*b*).

	Without rewiring	With rewiring
Without emotional strategies	No cooperation	Cooperation through clustering of strategies
With emotional strategies	Some cooperation, only if most agents are emotional	**The emergence and diffusion of cooperation**

In the present study[4] we use this general setup to analyze the influence of the update rule, which essentially defines how and when agents interact, on the chances of cooperative behavior to become widespread in the population. In this way, our research

[3]This table and the results proposed for the parallel updating case are taken from Righi & Takács (2014*b*).

[4]All code and data-files from which the results are obtained are available upon request to the authors.

follows the pathway of earlier studies that examined synchronous vs real-time interactions in social dilemmas (Huberman & Glance 1993). Two different types of updating are proposed. The first is *sequential*, where single couples of agents are selected for interaction and as a consequence, the payoffs obtained in their interaction drive evolutionary and network update. The second is *parallel*, in which all agents play at the same time and average payoffs from the interactions with neighbors are calculated and used to drive the evolutionary process.

We show how the survival and diffusion chances of cooperation depend strictly on the type of updating rule used. We provide evidence that under a rather general set of parameters combinations, the parallel updating rule provides better conditions for the diffusion of cooperation as it allows conditional strategies that makes use of emotions to act as catalyst of virtuous behavior. Where the sequential update is applied instead, unconditional defection progressively diffuses and comes to dominate the population.

The remaining of the paper is divided as follows. In the next section, we describe our model and its characteristics as they were proposed in Righi & Takács (2014*b*). In addition, we describe the details of the two updating rules that we study. The following Section 5.3 presents our new results, while a discussion concludes (Section 5.4).

5.2 The model

We consider the model first introduced in Righi & Takács (2014*b*). We study a population of N agents. Agents are connected initially in a random network (Erdős & Rényi 1959) where each possible edge exists with probability $\rho \in [0, 1]$ [5]. The cardinality k_i of $\mathcal{F}_i$ is the degree (or number of network contacts) of agent i. The network is signed and each network tie is labelled either *negative* or *positive*. In this paper, we report results from setups where each link is initialized with the same probability $(1/2)$ as either negative or positive.

Each agent in the population can interact and play the single-shot Prisoner's Dilemma (with binary options of cooperation or defection) with partners selected from its first order social neighborhood. Among the social dilemmas, the Prisoner's Dilemma is the one that sets the stakes the most against the emergence of cooperation since it is characterized by the classical payoff structure Temptation(T) $>$ Reward(R) $>$ Punishment(P) $>$ Sucker(S) (Table 5.2). The maximum payoff, labelled *Temptation (T)*, for each single individuals is obtained if each of them by defecting under the assumption that the other agents cooperates. If it is the case the cooperating agent obtains the *Sucker (S)* payoff. However if both agents defect the outcome - where both of them obtain the *Punishment (P)* payoff, is sub-optimal with respect to the one where both agents cooperate, thus obtaining the *Reward (R)* payoff. The specific numerical payoffs used here are the same of Axelrod (1984).

	C	D
C	$(R = 3, R = 3)$	$(T = 5, S = 0)$
D	$(S = 0, T = 5)$	$(P = 1, P = 1)$

Table 5.2: The Prisoner's Dilemma payoff matrix.

As discussed, we assume that network signs, embedding an emotional content that

[5] In Righi & Takács (2014*a*) we extend our model and we consider also networks initialized as regular lattices. We show that changing the degree variance of the nodes the results are qualitatively the same.

follows from previous interaction, can affect behavior. From this point of view, we can characterize three types of strategies:

- Unconditional Defection (UD);
- Unconditional Cooperation (UC);
- Conditional Strategy (COND): cooperate if the tie with the interaction partner is positive; and defect otherwise.

While UC always cooperates and UD always defects, the strategy COND is conditional on the sign of the link between the interaction partners. The COND strategy, therefore, can be interpreted as a differentiated emotional reaction or affectional response towards others with harmonic or disharmonic interaction record as it prescribes cooperation with agents connected with a positive tie, and defection with partners connected with a negative relation. Below, we report results for initialization in which agents are assigned with one of the three strategies randomly in equal proportions: $(1/3 = \mu_{UC} = \mu_{UD} = \mu_{COND} = 1/3)$. Clearly the COND strategy outlined in this paper provides only a very simplified implementation of the concept of emotion. In this paper we shy away from the huge complexity that would derive from opening the black box of human feelings. We provide instead a restrictive definition of emotions, functional to our construction. The COND strategy is emotional in the sense that it draws upon the simple, and imperfect, signal provided by the network signs (which in turn summarizes past behavior of the partner) to condition the agent's behaviour.

As discussed, our model allows for the co-evolution of network signs, agent strategies and network topology. Network signs and agent behavior influence each other and the latter also affects the evolution of network topology. Each of these modules requires some clarification.

Sign update: agent behavior influences relational signs. Relational sign update simulates the consequences of behavior on the emotional relationship with peers. This type of update happens automatically, i.e. it is not part of individual strategies. It is relatively straightforward to assume that a relationship in which both agents defect turns negative and one in which both agents cooperate turns positive. When actions differ, we have a more complex case. In this situation an asymmetric tension arises since the cooperator could be frustrated of having a positive tie with a defector and the defector could appreciate the cooperation of the partner and might be ashamed of having a negative tie to him. In this case we assume that the link *could* change its sign. Specifically, we assume that a frustrated positive link can turn negative with probability P_{neg} and a frustrated negative link can turn positive with probability P_{pos}. Given the payoff structure of the PD (where a cooperator always obtains a very low payoff when its partner defects obtaining a high payoff), it is logical to assume that the frustration from disappointment is larger than the frustration from shame, that is $P_{neg} >> P_{pos}$. In particular we fixed $P_{neg} = 0.2$ and $P_{pos} = 0.1$. The Sign update rule for our model is summarized in Table 5.3.

Network topology update: rewiring. In addition, we allow for an endogenous update of network topology (as suggested, for example by Santos et al. 2006). It means that behavior can influence the network structure directly. With a probability P_{rew} (named *rewiring probability*) the frustration, emerged as a consequence of different strategies played in the PD game, can lead the frustrated agent to sewer its relationship

Agent i plays	Agent j plays	Old sign	New sign
C	C	+	+
C	C	-	+
D	D	+	-
D	D	-	-
C	D	-	With P_{pos}: +
C	D	+	With P_{neg}: -
C	D	+ / -	otherwise + / -

Table 5.3: Sign Update Rules.

and to search for a new partner. From the technical point of view, the rewiring assumes a certain degree of transitive closure (Granovetter 1973), meaning that we allow new connections to be created only between friends of friends. This modeling choice naturally follows from sociological observations. Still, with a small but positive probability (fixed in the following to $P_{rand} = 0.01$) the new link can be constructed with a randomly selected new partner. An example of our rewiring procedure is displayed in Figure 5.1. In Left Panel, Agent 2 interacts with Agent 1. The former cooperates, but his partner defects. In the Right Panel, Agent 2 sewers then his link with Agent 1 and forges a new link with one among the friends of his friends. In this example only Agent 4 is available and the new link is created. By assumption the new link is created as positive.

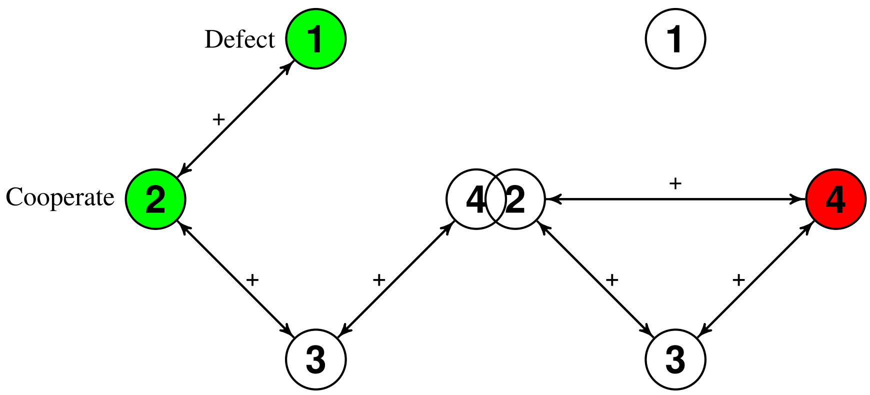

Figure 5.1: Example of network topology update through rewiring.

Strategy update: parallel vs dyadic update. Individual payoffs measure the efficiency of an agent's strategy in its social neighborhood. In this paper, we focus on how the choice of the timing of this update changes the results regarding the emergence of cooperation in signed networks. In particular, two alternative types of updating rules are studied:

- **Sequential Update**: At each time t, two connected agents are selected randomly for playing the PD. After playing and observing the relative payoffs, the agent with a strictly lower payoff (if any) updates its type and adopts the strategy of the more successful partner with probability P_{adopt} (assumed to be equal for all agents). Therefore, only the current dyadic payoff matters in the determination of the survival chances of a strategy. Including the modules discussed above, Algorithm 1 reports the pseudo-code of the intra-step dynamics with sequential updating.

Select randomly two connected agents (i and j);
Play the PD and compute payoffs;
Update relational signs between i and j;
if *link is tense* **then**
    Rewire link between i and j (with probability P_{rew});
end
if *link is tense and not rewired* **then**
    The agent with (strictly) lower payoff adopts the strategy of the partner (with probability P_{adopt});
end

Algorithm 1: Intra-step dynamics, repeated at each time step t, in the sequential update case.

- **Parallel Update**: At each time t, for each agent i the average payoff across all its interactions is calculated. Each agent then compares its payoff with the one of all peers in its first order social neighborhood. If a subset of these agents has a payoff higher than its own, then agent i will adopt the strategy played by one of them, selected uniformly at random. Evolutionary update happens, for each agent, with probability P_{adopt}, which is assumed to be equal for all players. In order to avoid that the order in which we select the agents influences the outcome, each of them refers to the situation at $t-1$ when changing either its relational signs or the network topology at time t. Moreover, the update of strategies happens for each agent after observing payoffs, at time t, of every other agent. Again, including the modules discussed above, Algorithm 2 reports the pseudo-code for our model intra-step dynamics with parallel update.

for *each agent* i **do**
    Compute its social neighborhood $\mathcal{F}_i^{t-1} \in N$;
    for *each agent* $j \in \mathcal{F}_i^{t-1}$ **do**
        Play the PD and compute payoffs;
        Update relational signs between i and j;
        Rewire link between i and j if tense (with Probability P_{rew});
    end
    Compute average payoff of agent i;
end
for *each agent* i **do**
    Observe the average payoffs of each agent $j \in F_i^t$;
    Adopt a random (strictly) better strategy (with probability P_{adopt});
end

Algorithm 2: Intra-step dynamics, repeated at each time step t, in the parallel update case.

One can immediately appreciate that the sequence of events is identical in the two implementations. The number of agents that play at each time step and the rule used to determine the evolutionary update, however, are different. While these differences seem minimal, they are consequential for the chances of cooperation to evolve in dynamic signed networks.

The parallel updating strategy is surely the most used in theoretical models featuring evolutionary games. Making a parallel with the real world interactions, this strategy update method implies that each individual updates his strategy only after having observed the relative payoffs of all his peers. This may be the case in some cases where very important decisions are made. In all other cases however it is unlikely for this to happen. On the contrary, many decisions about the future strategy to follow are taken as consequence of one single event, which is what we model - in a simple fashion - in the sequential update case. A comparative analysis of these two updates mechanisms is therefore useful to asses the realism of many of the models available in the literature. In this sense, it is clear from a theoretical perspective that the decision making in the two cases is supported by different levels of information. When the agents update in parallel, each of them has a very good assessment of the performance of the strategies used in their neighborhood. At the opposite, with the sequential update only the efficiency of own strategy relative to the one of the current partner is available. This second setup is expected and will favor defection when compared to the first.

5.3 Results

5.3.1 Evolution with sequential and parallel updating

The main objective of this paper is to figure out whether the rule of update influences the chances of emergence for cooperation in the single-shot PD played on signed networks.

We find that the two implementations differ radically with regard to the chances of cooperation to emerge (Figure 5.2). Using the sequential update, all forms of cooperation (both in conditional and unconditional strategies) are progressively eliminated from the population and remaining strategies all defect. Indeed, while the disappearance of CONDs is slowlier than the one of UCs (due to their relatively better performance against UDs), given that all signs progressively become negative, all remaining conditional strategies act as defectors and are effectively impossible to discern them from universal defectors. This type of evolution, whose statistical relevance for the selected parameters set is shown in the lower panel of Figure 5.2, is not limited to these conditions, and it holds in general. This system level evolution follows from the nature of the micro-level interactions. The COND players safeguard themselves from direct exploitation from UDs by exploiting the emotional content of the relationship embedded in the link. In a dyadic comparison, however, they can never outperform the latter as they progressively diffuse in the population. As a matter of fact, while UCs are systematically exploited by UDs and thus destined to disappear rather quickly, CONDs have the "choice" of either progressively turning their links to UD players to negative, thus becoming functionally equivalent to them; or being progressively eliminated.

The mechanism of rewiring of tense connections has been shown to help the survival of cooperation in networks (Yamagishi & Hayashi 1996, Yamagishi et al. 1994). It does so by segregating agents by type and thus increasing the probability that a cooperator plays with another cooperator (Becker 1976, Nowak 2006, Németh & Takács 2007). The level of rewiring that is proposed in Figure 5.2, however, is not sufficient to guarantee the survival of cooperation. We will provide a more comprehensive study

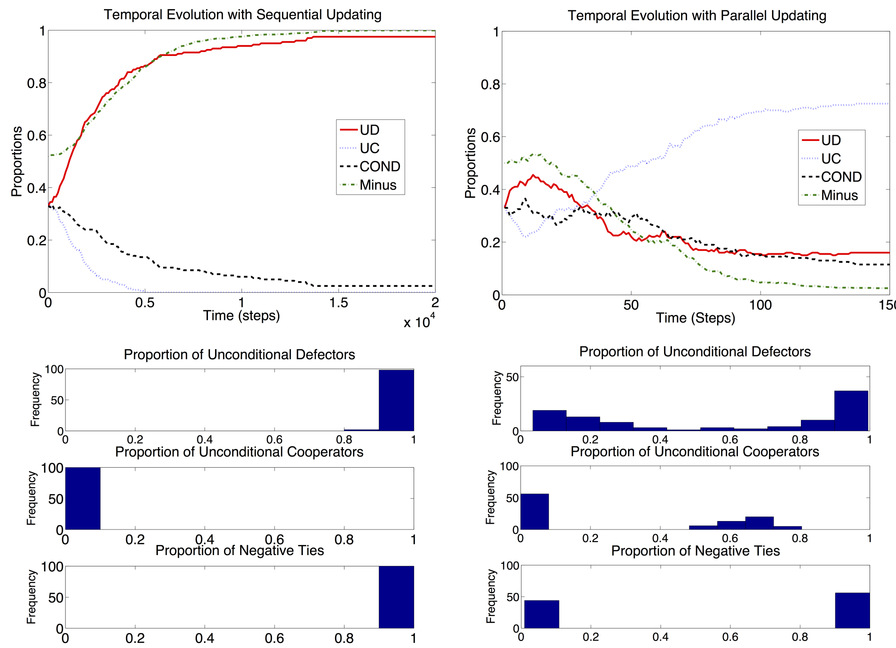

Figure 5.2: Upper panels: dynamic evolution of the proportions of agent types and network signs in typical simulations. The left panel shows the evolutionary process with *sequential updating* and the right panel with *parallel updating*. Lower panels: distribution of the final proportions of UDs, UCs, and negative ties in the sequential (Left panel) and parallel (Right panel) update dynamics (calculated on 100 simulations each). For all simulations: N=200 and $P_{rew} = P_{adopt} = 0.1$. The initial population is divided equally among UC, UD, and COND strategies. Moreover, the network signs are randomly initialized positive or negative with equal probability and the probability of existence for each tie is $P_{link} = 0.05$.

of the impact of this variable in the following.

When parallel update is applied, things change in favor of the emergence of cooperation. Now the UCs tend to dominate the population at the end of a significative number of simulations. COND players are able to obtain payoffs that are higher than those obtainable by an UD in a mixed population, because averages are calculated from all interactions in the social neighborhood. While the CONDs do not gain dominance themselves, their presence allows for the evolution of unconditional cooperation. Again, a look at the interaction level is pivotal to understand these results. The mechanism allowing this emerging behavior, described in Righi & Takács (2014*b*), relies on the fact that conditional players tend to develop a collaborative relationship with UCs while not being systematically cheated by UDs. This ensures good performances of those COND players that act as interphase between the two pure strategy types. Dynamically, the UDs progressively become CONDs and these, in turn tend to become UCs (which in a connected and clustered world dominated by cooperation is the strategy with the highest average payoff). This effect is reinforced by the presence of the possibility of sewering the relationship and rewiring it with a friend of a friend as negative links can also be erased, which tends to isolate defectors from cooperators.

5.3.2 The two main dynamics: adoption vs rewiring

Let's now discuss the results of the previous section in a more systematic fashion. Our model's evolution is driven by two major forces. First, agents with lower average payoff adopt strategies in their social neighborhood that perform better (evolutionary dynamics). Second, stressed relationships can be rewired (rewiring dynamics). In order to analyze the joint influence of these two important forces, we study their effects systematically changing their relative strength (measured as their probability to happen, respectively, at each time step and interaction). Logically, this is a similar inquiry to the analysis of network and strategy update in models with positive ties only (Santos et al. 2006).

Figure 5.3 shows the results for the proportion of minus signs (Left Panels), unconditional defectors (Central Panels), and unconditional cooperators (Right Panels) for $P_{adopt} \in [0, 1]$ and $P_{rew} \in [0, 1]$ progressively changing values of both variables in steps of 0.05. For each combination of parameters we provide the average results of 50 simulations.

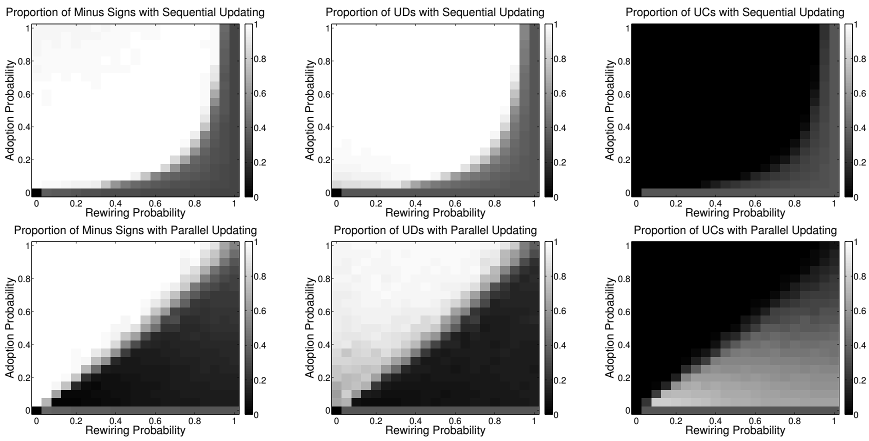

Figure 5.3: Effect of the competing dynamics of adoption of strategies with higher payoffs (vertical axis) and of rewiring of stressed links (horizontal axis) on the final proportion of negative ties in the network (Left panels), of UDs (Central panels) and of UCs (Right panels). Top panels show the results for sequential updating and Lower panels for parallel updating. In all simulations N=200. Network signs are randomly initialized with equal probability and the population is equally divided between UCs, UDs and CONDs. The probability of existence for each tie is $P_{link} = 0.05$.

Results show that, for the cooperative strategies to survive, there needs to be a relatively low invasion and a relatively high rewiring probability. This is valid for both update mechanisms and it is coherent with what observed in the literature on non-signed networks: in absence of negative ties, the rewiring mechanism limits the capacity of UDs to spread in the population. Focusing on *sequential update* (Figure 5.3, Top Panels), we can observe two characteristic facts. The first is that universal cooperators may survive, but they never become dominant in the population. Indeed, their proportion never exceeds the original proportion of one third. The second observation is that cooperation survives in this setup only if $P_{rew} >> P_{adopt}$. This is in line with the literature considering positive ties only that shows how the scale of network update relative to the scale of strategy update is a key explanatory factor behind the chances for the evolution of cooperation (Santos et al. 2006). Network update helps the relative clustering (it progressively eliminates negative ties with defectors) and the survival of cooperators, while frequent strategy updates provide higher importance to immediate payoffs and drive the system towards a Hobbesian destiny of no cooperation and negative links. As we have seen in the previous section, with sequential updating, the dynamics of the model tends to favor unconditional defectors that thus tend to spread in the population. This process of spread is obviously faster, the higher is P_{adopt} and the rewiring mechanism is here the only mechanism that allows the survival of cooperation.

In the case of *parallel updating*, the situation is different. Cooperation can now survive also for $P_{rew} \approx P_{adopt}$. As we have seen before, the parallel update rule provides a more favorable conditions for the evolution of cooperation than sequential updating, mainly due to averaging of payoffs across multiple interactions. Averaging of payoffs and hence the increased importance of being clustered among cooperators increase the importance of the flexible character of the COND strategy. While UD still provides the best way to exploit neighbors in the short term in *any* environment, COND is prepared to defect and achieves at least equally good payoffs with UDs, while cooperates with cooperator neighbors and consequently earns more *on average* than UDs in a UD-dominated environment as well as in a COND-dominated environment. Obviously, UDs still outperform COND in a UC-dominated environment, but due to strategy updates and rewiring, such a victory is a Pyrrhic one. For these reasons, high rates of strategy update are here not that bad for conditional strategies as in the sequential update case. Emotional strategies can then act as catalysts of cooperation at least as long as $P_{rew} \geq P_{adopt}$. When P_{adopt} is to high, however, strategy update favors the spread of universal defection even in the case of parallel updating.

Finally, when cooperation is supported, the proportion of UCs can extend to more than its initial value (and in some cases even above the initial sum of conditional players and unconditional cooperators) if the adoption probability is sufficiently small (with respect to rewiring). On the contrary, when both dynamic forces are strong, the proportion of UCs in the final population decreases in favor of an higher share of conditional cooperators. Indeed, a dynamic environment with high probability of rewiring associated with high probability of adoption allows the emotional strategy to extricate its power while highlighting the weakness of unconditional cooperation. On the one side, CONDs tend to diffuse since they obtain systematically higher payoffs than UDs when at the border between UCs and UDs. The intensity of the adoption rate makes it possible for CONDs to spread in the direction of universal defectors. On the other side, universal cooperators are unable to outperform UDs locally and, as a result, their survival rate decreases, being bounded below only by the fact that network rewires relatively fast. This creates clusters of both conditionals and (few) unconditional cooperators that are sustained at equilibrium.

5.4 Conclusions

The evolution of cooperation is one of the most puzzling problems in the social sciences. In this study, we make two contributions to the resolution of the puzzle. First, building on Righi & Takács (2014*b*), we make existing models more realistic by allowing negative as well as positive ties among connected agents and, in relation, we introduce and analyze the role of emotional strategies in the single-shot Prisoner's Dilemma. We show that the simple adaptive rules we defined for evolution results in the emergence of cooperation in a non-trivial way: emotional strategies act as catalysts for the success of unconditional cooperation.

Second, we analyze how this conclusion is dependent on whether we implement sequential or parallel updates in the model. With this inquiry, we follow earlier studies in complex systems that examined the importance of assuming synchronous versus real-time interactions in social dilemmas which showed that such systems might behave very differently (Huberman & Glance 1993, Lumer & Nicolis 1994). Besides, this question is important also substantially as sequential and real-time interactions and updates are much more realistic than parallel ones. In our case, sequential updating means that single couples of individuals are selected for interactions and evolutionary and network updates immediately after. This model implementation is contrasted with parallel update, in which agents play at the same time with all their network neighbors and where average payoffs from all of their interactions determines evolutionary success.

We provide evidence that the survival and diffusion chances of cooperation are indeed strictly limited in the sequential update rule case. Under a rather general set of parameters combinations, the parallel updating rule provides better conditions for the diffusion of cooperation. We explore the nature and range of these differences by manipulating two crucial parameters of our model: the extent of strategy updates and rewiring possibilities. While the rewiring probability should be in general higher than the strategy update one in order to find universal cooperators in the final population, the difference between the two can be small in case of parallel update, but needs to be substantial in case of sequential update.

Our results might imply that the majority of models that study the evolution of cooperation in networks or spatial settings and offer a solution for the emergence of cooperation miss an important aspect: they implicitly or explicitly assume that actions or updates are synchronous. This is in line with our parallel update rule that provides favorable conditions for the emergence of cooperation via the assistance of emotional strategies that act as catalysts in the evolutionary process. Most historical events, however, are sequential or happen in real time. As our results highlighted, the chances of cooperation are much more limited under such circumstances. This leaves the puzzle of the evolution of cooperation in case of sequential interactions still to be solved by subsequent research.

Finally, our model presents very simple strategies based on agents with no memory. Future research should explore the role of repeated games with memory on the sustainability of cooperation. Indeed, the introduction of repeated interactions before rewiring is expected to make this mechanism more effective in preserving cooperation due to the better available information.

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Bibliography

Anderson, P. W. et al. (1972), 'More is different', *Science* **177**(4047), 393–396.

Axelrod, R. (1984), *The Evolution of Cooperation*, Basic Books.
URL: *http://books.google.hu/books?id=KFf2HXzVO58C*

Axelrod, R. (1997), *The Complexity of Cooperation: Agent-based Models of Competition and Collaboration*, Princeton studies in complexity, Princeton University Press.
URL: *http://books.google.hu/books?id=J0dgRGMdjmQC*

Axelrod, R. & Hamilton, W. D. (1981), 'The evolution of cooperation', *Science* **211**(4489), 1390–1396.

Becker, G. S. (1976), 'Altruism, egoism, and genetic fitness: Economics and sociobiology', *Journal of economic Literature* **14**(3), 817–826.

Bowles, S. & Gintis, H. (2004), 'The evolution of strong reciprocity: cooperation in heterogeneous populations', *Theoretical population biology* **65**(1), 17–28.

Camerer, C. (2003), *Behavioral game theory: Experiments in strategic interaction*, Princeton University Press.

Darwin, C. (1965), *The expression of the emotions in man and animals*, Vol. 526, University of Chicago Press.

Dreber, A., Rand, D. G., Fudenberg, D. & Nowak, M. A. (2008), 'Winners don't punish', *Nature* **452**(7185), 348–351.

Erdős, P. & Rényi, A. (1959), 'On random graphs', *Publicationes Mathematicae Debrecen* **6**, 290–297.

Ernst, F. & Gaechter, S. (2005), 'Human behaviour: Egalitarian motive and altruistic punishment(reply)', *Nature* **433**(7021).

Fowler, J. H. (2005), 'Altruistic punishment and the origin of cooperation', *Proceedings of the National Academy of Sciences of the United States of America* **102**(19), 7047–7049.

Fowler, J. H., Johnson, T. & Smirnov, O. (2005), 'Egalitarian motive and altruistic punishment', *Nature* **433**(10.1038).

Frank, R. H. (1988), *Passions within reason: The strategic role of the emotions.*, WW Norton & Co.

Gigerenzer, G. (2008), *Gut Feelings: The Intelligence of the Unconscious*, Penguin Books.
URL: *http://books.google.com/books?id=iiGTs1CnTHcC*

Granovetter, M. S. (1973), 'The strength of weak ties', *American journal of sociology* pp. 1360–1380.

Hauert, C. (2004), 'Virtuallabs', http://www.univie.ac.at/virtuallabs/Moran/. Accessed: 2010-09-30.

Helbing, D. (2012), *Social self-organization: Agent-based simulations and experiments to study emergent social behavior*, Springer.

Hofbauer, J. & Sigmund, K. (1998), *Evolutionary games and population dynamics*, Cambridge University Press.

Huberman, B. A. & Glance, N. S. (1993), 'Evolutionary games and computer simulations', *Proceedings of the National Academy of Sciences* **90**(16), 7716–7718.

Johnson, J. C., Boster, J. S. & Palinkas, L. A. (2003), 'Social roles and the evolution of networks in extreme and isolated environments', *Journal of Mathematical Sociology* **27**(2-3), 89–121.

Keltner, D., Haidt, J. & Shiota, M. N. (2013), Social functionalism and the evolution of emotions, *in* M. Schaller, J. A. Simpson & D. T. Kenrick, eds, 'Evolution and social psychology', Psychology Press, pp. 115–142.

Kerr, N. L. & Levine, J. M. (2008), 'The detection of social exclusion: Evolution and beyond', *Group Dynamics: Theory, Research, and Practice* **12**(1), 39.

Kurzban, R. & Leary, M. R. (2001), 'Evolutionary origins of stigmatization: the functions of social exclusion.', *Psychological bulletin* **127**(2), 187.

Lumer, E. D. & Nicolis, G. (1994), 'Synchronous versus asynchronous dynamics in spatially distributed systems', *Physica D: Nonlinear Phenomena* **71**(4), 440–452.

March, J. G. (1978), 'Bounded rationality, ambiguity, and the engineering of choice', *The Bell Journal of Economics* pp. 587–608.

Nakamaru, M., Matsuda, H. & Iwasa, Y. (1997), 'The evolution of cooperation in a lattice-structured population', *Journal of Theoretical Biology* **184**(1), 65–81.

Németh, A. & Takács, K. (2007), 'The evolution of altruism in spatially structured populations', *Journal of Artificial Societies and Social Simulation* **10**(3), 4.

Nowak, M. A. (2006), 'Five rules for the evolution of cooperation', *science* **314**(5805), 1560–1563.

Nowak, M. A. & May, R. M. (1992), 'Evolutionary games and spatial chaos', *Nature* **359**(6398), 826–829.

Phan, D. (2003), Small worlds and phase transition in agent based models with binary choices, *in* 'Muller JP, Seidel MM eds. 4 workshop on Agent-Based Simulation, Montpellier, SCS Publishing House, Erlangen, San Diego'.

Rand, D. G. & Nowak, M. A. (2011), 'The evolution of antisocial punishment in optional public goods games', *Nature Communications* **2**, 434.

Righi, S. & Takács, K. (2014*a*), 'Degree variance and emotional strategies catalyze cooperation in dynamic signed networks', *Proceedings of the European Conference on Modelling and Simulation* .

Righi, S. & Takács, K. (2014*b*), 'Emotional strategies as catalysts for cooperation in signed networks', *Advances in Complex Systems* **17**(02).

Santos, F. C. & Pacheco, J. M. (2005), 'Scale-free networks provide a unifying framework for the emergence of cooperation', *Physical Review Letters* **95**(9), 098104.

Santos, F. C., Pacheco, J. M. & Lenaerts, T. (2006), 'Cooperation prevails when individuals adjust their social ties', *PLoS Computational Biology* **2**(10), e140.

Schuessler, R. (1989), 'Exit threats and cooperation under anonymity', *Journal of Conflict Resolution* **33**(4), 728–749.

Simon, H. A. (1982), *Models of bounded rationality: Empirically grounded economic reason*, Vol. 3, MIT press.

Szolnoki, A., Xie, N.-G., Ye, Y. & Perc, M. (2013), 'Evolution of emotions on networks leads to the evolution of cooperation in social dilemmas', *Physical Review E* **87**(4), 042805.

Taylor, P. D. & Jonker, L. B. (1978), 'Evolutionary stable strategies and game dynamics', *Mathematical biosciences* **40**(1), 145–156.

Trivers, R. L. (1971), 'The evolution of reciprocal altruism', *Quarterly review of biology* pp. 35–57.

Vanberg, V. J. & Congleton, R. D. (1992), 'Rationality, morality, and exit', *The American Political Science Review* pp. 418–431.

Von Neumann, J. & Morgenstern, O. (1944), 'Game theory and economic behavior'.

Wedekind, C. & Milinski, M. (2000), 'Cooperation through image scoring in humans', *Science* **288**(5467), 850–852.

Yamagishi, T. & Hayashi, N. (1996), Selective play: Social embeddedness of social dilemmas, *in* 'Frontiers in social dilemmas research', Springer, pp. 363–384.

Yamagishi, T., Hayashi, N. & Jin, N. (1994), Prisoner's dilemma networks: selection strategy versus action strategy, *in* 'Social dilemmas and cooperation', Springer, pp. 233–250.

Chapter 6

Social network analysis: an emerging methodology to study interactions within networked learning communities

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Abstract

Networked Learning Communities (NLCs) are complex systems made up of course users with a shared purpose: achieving learning goals. When these communities and the online courses they take part in are supported by Virtual Learning Environments (VLEs), studying interactional patterns and the communication structure of the community is a real challenge for researchers as VLEs do not usually provide relational data. Researchers thus have to (1) produce this type of data while building the corpora they wish to analyse, and (2) resort to specific methodologies to analyse the corpora built. One such methodology is Social Network Analysis (SNA), an emerging methodology in the study of NLCs as it offers various measures and modelling tools for the analysis of relational patterns within a group. In this chapter, we show how powerful this method is through a case study on interactional competence development in English as a second language through an online course. Indeed, the sociometric analysis of the corpus built highlighted the influence of the communication tool used on the interactional load and configuration of interactions, and demonstrated the extent to which telecollaboration was successful depending on the tool used. More general conclusions are also drawn on the invaluable contribution of SNA in the study of NLCs.

6.1 Introduction

The rapid development of computer-based technologies has led to the growing popularity of e-learning systems, thus making web-based education more popular in recent years. The online courses offered are often supported by Virtual Learning Environments (VLEs), also called Learning Management Systems or Courseware Management Systems. These are systems which offer a number of tools which are necessary for a course to be administered online, the most famous of these being Blackboard, WebCT or Moodle. VLEs usually support "the distribution of study materials to students, content building of courses, preparation of quizzes and assignments, discussions and distance management of classes" (Drazdilova et al., 2010, p. 299). In addition, they facilitate communication as they provide a number of collaborative learning tools. These enhanced learning environments can be considered as social networks of course users if we accept Garton et al.'s (1997) definition of a social network as "a set of people (or organizations or other social entities) connected by a set of social relationships, such as friendship, co-working or information exchange". As these specific social networks aim at connecting course users with each other with a view to learning, they can also be termed Networked Learning Communities as they fit both of the following definitions:

> Networked learning is learning in which information and communication technology (ICT) is used to promote connections: between one learner and other learners, between learners and tutors; between a learning community and its learning resources (Jones and Esnault, 2007).

> A learning community is a group of individuals who come together to acquire knowledge (Dillenbourg et al., 2003).

It should be noted, however, that groups of learners do not systematically become learning communities (Chanier and Cartier, 2006): the close study of their relationships and interactions is necessary to determine whether or not a learning community has emerged from a group of learners.

Finally, in line with Holtzer's (1995) definition of complex systems as a whole of interdependent elements (course users) organized for a purpose / a definable objective (achieving learning goals), NLCs can also be considered as complex systems. Thus the dynamic nature of these systems lies in the interactions between their components which researchers strive to examine. Still, researchers interested in studying VLE-supported NLCs might have to overcome several obstacles, one of these being the type of data provided by these new technological learning environments. Indeed, if the data usually provided by VLEs include user profile, information about student learning habits, student results and user interaction data (mainly chat logs and posts on discussion boards), information on participation patterns and on the communication structure of the group is usually not automatically made available by VLEs (Reffay and Chanier, 2003).

As a consequence, researchers have to face two problems when working with VLE-based data:

1. it is sometimes difficult to extract useful information from the data provided (Drazdilova et al., 2010); for example, connection time is the type of information that is systematically provided but is difficult to use by researchers as we all know that a course user who has logged on the VLE can always do something else (make themselves a cup of tea!) or simply forget to log off, but the system will still consider this time as connection time; this type of tracking information is thus very unreliable and often unusable by researchers.

2. In addition, the data provided by VLEs is centered on the individual: no relational data is usually readily available. Consequently, researchers interested in the study of interactional patterns have to produce this type of relational data while building their corpora from the raw data made available by the VLE. One methodology to then analyse relational data in the study of NLCs is that of Social Network Analysis (SNA).

The aim of this chapter is to show to what extent SNA is a valuable methodology to study interactional patterns in VLE-based NLCs. The basic principles and various applications of SNA will first be examined; then, a case study in the field of second language acquisition will be presented in which SNA was used to study the development of learners' interactional competence in English as a second language in a VLE-based NLC. Finally, conclusions will be drawn as regards the usefulness of SNA in the study of NLCs and its potential implementation within VLEs.

6.2 Social Network Analysis (SNA)

Social Network Analysis (also known as structural analysis) has developed from three different traditions or strands (Scott, 2000):

1. Sociometric analysts (Moreno, 1934; Lewin, 1936) whose work on small groups gave rise to a major technical breakthrough: graph theory (a combination of mathematics and social theory);

2. Harvard researchers of the 1930s (Mayo, 1933) whose work focused on patterns of interpersonal relations and the way cliques are formed;

3. Manchester anthropologists (Barnes, 1954; Bott, 1955; Mitchell, 1969) whose work was based on the first two strands and consisted in investigating the structure of community relations in village and tribal communities.

These traditions were brought together in the 1960s and 1970s at Harvard to forge contemporary SNA. It consists of a body of qualitative measures of network structure (Scott, 2000).

6.2.1 Principles

First, it's important to understand that SNA is an approach which does not focus on individual attributes or properties, nor on the fine-grained analysis of every network participant's contribution. On the contrary, it focuses on the level of activity of a group as a whole and on the patterns of relations - the ties (links, connections) relating one participant to another. Indeed, SNA's objectives are to study relationships between individuals and to compute representations that highlight global information invisible in raw data: formal properties of social configurations.

Although SNA is often considered as difficult to come to grips with (due to the technical and mathematical language used) (Scott, 2000), its underlying principles are relatively simple (Garton et al., 1997):

1. The unit of analysis is the relation (between one or more network participants);

2. The main feature of a relation is its pattern (and not the specific attributes of network members);

3. A relation is characterized by its content, direction and strength;

4. A link (or tie) connects two (or more) participants by one or more relations.

As noted by Drazdilova et al. (2010), SNA is more than an approach and can be considered as a full methodology for data mining in online educational research following four steps:

1. Data collection (through the VLE)

2. Data pre-processing: drafting matrices

3. Data mining application: using techniques and algorithms to obtain required information (specific software)

4. Data interpretation and result implementation (to improve student learning processes).

6.2.2 Two tools, two key indicators

Two Tools

Matrices: A matrix is a table of figures, a pattern of rows and columns where rows represent each case studied and columns correspond to variables on which attributes are measured. Matrices are extremely useful as they support mathematical manipulations.

Sociograms: SNA can be used to visualize the network through its graphical representation (node-link graph) which aims at mapping chains of connections and at indicating the strength and direction of relations. Participants are represented as nodes and their connections as lines between the nodes (Figure 6.1). With sociograms, SNA offers a modelling technique which is invaluable to uncover asymmetry and reciprocity, to identify groups of individuals within the network (named cliques) and to identify leaders (central - node C in Figure 6.1) and isolated individuals (peripheral - node K in Figure 6.1).

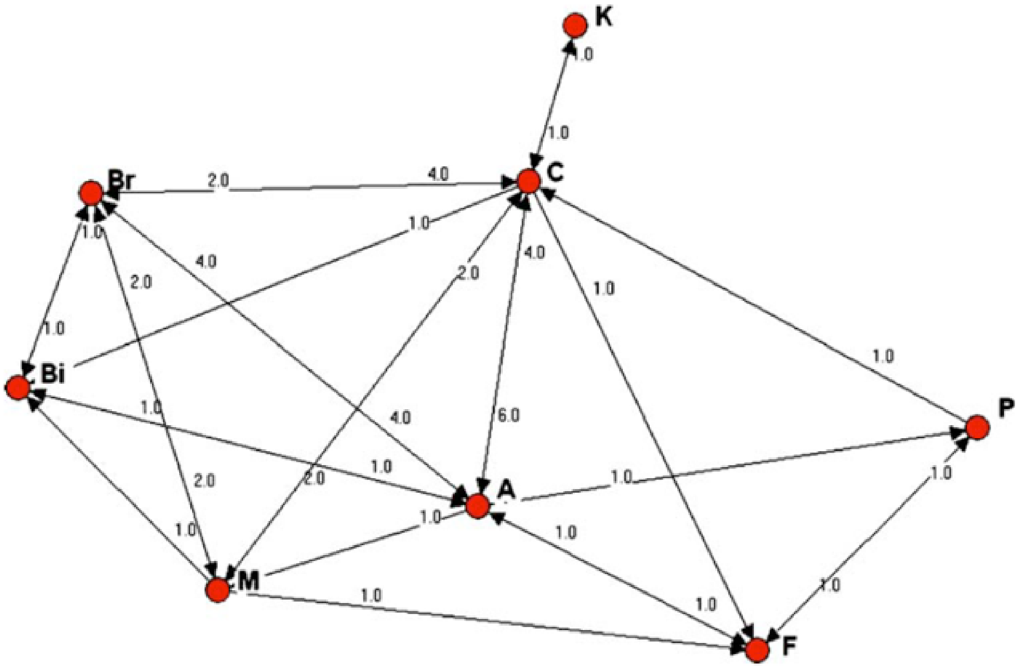

Figure 6.1: A sociogram (de Laat et al., 2007).

Two key indicators of SNA

Network density provides "a measure of the overall connections between participants" (de Laat et al., 2007) and corresponds to the number of observed ties divided by the number of all possible ties. Network density ranges from 0% to 100%: the more participants are connected to each other, the higher the density of the network. The average geodesic distance of a network is defined as "the number of relations in the shortest possible walk from one actor to another" (Hanneman and Riddle, 2005), in other words the length of the shortest path to link two nodes. This basic definition of geodesic distance is that used by the UCINet software package[2]. It can be obtained "by adding distances for all the links in the path between [two people]. If there are multiple paths between people, we define the distance using the shortest path. If there are no paths, we define the distance as infinite. This definition [...] generalizes the concept of *geodesic distance"* (Dekker, 2005). It is thus expressed as a number of ties and ranges from 1 to infinity: if the average geodesic distance of a network is 1 (=1), the length of the shortest path between each participant and their partners corresponds to one single link, which means that all participants are directly connected to one another (everyone is interconnected). On the contrary, if one or more participant is not directly connected to one or more of their partners, the length of the shortest path between them corresponds to more than one link, which means that the average geodesic distance of the network will be higher than 1 (>1). Consequently, the closer to 1 the average geodesic distance of a network is, the more participants are directly connected to each other.

In a nutshell, SNA is an approach which "offers a method for mapping group interactions, visualizing 'connectedness' and quantifying some characteristics of these processes within a community" (de Laat et al., 2007). It requires the use of specific software packages to compute, represent and analyze network structure. The most popular of these are UCINet (Borgatti et al., 1999), Pajek (Batagelj and Mrvar, 2014) and NetMiner (Cyram Inc., 2014).

6.2.3 Applications

According to Drazdilova et al. (2010, p. 301), Social Network Analysis is used in a variety of fields: from the commercial sphere in the case of viral marketing, to biology and medical diagnoses for the application of viral prevention; from law enforcement in order to investigate organized crime to the e-business sphere (online advertising, recommendation systems and auction markets). SNA has also been used to study organizational communication: for example, workplace interactions have been analyzed with SNA after the introduction of computer-mediated communication in the workplace (Garton et al., 1997). Obviously, virtual social networks have also recently been studied thanks to SNA: for example, LinkedIn (D'Andrea et al., 2010).

Several studies in the field of educational research have also started using SNA, among which a few have attempted to study NLCs: while some researchers have studied elementary school learners' patterns of interaction during the completion of a collaborative online task (Palonen & Hakkarainen, 2000), others have studied VLE-based activities (De Laat et al., 2007; Drazdilova et al., 2010); and while some have studied postings in a discussion board, as part of an online graduate class (Russo & Koesten, 2005), others have studied the cohesion of small groups in interactions based on computer-mediated communication (e-mail, text chat, discussion board) as part of a French as a Foreign Language course (Reffay & Chanier, 2003). As we can see from these examples, SNA seems to be an emerging approach in the study of NLCs.

6.3 Case study

In this section, a brief account of one case study will be given to illustrate how SNA can be extremely useful in the study of computer-mediated communication patterns

[2] Source: http://www.arschile.cl/ucinet_ing/calcular.html

within an NLC. As this is part of a larger study, only part of it will be presented here, but interested readers might want to refer to Sarré (2013) for more details.

6.3.1 Context and participants

Over one semester (January - June) at Orléans University (Sciences Faculty), 48 first year Master's students specializing in Biology took part in a 25-hour online module of English (as a second language) whose aim was to help them develop all five skills (reading, listening, writing, speaking, interacting), with special emphasis on interactional competence development. The online module consisted of 6 collaborative tasks that learners had to complete in groups through computer-mediated communication.

Prior to the start of the course, a computerized language skills diagnosis test was administered (DIALANG, European Commission, 2004). As taking part in interactions with more competent interactants is claimed to help develop one's interactional competence through peer scaffolding (He & Young, 1998), the results of the test were used to split all participants into 12 mixed-ability groups of 4 students. In addition, all 12 groups were then split into 3 meta-groups and each was assigned a specific computer-mediated communication tool to interact with while completing the online collaborative tasks: a text chat tool (4 groups), a discussion board (4 groups) or a desktop videoconferencing tool (4 groups).

6.3.2 Research question

The main objective of the study was to explore L2 Interactional Competence development through three computer-mediated communication modes: (1) asynchronous text-based communication (discussion board), (2) synchronous text-based communication (text chat), (3) synchronous voice-based communication (desktop videoconferencing).

The research question to answer was the following: Does the computer-mediated communication mode used have an impact on the interactional load and configuration of online interactions in a second language?

The main hypothesis consisted in considering that the computer-mediated communication mode influences the interactional load of learners' contributions, the social configuration of their interactions, their integration in their NLC and the efficiency of their telecollaboration.

6.3.3 Equipment and materials

The online module was based on the technical infrastructure offered by an open-source VLE: Dokeos 1.8.3 (De Praetere, 2010). It provided, among other functionalities, a text chat tool and a discussion board. However, as it did not provide any desktop videoconferencing tool, an external web-based application was used: Flashmeeting (Knowledge Media Institute, 2010).

Corpus building and analysis also required the use of several technological tools:

- Camstudio (Rendersoft, 2013): an open-source screen recording tool to capture the videoconferencing sessions;
- EXMARaLDA (Schmidt et al., 2013): a transcription and data mining software package;
- UCINet (Borgatti et al., 1999): an SNA software package.

6.3.4 Method

Over the course of the semester, learners had to complete 6 collaborative tasks, the completion of which required the students to interact in order to solve specific problems and make decisions as a group. The tasks were part of five subject-specific scenarios which put learners in realistic situations where they had missions to complete. The outcome of each scenario was a written language production which could only be done after the completion of the collaborative tasks: closed problem-solving or decision-making tasks and open opinion-gap tasks. For example, one of the scenarios about phytoremediation puts learners into the realistic situation of an internship that they have to carry out in Crozet, Virginia. During their internship, learners are supposed to take part in the decontamination process of the Crozet site which used to be an orchard and got contaminated with arsenic over time. At the end of their internship, they have to produce a two-page brochure about the phytoremediation procedures used in Crozet to explain them to the general public, as well as the risks of such procedures. The collaborative task they have to complete is a problem-solving task: learners notice strange phenomena during their internship (deaths of moles and voles, damage of certain types of fern, etc.) and have to come up with possible reasons for these phenomena as well as recommendations and measures to be taken to solve the problems observed in the short and long terms.

Corpus building consisted in collecting, transcribing and tagging data:

- The data collected comprised 24 chat log files in the form of text files (25 440 words), 24 discussion board files copied and pasted into text files (27 324 words) and 24 videoconferencing files which were captured video files in AVI format (521 minutes);
- Conversation Analysis-based data transcription and annotation were performed: chat files were annotated, discussion board files were annotated and videoconferencing files were transcribed, time-aligned and annotated.

Specific interactional resources were tagged in order to analyse the types of interactional resources used in each group and draw specific interactant profiles as well as conclusions in terms of interaction efficiency. The interactional resources under study (Figure 6.2) were all considered to be indicators of the 'interactional load' (or "*measures* of interactive involvement", Skehan 2003) of the exchanges, that is the extent to which interactants truly engage with their interlocutors through their use of specific interactional resources which enable them to negotiate meaning, coconstruct discourse and manage the interaction. An interaction with a very low interactional load often takes the form of parallel monologues, i.e. interactants talk to each other but do not take their interlocutors into consideration, so do not truly engage with their interlocutors. The resources under study thus were to show to what extent each interactant (1) took part in the coconstruction of meaning and (2) made good use of their interactional competence.

6.3.5 Results

The interactional resources used per computer-mediated communication mode presented in Table 6.1 show that learners almost consistently used more interactional resources in the text chat groups, with the exception of negotiation routines which were more numerous in the videoconferencing groups: this can probably be explained by

Resource category	Resource type	Tag	Description
Negotiation of Meaning	Routines	SCR, SCC, SST	Signal
		RMIN, RSR, RPAR, RSC, RCOMPC	Response to signal
		REAC	Reaction to response
	Negative feedback	EXCO	Explicit Correction
		QUES	Question
		RECA	Recast
		INC	Incorporation
Coconstruction	Positive alignment moves	AAP	Assessment Activity Positive
		COLCO	Collaborative Completion
		COCON	Collaborative Contribution
		FORMU	Formulation / rephrasing
	Negative alignment moves	AAN	Assessment Activity Negative
		COUNTER	Counter Argument
Turn Management		NCSSS	Non Current Speaker Selects Self
		CSSO	Current Speaker Selects Other
Interaction Management		SOCFOR	Social Formulae
		METATA, METATEC	Metacommunication about Task or about Technical aspects

Figure 6.2: Tagged interactional resources

the fact that learners interacting with videoconferencing experienced more technical glitches which gave rise to more negotiation routines (as non-comprehension, whether because of a technical problem or a language problem, is what usually sets off a negotiation routine). The data can be even finer-grained, as shown in Figure 6.3.

As we can see in Figure 6.3, the number of interactional resources used to coconstruct meaning follow the global pattern mentioned above: text chat groups consistently used more than the other groups. We could, in turn, examine the other types of interactional resources under study with such detail. Still, however interesting they may be, these quantitative analyses do not account for how the various interactional resources are used within the NLCs. This is where SNA comes into play to provide a more qualitative analysis of the data. As previously mentioned, the first thing we need to perform SNA is relational data.

Figure 6.4 represents the extraction of the annotated data and shows that each participant is potentially assigned three separate tiers: tiers coded [v] (v for verbal) correspond to the orthographic transcription of the exchange, the other tiers [NOM] (for Negotiation Of Meaning) and [INTERAC] (for Interactional resources) are devoted to the tagging of the specific interactional resources under study. During the tagging phase, interpersonal links between participants were also coded on resource-specific tiers. For example, on line 2, when LAU asks MAM to clarify what she just said, this particular interactional resource (a clarification request - coded SCR on the [NOM] tier as this is a signal used in negotiation of meaning routines) was tagged as well as

Table 6.1: Interactional resources used per computer-mediated communication mode

Resource Category	Resource Type	Text Chat	Videoconferencing	Discussion Board
Negotiation of Meaning	Negotiation routines	54	**102**	14
	Negative feedback	**61**	58	0
Coconstruction	Positive alignment moves	**1 109**	583	260
	Negative alignment moves	**155**	55	59
Interaction Management	Social formulae	**345**	154	165
	Metacommunication	**242**	230	25
	TOTAL	**1966**	**1182**	**523**

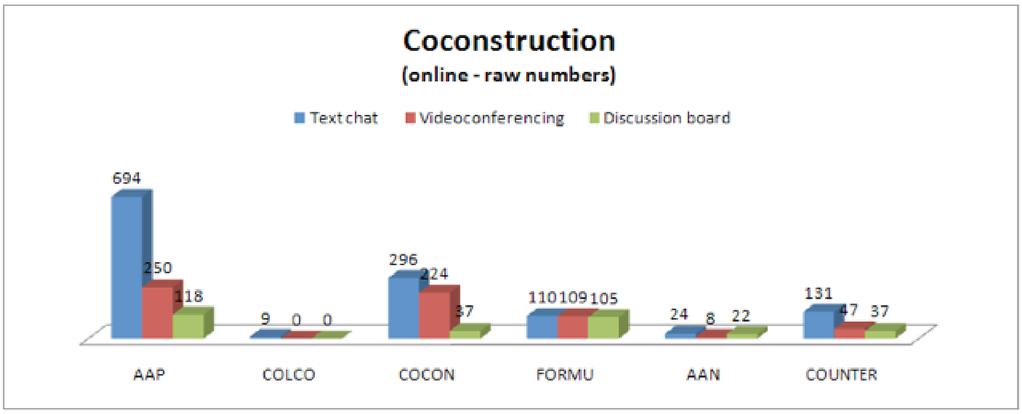

Figure 6.3: Coconstruction resources used per CMC mode

the participant it was addressed to (the SCR tag is followed by (MAM) to identify the participant). Another example can be seen on line 3 when COR says she agrees with MAM: on the [INTERACT] tier, the AAP tag has been used to identify the type of interactional resource used (a Positive Assessment Activity), as well as the (MAM) tag to indicate who the link is made with. Thanks to this specific tagging of interpersonal link from the raw data, which is a way of producing relational data, matrices were drafted.

The matrix shown in Figure 6.5 represents all the links made by the members of Group 1 during the completion of their 6 collaborative tasks. Column A and line 1 show sets of three letters which are used to identify participants, the convention commonly used being to indicate the origin of the link on the line and the destination of the link in the column. Each cell presents the number of connections made between the different participants as coded on the [NOM] and [INTERACT] tiers. For example, line 3 column B shows that JUM made direct interactional contact with HAY 18 times. As connections between participants can be two-way (reciprocal ties) and as the intensity of each tie does matter (number of connections made), the sociograms drafted were both valued and directed. Thanks to these matrices, density and geodesic distance measures were conducted using the UCINet software package and the results are presented in Table 6.2.

In addition, weighted (or valued) directed graphs were produced using UCINet to

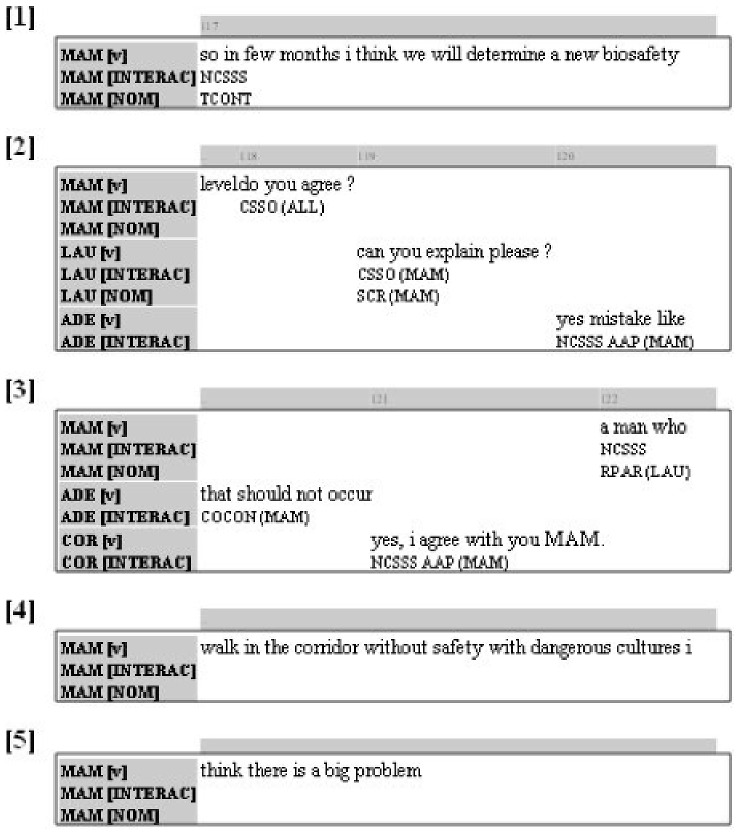

Figure 6.4: Extraction of tagged data

	A	B	C	D	E
1		HAY	JUM	KHE	CEL
2	HAY	0	14	11	44
3	JUM	18	0	15	25
4	KHE	13	10	0	25
5	CEL	47	27	17	0

Figure 6.5: Group 1 Matrix

Table 6.2: Density and average geodesic distance

		Density	Average Geodesic Distance
Text Chat	Group 1	22.1667	1
	Group 2	26.7500	1
	Group 3	36.1667	1
	Group 4	29.9167	1
Videoconferencing	Group 5	7.1667	1
	Group 6	14.5000	1.083
	Group 7	27.9167	1
	Group 9	4.5833	1.250
Discussion Board	Group 14	12.4167	1
	Group 15	9.3333	1.111
	Group 16	3.8333	1.167
	Group 17	2.0833	1.167

show who interacted with whom during the completion of the online tasks (interactional patterns and communication configuration). An additional attribute was added to the graphs: the amount of participation (number of turns) was represented by the nodes themselves (the bigger the diameter of a node, the more the learner participated in the interactions).

6.4 Discussion and Conclusions

In all 3 computer-mediated communication modes (Figures 6.6 to 6.9), SNA has made it possible to identify one (or more) key player(s), the "virtuosos" (Perkins and Newman, 1996) who are "highly skilled practitioner[s] of e-discourse", in other words, a participant who "serves as a guide, gentle teacher and exemplar" (ibid., p. 163).

SNA also showed that text chat interactions are the most symmetrical ones as their characteristics include: (1) balanced participation and strength of ties, (2) reciprocal ties only (geodesic distance = 1), (3) interactional load is high and well distributed (high density).

A the other end of the scale, the sociometric analysis also highlighted the fact that discussion board interactions are the most asymmetrical ones as their characteristics include: (1) unbalanced participation and weak ties, (2) few reciprocal ties (geodesic distance >1), (3) one (or more) peripheral participant(s), the "lurkers" (Perkins and Newman, 1996) who are participants who do not actively take part in the exchanges but simply read/listen to other participants' contributions, (4) interactional load is low and unevenly distributed (low density): there are many "parallel monologues" (House, 2002).

As for Desktop Videoconferencing interactions, SNA showed that they are the most difficult ones to map as half seem fairly symmetrical, and half asymmetrical. It is hypothesized that this may be due to the videoconferencing tool itself: indeed, Flashmeeting - like most desktop videoconferencing applications to date - does not allow for multiple speakers to speak at the same time when using their webcam (audio and video feeds), which means that a queuing system has to be used to be given the floor. This

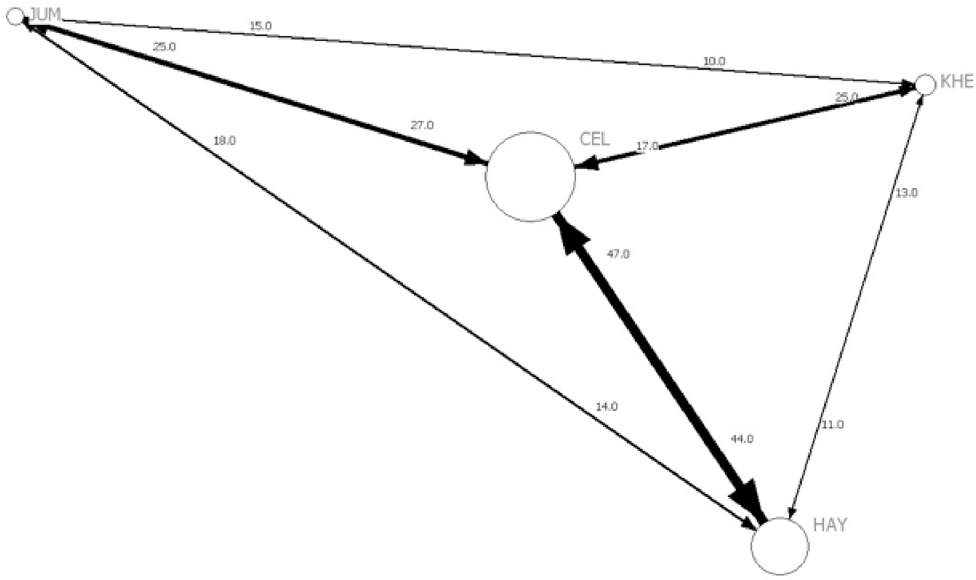

Figure 6.6: Text chat (group 1)

probably explains why certain participants rush and say everything they need to say without really engaging with their interlocutors as they are afraid they might not get to talk again later in the exchange. Whatever the interpretations, this type of qualitative analysis would not have been possible without using a methodology like SNA. As previously mentioned, this sociometric analysis is part of a larger study which includes in-depth quantitative analyses and qualitative micro-analyses based on the tagged interactional resources presented here in order to uncover the interactional patterns at work when participants truly engage in a computer-mediated exchange and display their interactional competence in a second language.

Clearly, there is a growing need today for new ways of analyzing NLCs as social interactions are now central to online learning communities and not "simply scaled-up individuals and ties" (Garton et al., 1997). This is where the SNA approach provides real added value, especially when studying computer-mediated communication, as it (1) is a valuable complementary analytical tool in NLC research, (2) can be an answer to the need for data triangulation, (3) has a role to play in mixed-method research. It seems necessary indeed to study NLCs as complex environments in rich ecological settings both from a quantitative and a qualitative point of view. For all these reasons, SNA is definitely a promising approach in the study of networked learning communities.

Finally, in an ideal world, we could go as far as to imagine that future VLEs will make the most of SNA and start implementing monitoring functionalities which will automatically make relational data available to tutors and researchers as these are often a lot more relevant and interesting than connection time, for example!

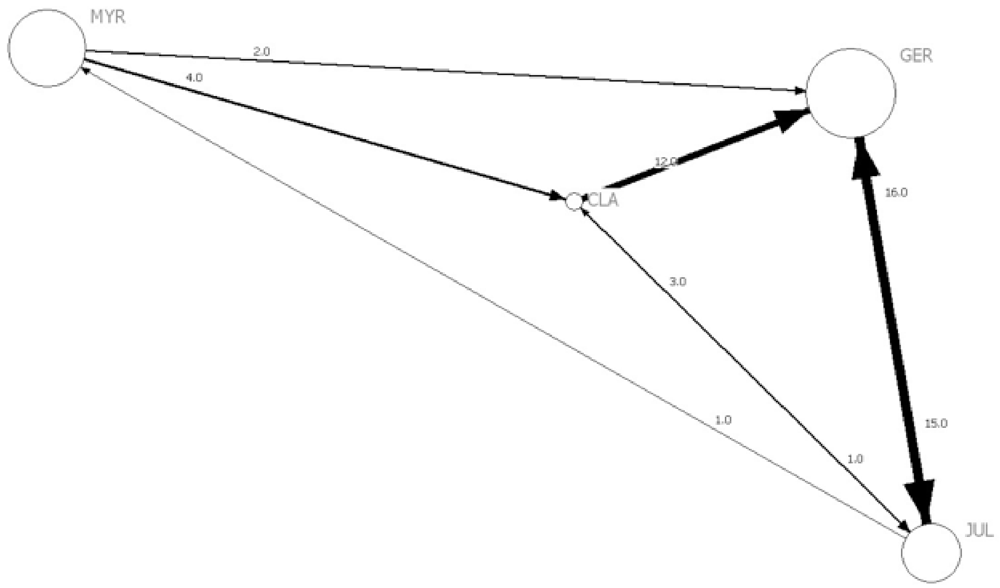

Figure 6.7: Videoconferencing (group 9)

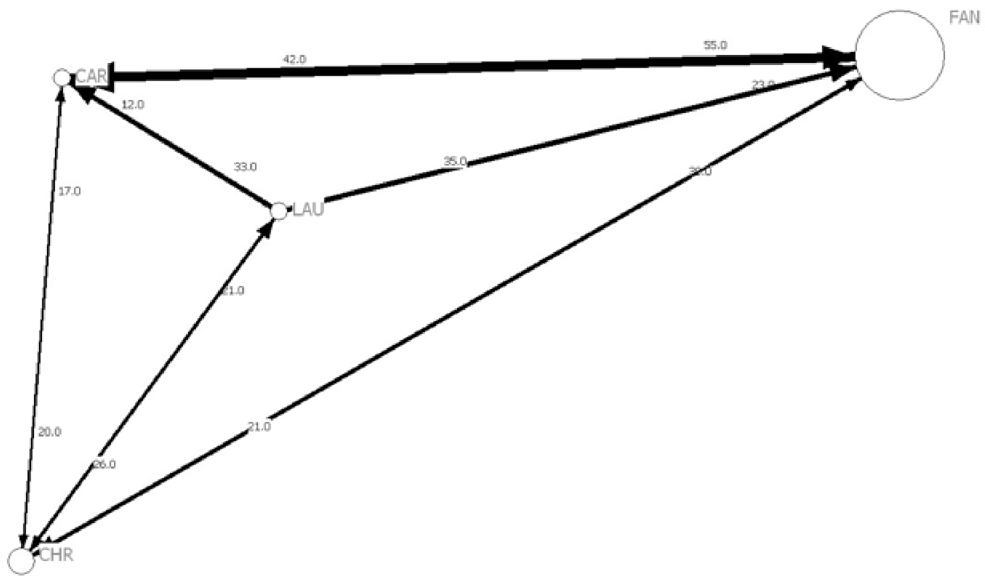

Figure 6.8: Videoconferencing (group 7)

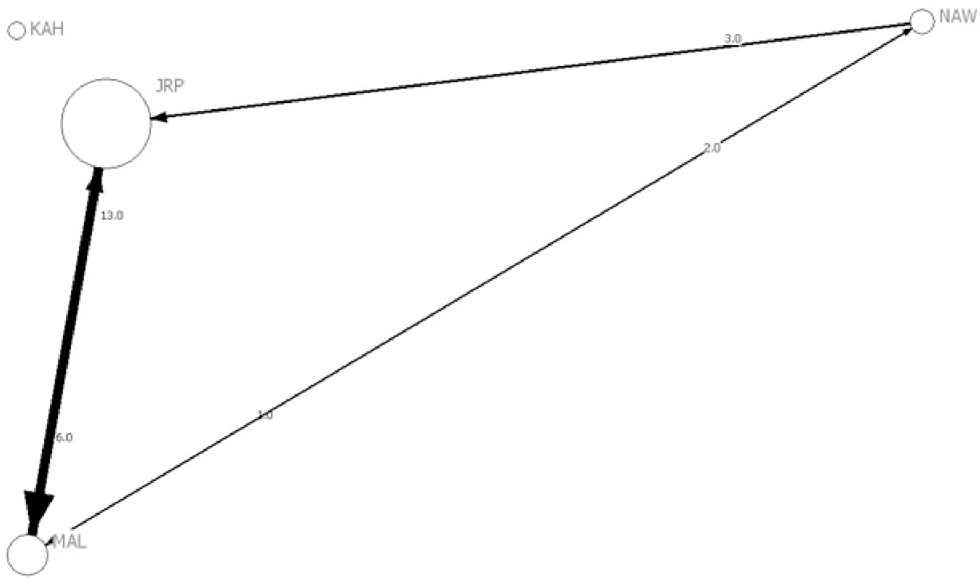

Figure 6.9: Discussion board (group 17)

Bibliography

Barnes J. A., 1954, Class and committee in a Norwegian island parish. *Human Relations*, 7, 39-58.

Batagelj A., A. Mrvar, 2014, Pajek (version 4.01) [computer software]. University of Ljubljana, Slovenia. http://pajek.imfm.si/

Borgatti S.P., M. G. Everett, L. C. Freeman, 1999, UCINet 6.0 (Version 1.00) [computer software]. Natick, Analytic Technologies.

Bott E., 1955, Urban families: conjugal roles and social networks. *Human Relations*, 8, 345-384.

Chanier T., J. Cartier, 2006, Communauté d'apprentissage et communauté de pratique en ligne - Le processus réflexif dans la formation des formateurs. *Revue internationale des technologies en pédagogie universitaire*, 3(3), 64-82.

Cyram Inc., 2014, Netminer 4 (version 4.2.1) [computer software]. Seoul, South Korea: Seoul University Research Park. http://www.netminer.com

D'Andrea A., F. Ferri, P. Grifoni, 2010, An overview of methods for virtual social network analysis. In Abraham, A., Hassanien, A. E., Snasel, V. (Eds.). *Computational social network analysis - Trends, tools and research advances* , 3-25, London, Springer Verlag.

De Laat M., V. Lally, L. Lipponen, R.-J. Simons, 2007, Investigating patterns of interaction in networked learning and computer-supported collaborative learning: a role for social network analysis. *Computer-Supported Collaborative Learning*, 2(1), 87-103.

De Praetere T., 2010, Dokeos (version 1.8.3) [computer software]. Brussels, Dokeos S.A. http://www.dokeos.com

Dekker A., 2005, Conceptual distance in social network analysis. *Journal of Social Structure*, 6(3).

Dillenbourg P., C. Poirier, L. Carles, 2003, Communautés virtuelles d'apprentissage: e-jargon ou nouveau paradigme ? In Taurisson, A., Sentini, A. (Eds.). *Pédagogies.net* , 1-26, Montréal, Presses Universitaires du Québec.

Drazdilova P., G. Obadi, K. Slaninova, 2010, Analysis and visualization of relations in eLearning. In Abraham, A., Hassanien, A. E., Snasel, V. (Eds.). *Computational social network analysis - Trends, tools and research advances*, 291-318, London, Springer Verlag.

European Commission, 2004, DIALANG [computer software]. Lancaster: University of Lancaster. http://www.lancaster.ac.uk/researchenterprise/dialang/about.htm

Garton L., C. Haythornthwaite,B. Wellman, 1997, Studying online social networks. *Journal of Computer Mediated Communication*, 3(1), 0.

Hanneman R., M. Riddle, 2005, *Introduction to social network methods*. University of California, Riverside. http://faculty.ucr.edu/~{}hanneman/nettext/

He A., R. Young, 1998, Language proficiency interviews: a discourse approach. In Young, R. & He, A. (Eds.). *Talking and testing: discourse approaches to the assessment of oral proficiency*,1-24, Amsterdam: John Benjamins.

Holtzer G., 1995, *Autonomie et didactique des langues : le Conseil de l'Europe et les langues étrangères.* Besançon, Presses universitaires de Franche-Comté.

House J., 2002, Developing pragmatic competence in English as a lingua franca. In Knapp, K., Meierkord, C. (Eds.) *Lingua franca communication*, 245-267. Frankfurt, Peter Lang.

Jones C., L. Esnault, 2007, The metaphor of networks in learning: communities, collaboration and practice. In Banks, S., Goodyear, P., Hodgson, V., Jones, C., Lally, V., McConnell, D., Steeples, C. (Eds) *Networked Learning 2004: Proceedings of the Fourth International Conference on Networked Learning 2004* , 317-323, Lancaster: Lancaster University and University of Sheffield.

Knowledge Media Institute, 2010, Flashmeeting [computer software]. Milton Keynes: The Open University. http://flashmeeting.open.ac.uk/home.html

Lewin K., 1936, *Principles of topological psychology*. New York, McGraw Hill.

Mayo E., 1933, *The human problems of an industrial civilisation*. Cambridge, MA, Macmillan.

Mitchell J. C., 1969, The concept and use of social networks. In Mitchell, J. C. (Ed.), *Social networks in urban situations*, Manchester, Manchester University Press.

Moreno J. L., 1933, Psychological organization of groups in the community. *57 th Yearbook of Mental Deficiency*, 3-25

Palonen T., K. Hakkarainen, 2000, Patterns of Interaction in Computer-Supported Learning: A Social Network Analysis. In Fishman B.,O'Connor-Divelbiss S. (Eds.), *Fourth International Conference of the Learning Sciences* , 334-339, Mahwah, NJ: Erlbaum.

PerkinsJ., K. Newman, 1996, Two archetypes in e-discourse : Lurkers and virtuosos. *Journal of Educational Telecommunications*, 2(2), 155-170.

Reffay C., T. Chanier, 2003, How social network analysis can help to measure cohesion in collaborative distance learning. In Wasson, B., Ludvigsen, S., Hoppe, U. (Eds.). *Designing for change in networked learning environments*, 343-352, Dordrecht, Kluwer Academic Publishers.

Rendersoft, 2013, Camstudio (version 2.7.2) [computer software]. Southend-on-Sea, UK. http://camstudio.org

Russo C., J. Koesten, 2005, Prestige, centrality and learning: a social network analysis of an online class. *Communication Education*, 54(3), 254-261.

Sarré C., 2013, Technology-mediated tasks in English for Specific Purposes (ESP): Design, implementation and learner perception. *International Journal of Computer-Assisted Language Learning and Teaching (IJCALLT)*, 3(2), 1-16.

Schmidt T., K. Wörner, T. Lehmberg, H. Hedeland, 2013, EXMARaLDA (Partitur Editor version 1.5.2) [computer software]. Hamburg: University of Hamburg. http://www.exmaralda.org

Scott J., 2000, *Social network analysis: a handbook - Second edition*. Los Angeles, London, New Delhi, Singapore, SAGE Publications.

Skehan,P., 1998, *The cognitive approach to language learning*. Oxford, Oxford University Press.

Chapter 7

Link prediction in large-scale multiplex networks

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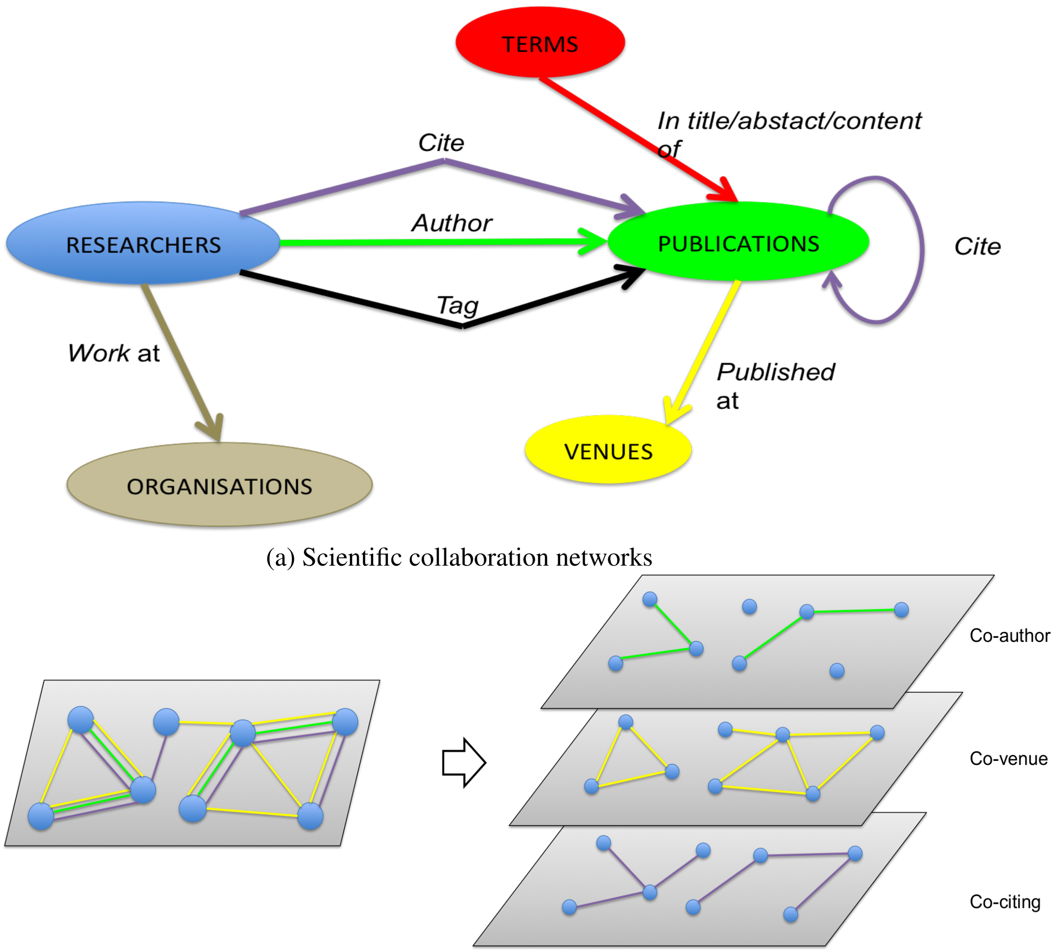
Abstract

Complex networks are highly heterogeneous in nature and can be structured into multiplex layers, each having same nodes but different types of links. Link prediction is one of the important tasks in the analysis of complex networks. It has a wide range of application: recommender systems, protein-protein interactions, identification of criminal links, and prediction of scientific and commercial collaborations to name a few. In this paper we provide a formal definition of link prediction. We give a brief account of various existing link prediction approaches, focusing mainly on dyadic topological approaches. We present two new approaches of link prediction. Both tackle the problem of predicting future collaborations between authors in a co-authorship network. The first approach is based on supervised rank aggregation where we use a rank based model to learn weights for different topological predictors. In this approach we use an existing rank aggregation method and our newly proposed method of weighted rank aggregation, to find the new links. The second approach works in a multiplex scenario, where we propose to use some new attributes to capture multiplex information available in different network layers (each having different type of links within the same nodes), to enhance the performance of prediction of future collaboration between authors. We experiment on DBLP datasets and preliminary results validate our approaches.

keywords: link prediction, multiplex network, complex network analysis, supervised rank aggregation, supervised machine learning.

7.1 Introduction

Complex networks and their characteristics have gained considerable attention of researchers in the field of computational analysis of social networks. Complex network can be any real world network which have an abstract form without any predefined structure or pattern of evolution. At times, they can be highly dynamical in nature, evolving or changing constantly. Also, starting with a tiny form, in this era of big data, they take the form of huge networks. Analyzing these dynamic large-scale networks is a major challenge for social network researchers. These networks are often heterogeneous in nature. That means a real network may have different types of nodes and also different types of links. Multiplex networks are a category of heterogeneous complex networks, which essentially have different kinds of links between same nodes. They can be represented as a set of simple networks, each having the same nodes but different sets of links. A common example of multiplex network is a scientific collaboration networks. Researchers or authors of research papers are an important part of these networks. They can be linked if they have co-published some articles or if they have published their articles in the same conferences or the domain of their research are the same. They can also be linked if they have referred to same works in their articles. Figure 7.1 shows a diagrammatic representation of a scientific collaboration network and multiplex structures present within them. In panel (b) of Figure 7.1, it is shown how a authors network can be represented by multiplex layers, each having same nodes but different types of links or edges.



(a) Scientific collaboration networks

(b) Multiplex layers in author (researchers) network

Figure 7.1: Multiplex structure in a scientific collaboration network

One of the most important problems in the analysis of complex networks, is the problem of *link prediction* (Liben-Nowell & Kleinberg 2003*a*, Lü & Zhou 2011). It consists in estimating the likelihood of existence or appearance of an edge between two unlinked nodes, based on observed links and attributes that contain information about the nodes, edges or the entire graph. It has important applications in many fields including social, biological and information systems etc. Link prediction has been widely used in biological networks like protein interaction network (Airoldi et al.

2006, Eronen & Toivonen 2012), metabolic networks, food web etc. to find missing links and thereby helps in reducing the experimental cost if the predictions are accurate. In social interaction and scientific or commercial collaboration networks they can play an important role to predict new associations (new links) (Liben-Nowell 2005, Al Hasan et al. 2006, Fu et al. 2007). This further has utility in the recommendation task: a service provided by almost all social networks and mainly used in e-commerce networks (Huang et al. 2005). Link prediction can also be helpful in finding hidden criminal links (Fire et al. 2013, Clauset et al. 2008) which is another critical field of research.

There are two basic types of link prediction: *structural* and *temporal*.

- *Structural link prediction* refers to the problem of finding *missing links* which probably exist in a partially observed network or graph (Liben-Nowell & Kleinberg 2007, Taskar et al. 2003, Yin et al. 2011, Menon & Eklan 2011). Structural link prediction have obvious utility for finding missing or hidden information in a network. It has direct application to find unobserved patterns of genes, protein and yeast interactions for the medical studies on various diseases like cancer, HIV, Alzheimer etc. (Airoldi et al. 2006, Eronen & Toivonen 2012). It can also help to find existing criminal links which often remain hidden from the public eyes.

- *Temporal link prediction* refers to the problem of finding *new links* by studying the temporal history of a network (Benchettara et al. 2009, 2010*b*, Berlingerio et al. 2009, Liben-Nowell & Kleinberg 2003*b*, Al Hasan et al. 2006, Huang & Lin 2008). So here we have information about the network till time t and the goal will be to predict a new link that may appear at some point of time in future say $t + k$. It has its application primarily in recommendation systems that are being used widely in e-commerce websites for product recommendations, in any search engines to help users with probably relevant terms they might be searching, for recommendation of tags in social resources sharing websites like Flickr[3], YouTube[4], De.li.ci.ous[5] etc. and very commonly used for recommendation of friends in many social networks like Facebook[6] and Twitter[7]. It has another significant use in predicting future collaborations between researchers for academic or scientific purposes. It also has an important use in order to identify probably upcoming criminal associations.

The problem have been keenly studied by many researchers over a long period of time. Many link prediction approaches has been proposed in recent years. They can be classified as *node-features based approaches* or *topological approaches* based on whether they use node-features or only structural information of the graph for prediction. In node-features based approaches, apart from the structure of graph we also have some extra information regarding the properties or characteristics of nodes. These extra information can be helpful in predicting links when the nodes are very sparsely connected in the graph. One such approach is local probabilistic model proposed by Wang

[3]http://www.flickr.com
[4]http://www.youtube.com
[5]http://www.delicious.com/
[6]http://www.facebook.com
[7]http://www.twitter.com

et al. (2007). Topological approaches refer to those which involve only exploitation of graph structure of the network. They compute scores for pairs of unconnected nodes based on only the graphical features of the network structure and without any extra information about the features of nodes. They observe mainly how the connections have been established between nodes and how they change over time. Based on former they try to predict a missing link or based on the later they predict a new link. Node features are very useful when the network graph is very sparsely connected and not much can be learned from graph topology. Whereas topological approaches are very efficient in the absence of content of features information. Both have their own utility and at times a combination of both can come out to give a very good predictor. This kind of approaches can be termed as *hybrid* approaches.

The topological (graph based) link prediction approaches can be further categorized as *temporal* or *non-temporal / static* based on the fact that whether they take into consideration the dynamic aspect of the network or not. Another way to classify them is as *dyadic* or *structural* approaches, based on the type of score calculation involved. The approaches using link score are dyadic approaches where as those looking for mining rules of evolution of sub-graphs can be considered as structural approaches. They can also be classified as *supervised* or *unsupervised*. Supervised approaches generate a model using many topological scores for unlinked node pairs to predict links where as unsupervised approaches use a single type of score for the node pairs and mostly use ranking to predict new links.

In section 7.3, we give brief account of the traditional methods of solving the problem of link prediction in a complex network, focusing mainly on dyadic topological approaches. In section 7.4 we describe our approach based on supervised rank aggregation. And in section 7.5 we present our new approach of link prediction in multiplex networks using multiplex link information.

7.2 Formal definition and notations

Before going further to describe our methods of link prediction, we would like to give a formal definition of link prediction and the mathematical notations used in the paper. In topology based link prediction approaches, only the structural properties of the underlying graph are used to implement statistical relational learning and to find a model that will be used to predict links. Suppose we have a social network graph $G =< V, E >$ where V is the set of nodes or vertices and E is the set of edges present in the graph. So the goal of link prediction is to find (u, v) pairs such that $u, v \in V$ and $(u, v) \notin E$.

For prediction of new links at a certain point of time t_{n+1} having network information till time t_n, the network will be presented as a sequence of graphs representing different snapshots of the network at different points of time $< t_0, t_1, ..., t_n >$. Suppose the temporal sequence of graphs is $G =< G_0, G_1, ..., G_n >$, so the goal of link prediction here will be to find the structure of graph G_{n+1}. In other words, here we try to find (u, v) pairs such that $u, v \in V$ and $(u, v) \notin E$ where $V = \bigcup_{i=0}^{n} V_i$ and $E = \bigcup_{i=0}^{n} E_i$.

In any network G, $\Gamma(v)$ is the set of neighbours of node v and degree of a node is given by

$$k_i = \begin{cases} |\Gamma(v_i)| & \text{if } G \text{ is simple graph} \\ \sum w_j \; \forall \, x_j \in \Gamma(v_i) & \text{if } G \text{ is weighted graph} \end{cases}$$

In machine learning terms, the unlinked pairs of nodes are called *examples* or *instances*. If the time aspect of the network are to be considered also, then the examples can be generated as follows. Let $G =< G_1, \ldots, G_n >$ be a temporal sequence of an evolving graphs. The whole sequence is divided into two parts: *training* and *testing*. Each part is then again divided into two phases one for generation of examples and another for labeling those examples. Thus, for example, in training we shall have a *learning* and *labeling* phases resulting in graphs namely G_{learn} and G_{label} generated by making union of the temporal sequences of the graphs for three corresponding time slots. The training data is constructed as follows. An example will be a couple of nodes (x, y) that are not linked in G_{learn} but both belonging to the same connected component. The class is obtained by checking whether the couple of nodes is indeed connected in G_{label}. If such a connection exists then it will be a *positive* example in the supervised learning task and if no connection exists, it will be a *negative* example (Benchettara et al. 2010a). Thus, examples are generated from these graphs for both training and testing. These examples are also characterized by a given number of topological attributes computed on learning (or test) graphs. Figure 7.2 and 7.3 illustrate the process diagrammatically.

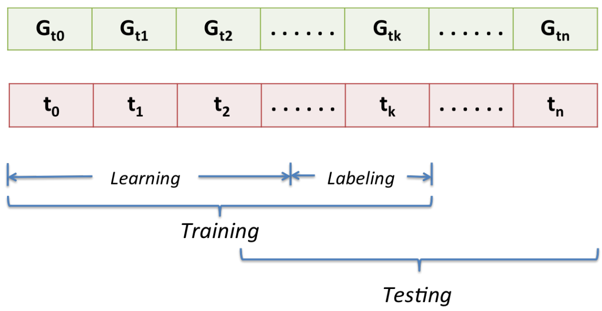


Figure 7.2: Generation of examples

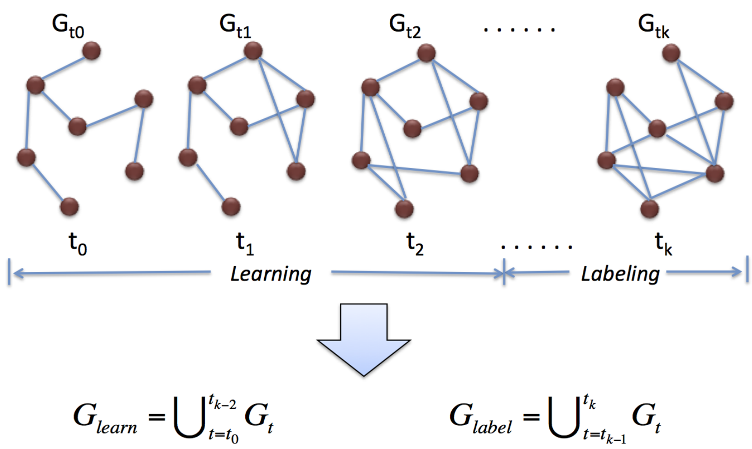


Figure 7.3: Construction of learning and labeling graphs

7.3 Link prediction approaches

The basic and most simple approach for predicting links using network graphs is to compute similarity scores for the unlinked node pairs and based on this score decide the presence or appearance of a link between them. In scientific literature we find many ways of computing this score. They can be *neighborhood-based*, *distance-based* or *an aggregation of node properties*. These approaches are mostly unsupervised. Below we list few of the important methods that have been used for link prediction.

Neighborhood based features

***Common neighbors*:** Common neighbors counts the number of nodes (i.e. neighbors) that are connected to both the nodes under observation. Newman (2004) used this quantity for studying collaboration networks , while Kossinets (2006) used it while analyzing large-scale social networks.

$$CN(x,y) = \mid \Gamma(x) \cap \Gamma(y) \mid$$

***Jaccard coefficient*:** Jaccard coefficient calculates the ratio of number of common neighbors to that of the total number of neighbors of the two nodes (Jaccard 1901).

$$JC(x,y) = \frac{\mid \Gamma(x) \cap \Gamma(y) \mid}{\mid \Gamma(x) \cup \Gamma(y) \mid}$$

***Adamic Adar coefficient*:** This metric proposes to weight the common neighbors based on their connectivity while computing the score. It gives more weight to less connected neighbors increasing their contribution in the score (Liben-Nowell & Kleinberg 2007).

$$AA(x,y) = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{log \mid \Gamma(z) \mid}$$

It is based on the coefficient proposed by Adamic & Adar (2003) to find similarity between two web pages . For two web pages x and y, sharing a set of features z, this coefficient is computed as

$$\sum_{z: feature\ shared\ by\ x\ and\ y} \frac{1}{log(frequency(z))}$$

***Resource allocation*:** This metric is based on resource allocation dynamics on complex networks (Ou et al. 2007). Like Adamic Adar coefficient, this index also depresses the contribution of high-degree common neighbors.

$$RA(x,y) = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{\mid \Gamma(z) \mid}$$

Path based features

Distance based

***Shortest path length*:** Number of edges in the shortest path between x and y in can also serve to predict links. It is also known as the distance between nodes. The more is the distance, the less is the similarity between the nodes and the less is the chance of having an link between them. This metric captures the fact that the path between two nodes in a social network can affect the formation of a link between them following the fact that friend of a friend can be a friend in a social network.

***Katz's index*:** One of the well known scoring index, commonly known as *Katz index*, has been proposed by Katz. (1953). It is based on paths between nodes in a graph. It sums over a collection of paths and is exponentially damped by length to give shorter paths more weights. Mathematically it is defined as,

$$Katz(x,y) = \sum_{l=1}^{\infty} \beta^{\ell} \times \mid path_{x,y}^{(\ell)} \mid$$

where $path_{x,y}^{(\ell)}$ is the set of paths between x and y of length ℓ and β is a positive parameter (i.e. damping factor) which favors shortest paths. The same can be presented using adjacency matrix

$$Katz(x,y) = \beta A_{xy} + \beta^2 (A^2)_{xy} + \beta^3 (A^3)_{xy} + \dots$$

A_{xy} is the adjacency matrix where the values are either 1 or 0 based on whether x and y are directly connected. $(A^2)_{xy}$ is the matrix showing numbers of paths of length 2 between x and$y$ and so on. A very small β leads to a score close to number of common neighbors because long paths contribute very little. So the matrix showing Katz score between all pairs of nodes can be found as

$$K = (I - \beta A)^{-1} - I$$

β must be lower than the reciprocal of the largest eigenvalue of matrix A to ensure the convergence of above given equation (Lü & Zhou 2011).

Random walk based

***Matrix forest index*:** Matrix forest index computes the similarity between two nodes as the ratio of number of spanning rooted forests where the two nodes are in the same tree rooted at one of the nodes, to all the spanning rooted forests of the network. It can be computed as $M = (I - L)^{-1}$, I being the identity matrix and $L = D - A$ is the Laplacian matrix of the network where D is the degree matrix and A is the adjacency matrix (Chebotarev & Shamis 1997). This index was used for collaborative recommendation task in the work of Fouss et al. (2006).

***Hitting time and commute time*:** Hitting time is a random walks based feature that counts the time required by a random walker to go from node x to node y in a graph. It is defined as the expected number of steps required for a random walker to walk from one node to the other. Shorter hitting time may denote the nodes are similar and can have higher chance of linking in future. As this metric is not symmetrical, often for undirected graphs, average commute time is used instead.

If $HT(x, y)$ is the hitting time to reach node y from node x, average commute time is given by

$$CT(x, y) = HT(x, y) + HT(y, x)$$

A negated value of hitting or commute time can be used as a score for predicting links.

Rooted Pagerank: Pagerank denotes the importance of a node x by summing up the importance of all other nodes linked to x. This importance can also be represented by stationary distribution weight of a node. This feature can be altered to find a similarity score between two nodes and is termed as *rooted pagerank* in Liben-Nowell & Kleinberg (2007). The similarity between two nodes x and y is measured as the stationary probability of y in a random walk that returns to x with probability $1 - \alpha$ in each step, moving to a random neighbor with probability α. Rooted pagerank for all node pairs can be computed as follows.

$$RPR = (1 - \alpha)(I - \alpha N)^{-1}$$

where D is the diagonal degree matrix and $N = DA^{-1}$ is adjacency matrix with row sums normalized to 1.

***PropFlow*:** PropFlow captures the probability that a restricted random walk starting from one node x ends at another node y in l or less steps using link weights as the transition probabilities. The restriction is that a walk terminates on reaching y or on revisiting any node including x. The walk selects links based on their weights which produces a score to estimate likelihood of new links. This measure is a more localized measure of propagation and is insensitive to topological noise far from the source node (Lichtenwalter et al. 2010).

Aggregation of node features

***Preferential attachment*:** Preferential attachment combines the degrees of the two concerned nodes and can be used as a score for predicting links. Here the probability of appearance of a new link is directly proportional to the degree of the observed nodes (Barabási & Albert 1999).

$$PA(x, y) =\mid k_x \times k_y \mid$$

For a simple un-directed and un-weighted graph the degree of a node is equal to the number of neighbors i.e. $k_x = \Gamma(x)$.

***Sum of neighbors*:** In the work of Hasan et al. (2006), the authors have used sum of neighbors as a topological feature for characterizing an unlinked node pair. Formally, it can be defined as $\Gamma(x) + \Gamma(y)$

***Aggregation of clustering coefficients*:** As described in chapter. 1, clustering coefficients of a node quantifies the probability of the neighbors of the node to get connected to each other.

$$cf(x) = \frac{3 \times \#Triangles\ adjacent\ to\ x}{\#Possible\ triples\ adjacent\ to\ x}$$

This property can also be used for link prediction by taking an aggregation (sum or product) of the clustering coefficients of two unconnected nodes. So the similarity score for any two nodes x and y will be

$$CC(x, y) = cf(x) \times cf(y) \quad or \quad CC(x, y) = cf(x) + cf(y)$$

In a seminal work proposed in Liben-Nowell & Kleinberg (2003*a*), authors have shown that simple topological measures representing relationships between pairs of unlinked nodes in a complex network, can be used for predicting formation of new links. Let's consider the case of applying *common neighbors* as a topological measure. Let $\mathcal{L}$ by the list of pairs of unlinked nodes (belonging to same connected component). We have $\mathcal{L} = \{(x, y)\}$. Let $\Gamma(x)$ be the function returning a set of direct neighbors of node x in the graph. The common neighbors function of two nodes x, y is then defined by:

$$CN(x, y) = |\Gamma(x) \cap \Gamma(y)| \tag{7.1}$$

The list $\mathcal{L}$ is sorted according to the values obtained by applying the common neighbors function to couples of unlinked nodes. The top k couples of nodes are then returned as the output of the prediction task. The assumption here is that, the more a couple of unlinked nodes share common neighbors, the more they are likely to have a link in future. In Liben-Nowell & Kleinberg (2003*a*) k is equal to the number of really appearing links. Other types of topological measures can be applied for the same purpose.

Many other works have been published focusing on how to combine different topological metrics in order to enhance prediction performances. One widely applied approach is based on expressing the problem of link prediction as a problem of binary classification. The idea is to compute for each unlinked couple of nodes in $\mathcal{L}$, a set of topological measures. Then with each element in $\mathcal{L}$, associate one of the labels: `Linking` (positive) or `Not-linking` (negative) based on the status of the graph at a future step. The dataset hence computed (topological features with classes) can then be used to learn a model, for discriminating the *linking* class from the *not-linking* one using classical supervised machine learning approaches (Hasan et al. 2006, Benchettara et al. 2010*a*).

Another main category is matrix based approaches. In the work presented by Menon & Eklan (2011), the authors use supervised matrix factorization approach for link prediction. The model learns latent features from the structure of a graph. The authors show that combining these latent features with explicit node features and also with outputs of other models to make better prediction. They propose a new approach to deal with class imbalance problem by directly optimizing a ranking loss. The model is optimized with stochastic gradient descent and also scales to large graphs. Another work on temporal link prediction given in Gao et al. (2011) is also a model based on matrix factorization. Authors exploit multiple information sources in the network to predict link occurrence probabilities as a function of time. They propose a unique model combining global network structure, content information of nodes and local proximity information. For combining the temporal information of the network, they use a weighted exponentially decaying model to build an aggregate weighted link matrix over a set of *T* time slices.

Other approaches include Probabilistic models, Stochastic block models, Hierarchical models etc. A more detailed survey on link prediction and approaches can be found in Al Hasan & Zaki (2010) and Lü & Zhou (2011).

7.4 Supervised rank aggregation based link prediction

None of the previous work, attempt to combine the prediction power of individual topological measures by applying computational social choice algorithms (or what is also known as rank aggregation methods Chevaleyre et al. (2007)). *Rank aggregation* can be defined as a process of combining a number of ranked lists or rankings of candidates or elements to get a single list and with least possible disagreement with all the experts or voters who provide these lists. These methods were a part of social choice theory and were mostly applied to political and election related problems (*Mémoire sur les élections au scrutin* 1781, Young & Levenglick 1978, Black et al. 1998). These techniques were designed to ensure fairness among experts while combining their rankings and hence all experts are given equal weights. Expressing the link prediction problem in terms of a vote is straightforward: candidates are examples (pairs of unconnected nodes), while voters are topological measures computed for these pairs of unlinked nodes. Then we have a voting problem with quite huge set of candidates and rather a reduced set of voters. These settings are very similar to those encountered when considering the problem of ranking documents in a meta-search engines where voting schemes has also been applied with success (Dwork et al. 2001*b*, Aslam & Montague 2001, Montague & Aslam 2002).

In our settings, prediction performances can be boosted by weighting differently the applied topological measures in function of their individual performances in predicting new links. We propose here two different weighting schemes. Weights are used in two different weighted rank aggregation methods: The first one is based on the classical Borda count approach (*Mémoire sur les élections au scrutin* 1781), while the second is based on the Kemeny aggregation rule. The later is known to compute the *Condorcet* winner of an election (if it exists): the candidate that wins each duel with all other candidates is the winner.

Before describing the approaches based on *supervised rank aggregation* which refers to the same process of combining rankings but giving different weights to voters and these weights are learned in a due process of training, here is a brief description about two of the well known classical rank aggregation methods.

- **Borda's method** *Mémoire sur les élections au scrutin* (1781) is a truly positional method as it is based on the absolute positioning of the ranked elements rather than their relative rankings. A Borda score is calculated for each element in the lists and based on this score the elements are ranked in the aggregated list. It is primarily applicable to complete lists of ranked elements. Complete ranked lists are lists with exactly same elements but in different orders or ranking. Also, in a list L_k, the rank of an element x is represented by $L_k(x)$. For a set of complete lists $L = [L_1, L_2, L_3, ..., L_n]$, the Borda's score for an element x and a list L_k is given by:

  $$B_{L_i}(x) = \{count(y) | L_i(y) < L_i(x) \& y \in L_i\} \tag{7.2}$$

  The total Borda's score for an element is given as:

  $$B(x) = \sum_{t=1}^{n} B_{L_i}(x) \tag{7.3}$$

  Borda's method is mostly applicable to complete lists and is not very suitable for partial lists where the lists can have some different elements. Borda's method being a absolute position based method, is incapable of correctly treating elements which are not present all the lists taken into consideration. One option is to assign all unranked elements with equal scores as suggested in Sculley (2007). This is a separate topic of research and out of the scope of this paper.

- **Kemeny optimal aggregation** proposed in Dwork et al. (2001*a*), makes use of Kendall Tau distance to find the optimal aggregation. Kendall Tau distance counts the number of pairs of elements that have opposite rankings in the two input lists i.e. it calculates the pairwise disagreements.

$$K(L_1, L_2) = \mid (x, y)\ s.t.\ L_1(x) < L_2(y)\ \&\ L_1(x) > L_2(y) \mid \tag{7.4}$$

The first step is to find a initial aggregation of input lists using any standard method. The second step is to find all possible permutations of the elements in the initial aggregation. For each permutation, a score is computed which is equal to the sum of distances between this permutation and the input lists. The permutation having the lowest score is considered as optimal solution. For example, for a collection of input rankings $\tau_1, \tau_2, \tau_3, ..., \tau_n$ and an aggregation π , the score is given by:

$$SK(\pi, \tau_1, \tau_2, \tau_3, ..., \tau_n) = \sum_{i \in n} K(\pi, \tau_i) \tag{7.5}$$

The speciality of Kemeny optimal aggregation is that it complies with *Condorcet principle* which is not the case with positional methods like Borda's algorithm (Young & Levenglick 1978) . *Condorcet principle* states that if there exists an item that defeats every other item in simple pairwise majority voting then, it should be ranked above all other.

In spite of all advantages Kemeny optimal aggregation is computationally hard to implement. So while looking for an alternative solution that gives similar kind of aggregation but is computationally feasible, we are led to another approach named *Local kemenization* (Dwork et al. 2001*a*). A full list π is locally Kemeny optimal aggregation of partial lists $\tau_1, \tau_2, \tau_3, ..., \tau_n$, if there is no full list π' that can be obtained from π by performing a single transposition of a single pair of adjacent elements and for which

$$SK(\pi', \tau_1, \tau_2, \tau_3, ..., \tau_n) < SK(\pi, \tau_1, \tau_2, \tau_3, ..., \tau_n)$$

In other words, it is impossible to reduce the total distance of an aggregation by flipping any adjacent pair of elements in the aggregation.

Looking into the work based on rank aggregation techniques, we can say that not much have been explored when it comes to application of rank aggregation in link prediction. Moreover these works apply mostly unsupervised rank aggregation algorithms giving equal weight to all the experts who provide the ranked lists. One of the well known work is weighted majority algorithm proposed in Littlestone & Warmuth (1989) where the authors have proposed to use weights for predictors, all having equal weights in the beginning. There is a master predictor which makes the final prediction based on the class which corresponds to a maximum total weights of predictors. If the final prediction is wrong then weights of all predictors who disagreed with that label, is increased by a factor β such that $0 \leq \beta < 1$ and thus reducing the effect of unworthy predictors at each iteration. This approach has a limitation that the performance of the master predictor can be at most equal to the best performing predictor. On the contrary, the use of rank aggregation can provide even better prediction at times. This may be due the fact that, in these algorithms, the *"likes"* of majority of the predictors is given higher preference. At the same time, the *"dislikes"* are given least preference. So these algorithms are much more spam/noise resistant.

A significant work on supervised rank aggregation has been done in Liu et al. (2007) where authors propose supervised aggregation by Markov chain to enhance the ranking result on meta-searches. However, it has been shown that Local Kemenization improves on Markov chain-based approaches (Dwork et al. 2001*a*).

Another very recent work is in Subbian & Melville (2011) where the authors use supervised rank aggregation to find influential nodes and future links. Authors propose their own supervised Kemeny aggregation method based on quick sort and applied it to Twitter and citation networks. However, their method is mostly based on the topological features of nodes. Where as our work is based on the features of a couple of nodes(edges) with a use of merge sort algorithm to find supervised local Kemeny aggregation. The reason why we use merge sort is that it is seemingly more stable than quick sort.

In the next part (subsection 7.4.1), is the description about our work on link prediction using rank aggregation. We contribute in three ways: first we provide a way to generate weights for the topological measures; second, we propose a new way of introducing weights to approximate Kemeny aggregation; and third, we use supervised or weighted rank aggregation to link prediction task in complex networks. Our approach is evaluated in the context of a link prediction task applied to academic co-authorship networks. Experiments are conducted on real networks extracted from the now well known DBLP bibliographical server.

7.4.1 Link prediction by supervised rank aggregation

Each attribute of an example has the capacity to provide some unique information about the data when considered individually. The training examples are ranked based on the attribute values. So, for each attribute we will get a ranked list of all examples. Considering only the top k ranked examples and with an assumption that when we rank the examples according to their attribute values, the positive examples should be ranked on the top, we compute the performance of each attribute. This performance is measured in terms of either *precision* (maximization of identification of positive examples) or *false positive rate* (minimization of identification of negative examples) or a combination of both. Based on the individual performances, a weight is assigned to each attribute.

For validation, we use examples obtained from the validation graph characterized by same attributes and try to rank all examples based on their attribute values. So for n different attributes we shall have n different rankings of the test examples. These ranked lists are then merged using a *supervised rank aggregation* method and the *weights of the attributes* obtained during learning process. The top k ranked examples in the aggregation are taken to be the predicted list of positive examples. Using this predicted list, we calculate the performance of our approach. k in this case is equal to the number of positive examples in the validation graph.

Weights computation

We propose to compute voters (topological measures) weights based on their capability to identify correct elements in top k positions of their rankings. Weights associated to applied topological measures are computed based on the following criteria :

- **Maximization of positive precision:** Based on maximization of identification of positive examples the attribute weight is calculated as

$$w_i = n * Precision_i \tag{7.6}$$

where n is the total number of attributes and $Precision_i$ is the $precision$ of attribute i based on identification of positive examples. Just to remind, precision is defined as the fraction of retrieved instances that are relevant.

- **Minimization of false positive rate:** By minimizing the identification of negative examples we get a weight as below

$$w_i = n * (1 - FPR_i) \tag{7.7}$$

where n is the total number of attributes and FPR_{a_i} is the $false\ positive\ rate$ of attribute a_i based on identification of negative examples examples. False positive rate is defined as the fraction of non-relevant instances that are retrieved as relevant.

Supervised rank aggregation

First let's define some basic functions used later in defining weighted aggregation functions. Let L_i be a ranked list of n candidates (a vote). $L_i(x)$ denotes the rank of element x in the list L_i. The top ranked element has the rank 0. The basic individual Borda score of an element x for a voter i is then given by:

$$B_i(x) = n - L_i(x)$$

Let x and y be two candidates. We define the local preference function as follows :

$$Pref_i(x, y) = \begin{cases} 1 & \text{if } B_i(x) > B_i(y) \\ 0 & \text{if } B_i(x) < B_i(y) \end{cases} \tag{7.8}$$

Introducing weights in Borda aggregation rule is rather straightforward:

Let $(w_1, w_2, \ldots, w_r)$ be the weights for r voters providing r ranked lists on n candidates. The weighted Borda score for a candidate x is then given by:

$$B(x) = \sum_{i=1}^{r} w_i * B_i(x) \tag{7.9}$$

To approximate Kemeny aggregation (Dwork et al. 2001a) we introduce weights into the definition of the non-transitive preference relationships between candidates. This is modified as follows. Let w_T be the sum of all computed weights i.e. $w_T = \sum_{i=1}^{r} w_i$. For each couple of candidates x, y we compute a score function as follows: $score(x, y) = \sum_{i=1}^{r} w_i * Pref_i(x, y)$ The weighted preference relation($\succ_w$) is then defined as follows :

$$x \succ_w y : score(x, y) > \frac{w_T}{2}$$

This new preference relation is used to sort an initial aggregation of candidates in order to obtain a supervised Kemeny aggregation. The initial aggregation can be any of the input lists or an aggregation obtained by applying any other classical aggregation method like Borda. In our algorithm, we have applied merge-sort for the time being.

7.4.2 Experimentation

We evaluated our approach using data obtained from DBLP [8] databases. DBLP is a scientific bibliography website containing a large database of articles mostly related

[8] http://www.dblp.org

to computer science. Our network consists of authors as nodes and they are linked if they have co-published at least one paper during the observed period of time. The data corresponds to year between 1970-1979. We create three datasets out of that. Following the procedure described previously, we generate examples for each dataset. Table 7.1 provides information about the training or test graphs while Table 7.2 summarizes information about the examples generated.

Years	**Properties**	**Co-Author**
1970-1973	*Nodes*	91
	Edges	116
	Density	0.028327
1972-1975	*Nodes*	221
	Edges	319
	Density	0.013122
1974-1977	*Nodes*	323
	Edges	451
	Density	0.008673

Table 7.1: Graphs

Years		**# Positive**	**# Negatives**
Train/Test	**Labeling**		
1970-1973	1974-1975	16	1810
1972-1975	1976-1977	49	12141
1974-1977	1978-1979	93	26223

Table 7.2: Examples from co-authorship graph

We applied our approach to the complete datasets. For rank aggregation, we have used supervised Borda and supervised Kemeny methods. We compare our approach with link prediction approaches using basic machine learning algorithms like Decision tree, Naive bayes and k-Nearest neighbors algorithm. We name our approaches as Supervised Borda 1 and Supervised Borda 2 based on how the attribute weights are computed. 1 represents weights computed based on maximization of positive precision and 2 represents weights being computed based on minimization of false positive rates. We will follow the same convention to represent supervised Kemeny. We selected the following topological attributes: Number of common neighbors (CN), Jaccard coefficient (JC), Preferential attachment (PA) (Huang et al. 2005), Adamic Adar coefficient (AA) (Adamic et al. 2003), Resource allocation (RA) (Zhou et al. 2009) and Shortest path length (SPL).

Table 7.3 summarizes the results obtained in terms of F1-measure. F1-measure is the harmonic mean of *precision* and *recall*. *Recall* is the proportion of correctly predicted links out of total number of actual new links and *precision* is proportion of correctly predicted links out of total number predictions made. Formally it is given by

$$F = \frac{2 * Precision * Recall}{Precision + Recall} \tag{7.10}$$

While K-nearest neighbors and our method based on Borda and supervised Borda failed to provide any substantial results (due to which we have not listed them in the

	Learning:1970-1973 Test:1972-1975	Learning:1972-1975 Test:1974-1977
Decision tree	0.0357	0.0168
Naive Bayes	0.1032	0.0070
Kemeny	0.2449	0.0860
Supervised Kemeny 1	0.4286	0.2581
Supervised Kemeny 2	0.4286	0.2258

Table 7.3: Results in terms of f1-measure

table), our approximate Kemeny and supervised Kemeny based methods outperform the decision tree and naive bayes algorithms for both datasets. This shows the validity of our approach.

Although it is still early to say that rank aggregation based methods are better performing than the other approaches of link prediction, the preliminary results do show that rank aggregation especially with Kemeny method indeed adds some new information which may enhance the result of prediction task. This is quite encouraging for us to continue this work further. Still, the fact remains that rank aggregation methods especially Kemeny method has a high computational complexity which questions its applicability for link prediction in large scale networks. To cope with this we will be working on application of top-k rank aggregation. Much work needs to be done in this regards.

7.5 Link prediction using multiplex links

All these work that we see till now, address the link prediction in only simple networks having homogeneous links. In this section we explain how prediction of links can be done in a multiplex scenario and how prediction performances can be enhanced using multiplex information.

To our knowledge, not much have been explored in this aspect. Although there are a few recent work proposing methods for prediction of links in heterogeneous networks (networks which have different types of nodes as well as edges (Yizhou Sun et al. 2011), there have also been few work on extending simple structural features like degree, path etc. to the context of multiplex networks (Battiston et al. 2013, Berlingerio et al. 2011), but none have attempted to use them for link prediction. We propose a new approach for exploring the multiplex relations to predict future collaboration (co-authorship links) among authors. The applied approach is supervised machine learning based, where we attempt to learn a model for link formation based on a set of topological attributes describing both positive and negative examples. While such an approach has been successfully applied in the context on simple networks, different options can be used to extend it to the multiplex network context. One option is to compute topological attributes in each layer of the multiplex. Another one is to compute directly new multiplex-based attributes quantifying the multiplex nature of dyads (potential links). Both approaches will be discussed in the next section.

7.5.1 Our approach

Our approach includes computing simple topological scores for unconnected node pairs in a graph. Then we extend these attributes to include information from other dimension graphs. This can be done in three ways: First we compute the simple topological measures in all dimensions; second is to take the average of the scores; and third we propose an entropy based version of each topological measures which gives importance to the presence of a non-zero score of the node pair in each dimension. In the end all these attributes can be combined in various ways to form different sets of vectors of attribute values characterizing each example or unconnected node pair. Formally, we have a multiplex graph $G =< V, E_1, \ldots, E_m >$, which in fact is a set of graphs $< G_1, G_2, \ldots, G_m >$ and we want to compute a topological attribute X on it. For any two unconnected nodes u and v in graph G_i (where we want to make a prediction), attribute $X(u, v)$ computed on G_i will be *direct* attribute and the same computed on all other dimension graphs will be *indirect* attributes. The second category computes an average of the attribute over all the dimension i.e. $X_{average} = \frac{\sum_{\alpha=1}^{m} X(u,v)^{[\alpha]}}{m}$ for $u, v \in V$ and $(u, v) \notin E_i$. where m is the number of types of relations in the graph (dimension or layer). In the third category we propose a new attribute called *product of node degree entropy (PNE)* which is based on *degree entropy*, a multiplex property proposed by Battiston et al. (2013). If degree of node u is $k(u)$, the degree entropy is given by: $E(u) = -\sum_{\alpha=1}^{m} \frac{k(u)^{[\alpha]}}{k_{total}} \log(\frac{k(u)^{[\alpha]}}{k_{total}})$ where $k_{total} = \sum_{\alpha=1}^{m} k(u)^{[\alpha]}$ and we define *product of node degree entropy* as

$$PNE(u, v) = E(u) * E(v)$$

We also extend the same concept to define entropy of a simple topological attribute, say X_{ent}

$$X_{ent}(u, v) = -\sum_{\alpha=1}^{m} \frac{X(u, v)^{[\alpha]}}{X_{total}} \log(\frac{X(u, v)^{[\alpha]}}{X_{total}})$$

where $X_{total} = \sum_{\alpha=1}^{m} X(u, v)^{[\alpha]}$. The entropy based attributes are more suitable to capture the distribution of the attribute value over all dimensions. A higher value indicates uniform distribution attribute value across the multiplex layers. We address average and entropy based attributes as *multiplex attributes*.

7.5.2 Experiments

We evaluated our approach using data obtained from DBLP[9] databases of which we created three datasets, each corresponding to a different period of time. Table 7.4 summarizes the information about the graphs of each dataset. Each graph has four years for learning or training and next two years are used to label the examples generated from the learning graphs. Examples are unconnected node pairs and they are labeled as *positive* or *negative* based on whether they are connected during the labeling period or not. Table 7.5 shows the number of examples obtained for each dataset.

We use the same attributes that were used in the previous section for supervised rank aggregation based approach i.e. Number of common neighbors (CN), Jaccard coefficient (JC), Preferential attachment (PA) (Huang et al. 2005), Adamic Adar coefficient (AA) (Adamic et al. 2003), Resource allocation (RA) (Zhou et al. 2009) and Shortest path length (SPL). For any attribute XX

[9]http://www.dblp.org

Years	Properties	Co-Author	Co-Venue	Co-Citation
1970-1973	*Nodes*	91	91	91
	Edges	116	1256	171
1972-1975	*Nodes*	221	221	221
	Edges	319	5098	706
1974-1977	*Nodes*	323	323	323
	Edges	451	9831	993

Table 7.4: Graphs

Years		# Positive	# Negatives
Train/Test	Labeling		
1970-1973	1974-1975	16	1810
1972-1975	1976-1977	49	12141
1974-1977	1978-1979	93	26223

Table 7.5: Examples from co-authorship graph

- XX_{aut} : Value of attribute was computed on co-authorship graph during learning period
- XX_{ven} : Value of attribute was computed on co-venue graph
- XX_{cit} : Value of attribute was computed on co-citation graph
- $AvgXX$: Average of the attribute value over the different relation graphs in our case $m = 3$ as we are using co-authorship, co-venue and co-citation graphs.
- PNE : Product of node degree entropy. If degree of node i is $k(i)$, the entropy for node i is calculated as

  $$E_i = -\sum_{\alpha=1}^{m} \frac{k(i)^{[\alpha]}}{k_{total}} \log(\frac{k(i)^{[\alpha]}}{k_{total}})$$

  where $k_{total} = \sum_{\alpha=1}^{m} k(i)^{[\alpha]}$ and

  $$PNE(i,j) = E_i * E_j$$

- $XXent$: Entropy value of the corresponding attribute (based on the entropy equation proposed for node degree in the work of Battiston et al. (2013))

  $$XXent(i,j) = -\sum_{\alpha=1}^{m} \frac{XX(i,j)^{[\alpha]}}{XX_{total}} \log(\frac{XX(i,j)^{[\alpha]}}{XX_{total}})$$

We apply decision tree algorithm on one dataset to generate a model and then tested it on another dataset. We are using data mining tool Orange[10] for that. We use four types of combinations of the attributes creating five different sets namely: Set_{direct} (attributes computed only in the co-authorship graph); $Set_{direct+indirect}$ (attributes

[10]http://orange.biolab.si

computed in co-authorship, co-venue and co-citation graphs); $Set_{direct+multiplex}$ (attributes computed from co-authorship graph with average attributes obtained from three dimension graphs, and also entropy based attributes); Set_{all} (attributes computed in co-authorship, co-venue and co-citation graphs, with average of the attributes, and also entropy based attributes); and
$Set_{multiplex}$ (average attributes and entropy based attributes). Table 7.6 shows the result obtained in terms of F1-measure and area under the ROC curve (AUC). We can see that there is improvement in the F1-measure when we use multiplex attributes. AUC is better for all the sets that include multiplex and indirect attributes for both datasets.

Attributes	**Learning:1970-1973 Test:1972-1975**		**Learning:1972-1975 Test:1974-1977**	
	F1-measure	**AUC**	**F1-measure**	**AUC**
Set_{direct}	0.0357	0.5263	0.0168	0.4955
$Set_{direct+indirect}$	0.0256	0.5372	0.0150	0.5132
$Set_{direct+multiplex}$	0.0592	0.5374	0.0122	0.5108
Set_{all}	0.0153	0.5361	0.0171	0.5555
$Set_{multiplex}$	0.0374	0.5181	0.0185	0.5485

Table 7.6: Results of decision tree algorithm

The results clearly show that inclusion of different types of links surely affects the prediction of new links in a better way. Though marginal, the enhanced results in preliminary experiments do seem to validate our approach and encourage further experimentations.

7.6 Conclusions

In this paper we present the problem of link prediction in complex networks and multiplex networks. We present here a brief state of art of various link prediction approaches focusing mainly on dyadic topological approaches. The unsupervised methods involve computation of scores for unlinked pairs of nodes. While neighborhood based scores are easy to compute, some path based measures like Katz, commute time, rooted pagerank can be really time consuming. Same is the case of other matrix based approaches which have issues of computation time and memory when applied on real large scale networks. This makes them difficult to be employed for evolving real networks. So some approximate solutions for these measures such as truncated Katz and more can be a good choice.

In supervised approaches, especially machine learning based methods attempt is made to combine the effect of various topological attributes to generate a model which is then used to predict links on a test graph. Same is done in our proposed approach based on supervised rank aggregation. While machine learning methods have been in use since a long time and have given reliable performances in various contexts, supervised rank aggregation method is quite new and requires much work to establish its applicability in real applications. Also the fact remains that as they involve use of aggregation methods like approximate Kemeny aggregation, they have a computational complexity of $O(rn\log(n))$ where r is the number of attributes used and n is the number of examples in each input ranked list provided. But the preliminary results we get on the DBLP datasets validate the approach and encourage us to explore the method further.

A major challenge faced while using these types of supervised approaches, is the well known *extreme class skewness or class imbalance problem*. The number of actual new links is very small as compared to the number of possible links. As we can see, in the DBLP datasets we have used, the ratios of positive vs negatives links are 1:113, 1:248 and 1:282 in the three datasets respectively. Also note that this imbalance increases with the size of graphs used for experimentation. This makes it more difficult for an algorithm to generate a good model and give a good inference on the test data. Although very few of the negative examples have actual predictor value as positive examples, the model ends up giving a large number of raw false positives. Also in presence of large class skew, the information carried by the positive examples gets diluted in the vast negative class. Moreover unlike classical machine learning context, in link prediction, correct classification of positive examples are more important. Most common solution to this problem, as suggested by the existing research, is sampling of negative examples. This can be done by random methods or by using some filters by distance, node degree etc. Another way on which we are working is to use a filter based on community detection algorithm. The assumption here is that, two nodes that do not belong to the same community, tend to remain unlinked for a longer period than compared to those belonging to the same community. Thus they can have more meaning as negative examples during the learning of model. Each method has its own advantages and disadvantages, but some some can be fairer than others. The sampling of data is mostly done on the learning data. Sometimes it is required to sample test data like the case when extremely large number of test examples causes unreasonable demands on processing resources and storage. If for any reason this has to be done, proper care should be taken based on the context where link prediction is to be done. More details about class imbalance problem can be found in Al Hasan & Zaki (2010), Lichtnwalter & Chawla (2012). In Lichtnwalter & Chawla (2012), there is a detailed description about how the predictor performance changes with sampling of test data. They also provide valuable information about which performance measure is to be used for evaluating different link prediction techniques.

Last but not the least, we have presented in the end of this paper, how to extend the traditional supervised machine learning based link prediction approach to predict links in multiplex networks. We propose new attributes that capture multiplex information. By applying them for the prediction of co-authorship links, we show that the use of multiplex attributes improves the prediction result. The same method can be used to predict links in any of the multiplex layers. With the preliminary results, we are really excited and hopeful that the multiplex information can prove to be very useful for different tasks in the analysis of the network.

Bibliography

Adamic, L. A., Buyukkokten, O. & Adar, E. (2003), 'A social network caught in the Web', *First Monday* **8**(6).

Adamic, L. & Adar, E. (2003), 'Friends and neighbors on the Web', *Social Networks* **25**(3), 211–230.

Airoldi, E. M., Blei, D. M., Fienberg, S. E., Xing, E. P. & Jaakkola, T. (2006), Mixed membership stochastic block models for relational data with application to protein-protein interactions, *in* 'In Proceedings of the International Biometrics Society Annual Meeting'.

Al Hasan, M., Chaoji, V., Salem, S. & Zaki, M. (2006), Link prediction using supervised learning, *in* 'SIAM Workshop on Link Analysis, Counterterrorism and Security with SIAM Data Mining Conference', Bethesda, MD.

Al Hasan, M. & Zaki, M. J. (2010), A survey of link prediction in social networks, *in* C. C. Aggarwal, ed., 'Social network Data Analysis', Springer, chapter 9, pp. 243–275.

Aslam, J. A. & Montague, M. (2001), Models for metasearch, *in* 'Proceedings of the 24th annual international ACM SIGIR conference on Research and development in information retrieval', SIGIR '01, ACM, New York, NY, USA, pp. 276–284.
URL: *http://doi.acm.org/10.1145/383952.384007*

Barabási, A.-L. & Albert, R. (1999), 'Emergence of scaling in random networks', *Science* **286**(5439), 509–512.

Battiston, F., Nicosia, V. & Latora, V. (2013), 'Metrics for the analysis of multiplex networks'.
URL: *http://arxiv.org/abs/1308.3182*

Benchettara, N., Kanawati, R. & Rouveirol, C. (2009), Calcul de recommandation par prédiction de liens dans un graphe biparti, *in* 'Actes de l'ateiler sur l'apprentissage et graphes pour les systèmes complexes (plate-forme AFIA 2009)', Hammemt, Tunisie.

Benchettara, N., Kanawati, R. & Rouveirol, C. (2010*a*), Apprentissage supervisé pour la prédiction de nouveaux liens dans des réseaux sociaux bipartie, *in* 'Actes da la 17iéme Rencontre de la société francophone de classification (SFC'2010)', St. Denis, La réunion, pp. 63–66.

Benchettara, N., Kanawati, R. & Rouveirol, C. (2010*b*), Supervised machine learning applied to link prediction in bipartite social networks, *in* 'International Conference on Advances in Social Network Analysis and Mining, ASONAM 2010'.

Berlingerio, M., Bonchi, F., Bringmann, B. & Gionis, A. (2009), Mining Graph Evolution Rules, *in* W. L. Buntine, M. Grobelnik, D. Mladenic & J. Shawe-Taylor, eds, 'ECML/PKDD (1)', Vol. 5781 of *Lecture Notes in Computer Science*, Springer, pp. 115–130.

Berlingerio, M., Coscia, M., Giannotti, F., Monreale, A. & Pedreschi, D. (2011), Foundations of Multidimensional Network Analysis, *in* 'Advances in Social Networks Analysis and Mining (ASONAM), 2011 International Conference on', IEEE, pp. 485–489.
URL: *http://dx.doi.org/10.1109/asonam.2011.103*

Black, D., Newing, R., McLean, I., McMillan, A. & Monroe, B. (1998), *The Theory of Committees and Elections by Duncan Black, and Revised Second Editions Committee Decisions with Complementary Valuation by Duncan Black*, 2nd edn, Kluwer Academic Publishing.

Chebotarev, P. & Shamis, E. (1997), 'The matrix-Forest Theorem and measuring Relations in small Social Groups', *Automation and Remote Control* **58**(9), 1505–1514.

Chevaleyre, Y., Endriss, U., Lang, J. & Maudet, N. (2007), 'A short introduction to computational social choice', *SOFSEM 2007: Theory and Practice of Computer Science* pp. 51–69.
URL: *http://www.springerlink.com/index/768446470RPLJ120.pdf*

Clauset, A., Moore, C. & Newman, M. E. J. (2008), 'Hierarchical structure and the prediction of missing links in networks', *Nature* **453**(7191), 98–101.

Dwork, C., Kumar, R., Naor, M. & Sivakumar, D. (2001*a*), Rank aggregation methods for web, *in* 'Proceedings of the 10th international conference on World Wide Web', WWW '01, ACM, Hong Kong, pp. 613–622.
URL: *http://doi.acm.org/10.1145/371920.372165*

Dwork, C., Kumar, R., Naor, M. & Sivakumar, D. (2001*b*), Rank aggregation, spam resistance, and social choice, *in* 'WWW '01: Proceedings of 10th international conference on World Wide Web', pp. 613–622.

Eronen, L. & Toivonen, H. (2012), 'Biomine: predicting links between biological entities using network models of heterogeneous databases', *BMC bioinformatics* **13**(1), 119.

Fire, M., Puzis, R. & Elovici, Y. (2013), Link prediction in highly fractional data sets, *in* 'Handbook of Computational Approaches to Counterterrorism', Springer New York, pp. 283–300.

Fouss, F., Yen, L., Pirotte, A. & Saerens, M. (2006), An Experimental Investigation of Graph Kernels on a Collaborative Recommendation Task, *in* 'Sixth International Conference on Data Mining (ICDM'06)', IEEE, pp. 863–868.
URL: *http://dx.doi.org/10.1109/icdm.2006.18*

Fu, Y., Xiang, R., Liu, Y., Zhang, M. & Ma, S. (2007), Finding Experts Using Social Network Analysis, *in* 'Web Intelligence', IEEE Computer Society, pp. 77–80.

Gao, S., Denoyer, L. & Gallinari, P. (2011), Temporal link prediction by integrating content and structure information, *in* 'Proceedings of the 20th ACM international conference on Information and knowledge management - CIKM '11', ACM Press, New York, New York, USA, p. 1169.
URL: *http://dblp.uni-trier.de/db/conf/cikm/cikm2011.html#GaoDG11*

Hasan, M. A., Chaoji, V., Salem, S. & Zaki, M. (2006), Link prediction using supervised learning, *in* 'In Proc. of SDM 06 workshop on Link Analysis, Counterterrorism and Security'.

Huang, Z., Li, X. & Chen, H. (2005), Link prediction approach to collaborative filtering, *in* M. Marlino, T. Sumner & F. M. S. III, eds, 'JCDL', ACM, pp. 141–142.

Huang, Z. & Lin, D. K. J. (2008), 'The Time-Series Link Prediction Problem with Applications in Communication Surveillance', *INFORMS JOURNAL ON COMPUTING* **published**.

Jaccard, P. (1901), 'Étude comparative de la distribution florale dans une portion des alpes et des jura.', *Bulletin de la Société Vaudoise des Sciences Naturelles* **37**, 547–579.

Katz., L. (1953), 'A new status index derived from socimetric analysis.', *Psychmetrika, 18(1)* **18**(1), 39–43.

Kossinets, G. (2006), 'Effects of missing data in social networks', *Social Networks* **28**(3), 247–268.

Liben-Nowell, D. (2005), An Algorithmic Approach to Social networks, PhD thesis, M.I.T.

Liben-Nowell, D. & Kleinberg, J. (2003*a*), The link prediction problem for social networks, *in* 'Proceedings of the twelfth international conference on Information and knowledge management', CIKM '03, ACM, New York, NY, USA, pp. 556–559.
URL: *http://doi.acm.org/10.1145/956863.956972*

Liben-Nowell, D. & Kleinberg, J. M. (2003*b*), The link prediction problem for social networks, *in* 'CIKM', ACM, pp. 556–559.

Liben-Nowell, D. & Kleinberg, J. M. (2007), 'The link-prediction problem for social networks', *JASIST* **58**(7), 1019–1031.

Lichtenwalter, R. N., Lussier, J. T. & Chawla, N. V. (2010), New perspectives and methods in link prediction, *in* 'Proceedings of the 16th ACM SIGKDD international conference on Knowledge discovery and data mining - KDD '10', ACM Press, New York, New York, USA, p. 243.
URL: *http://dblp.uni-trier.de/db/conf/kdd/kdd2010.html#LichtenwalterLC10*

Lichtnwalter, R. & Chawla, N. (2012), Link prediction: Fair and effective evaluation, *in* 'Advances in Social Networks Analysis and Mining (ASONAM), 2012 IEEE/ACM International Conference on', pp. 376–383.

Littlestone, N. & Warmuth, M. K. (1989), 'Weighted majority algorithm', *IEEE Symposium on Foundations of Computer Science* .

Liu, Y.-T., Liu, T.-Y., Qin, T., Ma, Z.-M. & Li, H. (2007), Supervised rank aggregation, *in* 'Proceedings of the 16th international conference on World Wide Web', WWW '07, ACM, New York, NY, USA, pp. 481–490.
URL: *http://doi.acm.org/10.1145/1242572.1242638*

Lü, L. & Zhou, T. (2011), 'Link prediction in complex networks: A survey', *Physica A: Statistical Mechanics and its Applications* **390**(6), 1150–1170.
URL: *http://dx.doi.org/10.1016/j.physa.2010.11.027*

Mémoire sur les élections au scrutin (1781).

Menon, A. K. & Eklan, C. (2011), Link prediction via matrix factorization, *in* D. Gunopulos, T. Hofmann, D. Malerba & M. Vazirgiannis, eds, 'Machine Learning and Knowledge Discovery in Databases', Vol. 6912 of *Lecture Notes in Computer Science*, Springer Berlin Heidelberg, pp. 437–452.

Montague, M. & Aslam, J. A. (2002), Condorcet fusion for improved retrieval, *in* 'Proceedings of the eleventh international conference on Information and knowledge management', CIKM '02, ACM, New York, NY, USA, pp. 538–548.
URL: *http://doi.acm.org/10.1145/584792.584881*

Newman, M. E. J. (2004), 'Coauthorship networks and patterns of scientific collaboration', *Proceedings of the National Academy of Science of the United States (PNAS)* **101**, 5200–5205.

Ou, Q., Jin, Y. D., Zhou, T., Wang, B. H. & Yin, B. Q. (2007), 'Power-law strength-degree correlation from resource-allocation dynamics on weighted networks', *Phys. Rev. E* **75**, 021102.
URL: *http://dx.doi.org/10.1103/PhysRevE.75.021102*

Sculley, D. (2007), Rank aggregation for similar items, *in* 'Proceedings of the Seventh SIAM International Conference on Data Mining (SDM)'.

Subbian, K. & Melville, P. (2011), Supervised rank aggregation for predicting influence in networks, *in* 'In the proceedings of the IEEE Conference on Social Computing (SocialCom-2011).', Boston.

Taskar, B., Wong, M. F., Abbeel, P. & Koller, D. (2003), Link Prediction in Relational Data, *in* S. Thrun, L. K. Saul & B. Schölkopf, eds, 'NIPS', MIT Press.

Wang, C., Satuluri, V. & Parthasarathy, S. (2007), Local Probabilistic Models for Link Prediction, *in* Y. Shi & C. W. Clifton, eds, 'IEEE International Conference on Data Mining (ICDM)', IEEE.

Yin, D., Hong, L. & Davison, B. D. (2011), Structural link analysis and prediction in microblogs, *in* 'Proceedings of the 20th ACM international conference on Information and knowledge management - CIKM '11', ACM Press, New York, New York, USA, p. 1163.
URL: *http://dblp.uni-trier.de/db/conf/cikm/cikm2011.html#YinHD11*

Yizhou Sun, Rick Barber, Manish Gupta, Charu C. Aggarwa & Jiawei Han (2011), Co-Author Relationship Prediction in Heterogeneous Bibliographic Networks, *in* 'Advances on social network Analysis and mining (ASONAM)', Kaohsiung, Taiwan.

Young, H. & Levenglick, A. (1978), 'A consistent extension of condorcet's election principle', *SIAM Journal on Applied Mathematics* **35**(2).

Zhou, T., Lu, L. & Zhang, Y.-C. (2009), 'Predicting missing links via local information'.

Chapter 8

The social functions of gossip and the Leviathan model

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Abstract

We study the impact of gossip through the dynamic model called Leviathan. It considers agents gossiping and having an opinion of each other (Deffuant et al., 2013). They form their opinions in face-to-face meetings. They act in self-defence applying vanity, influence each other, and gossip about their peers. A highly valued speaker for a listener is more influential. The vanity impact depends on the distance between one's opinion of oneself and the opinion conveyed by the speaker. Listeners felt held in low esteem sanction their speakers by decreasing their opinion of them. Those felt held in high esteem reward them. Various social phenomena emerge, in particular consensuses and positivity bias (i.e. a population of a majority of people judging themselves better than the average). Our study pointed out that the consensus is almost never reached without gossip. We also show how an asymmetrical level of openness to the influence of others depending on how high they are held in esteem is important for the positivity bias and the bias to negativity, while the number of discussed peer during a meeting is essential for consensus. These results are discussed in regards of the debates in social psychology. They are possible and alternative explanations for social phenomena, confirming for example the bonding property of gossip.

8.1 Introduction

In everyday conversation, 70% of our time is spent gossiping (Emler; 1990, Foster; 2004, Wert and Salovey; 2004)! Our peers are our preferred subject of discussion whenever we meet each other. This choice is so natural and generic to human societies that it is an issue of great interest for social scientists. Indeed social scientists commonly wonder about the purpose and the impact of such a frequent activity. A body of literature has proposed many theories explaining why we gossip in terms of socials functions (Foster, 2004; Conein, 2011; Beersma and Van Kleef ,2012) but the question remains open to debate.

To participate to the debate, we studied the Leviathan model. It considers agents gossiping and having an opinion of each other (Deffuant et al. 2013). The question of the social impact of the gossip is then relevant for this model and our conclusions can feed the debate in social psychology even if they are only really shown significant for the model.

The Leviathan model has been recently proposed. It brings a new and unique insight into the relation between agent respective evaluations and group structure. What is the essence of this model? It is a theory explaining how people structure themselves from the agent need to form an opinion of the others, including themselves. It considers agent interactions through meeting in pairs. Motivated by the need to be held in high esteem (Hobbes, 1651), agents act in self-defence, applying a process called vanity. They protect themselves from being despised by sanctioning the despiser, or favour a compliment by rewarding the compliment giver. They also gossip about their peers influencing each other with regard to what they think of them. Various structures and leadership styles emerge from the meeting dynamics. The result could be an absolute dominance, a very hierarchical society, or a crisis in which everyone hates each other, including themselves. Egality and elite are also power structure forms emerging from the Leviathan model.

The power of such a virtual world model is the understanding of the impact the agent behaviour has on the structure. The choice to gossip or not can change the whole way people see each other. The intensity of the gossiping can change the equity of the structure and the leadership style. Even if the Leviathan model is a very simply constructed world, we can experiment with this world. We can observe and understand how agent direct interaction and gossiping practices build the structure. We can prove the emergence of a leadership style from chosen agent dynamics. That is the reason why it is the relevant tool to feed the debate, and possibly inspiring new experiments on social functions of gossip.

In the Leviathan model, gossip occurs during dyadic interactions. That is the most common situation for gossip accordingly to Conein (2011). However, the model also considers gossip varying in several ways. It can vary in intensity, from its absence to a high number of discussed peers: the more people a speaker talks about, the more intense is the gossiping during a meeting. The impact of gossiping is considered according to various levels of openness of people. This openness corresponds to a parameter controlling how high a speaker should be held in esteem to influence the listener. Very open-minded agents are influenced whatever their level of esteem for their speaker. Very narrow-minded agents are only influenced by the speakers held in high esteem. The strength of gossip is also ruled by a propagation coefficient. This coefficient and the openness are also used to control how strong two talkers influence each other.

In this paper, we are interested in understanding the relation between gossip and two social phenomena: consensuses and the positivity bias. These two properties of a population seem altogether somewhat counterintuitive: a population needs some consensuses to act as a group at the same time the positivity bias is said quite universal and means people diverge. This paradox can perhaps being solved by the understanding of their links to gossip and its social functions (Foster, 2004).

Deffuant et al. (2013) have shown the Leviathan model is able to exhibit these two social phenomena. They emerge from the individual need to form a value of themselves (ie self-value), as well as defining the value of others, through direct interaction and gossip. The particular role of gossip in their emergence and maintenance has not been exhaustively investigated in this model.

That is the purpose of this work which starts from four hypotheses: gossip leads to consensus which increases with its intensity; gossip decreases the strength of the positivity bias and can suppress it; positivity bias and disagreement are linked to each other; positivity bias and bias to negativity occurring in the Leviathan model appear conjointly whatever the level of gossip (they have been conjointly diagnosed in the first investigations of Deffuant et al., 2013). Overall, our hypotheses are confirmed. We especially pointed out that the consensus is almost never reached without gossip. We also show how an asymmetrical level of openness to the influence of others depending on how high they are held in esteem is important for the positivity bias, as well as for the bias to negativity. The number of discussed peer during a meeting is also shown essential for consensus.

While the next section is dedicated to a short review of the body of literature, the following one presents the Leviathan model as well as our experimental design. A section presenting the results of our analysis comes next. A final section is entirely focused onto synthesizing and discussing our conclusions.

8.2 Literature review

Firstly, we shortly review the body of literature related to the gossip and the properties of populations. Secondly, we sum-up what we already know from the Leviathan model which is susceptible to help our study. This literature review will be used in section 8.3.2 to argue about our hypotheses.

8.2.1 Gossip, reputation and positivity bias in the social literature

The social functions of gossip

In his review, Foster (2004) mentions gossip has been poorly studied in the past. From the works it has collected, it reports four major social functions of gossip: "information (Dunbar and Duncan, 1997), entertainment, friendship, and influence". Among the numerous functions proposed by the review, we can cite the following ones. "From gossip, the individual gets a map of his social environment ... can benefit from an elevated social status. It allows building norms ... reinforcing friendship through sharing norms..., controlling cheating, ... ; it hold communities together against the forces of social entropy". Similarly, the study of Kniffin and Wilson (2005) suggests that "gossip can be used within groups to enforce norms". Overall, it seems a lot of social functions are proposed for gossip without being always supported by experiments, or hierarchized.

The reputations

Reputations are "consensus among knowledge informations as to the attributes of targets" (Emler, 1990; Moscovici, 2000; Arrow and Burns, 2004). Emler describes reputations as "social representations" (Moliner (2001), describing this Moscovici's concept) of the self: "reputations are social constructions, created collectively through processes of social communication, and are not to be confused with one individual's perception of another". He also explained the reputation emerges from interactions between individuals who are motivated to form a social identity: "I also want to suggest that defining yourself in terms of a particular social identity is largely a matter of persuading others to so define you. ... Social identity are conferred or agreed by the collective, not merely assumed by the individual. ... they imply shared definitions. ... they are overtly expressed or communicated claims on the individual's part. ... those claims are negotiated with others." This negotiation and sharing is made through direct interactions between individual and gossip as it is again explained by Emler (1990): "... that people do regularly exchange information about their mutual acquaintances (Emler and Fisher, 1981). In a series of small-scale exploratory surveys of the informal conversations of students and teachers, we discovered that the most common topic of conversation after self-disclosure was named acquaintances, ... Gossip of this kind does seem to be a pervasive human activity (Paine, 1967), and given the frequency of such conversations (Emly and Grady, 1986), it seems a reasonable inference that people do in fact engage in extensive information-gathering about reputations. But in these conversations we also exchange a great deal of information about ourselves. There are grounds for believing these aspects of conversation concern our own reputations."

Complementary to Emler's point of view, we have to cite the process of self-categorization through which an individual socially defines himself as a group member. The category that we can also call stereotype, can be seen as a reputation. This process is the core of the social identity building and the group formations and maintenances (Tajfel, 1978; Turner, 1984; Turner et al., 1987; Hogg et al., 1990).

The positivity bias

On the contrary of a consensus, a positivity bias comes from someone's self-judgement better than the others. But similarly to the consensus, it is also a social phenomenon, not the fact of an individual. Indeed, it is diagnosed in an experiment when a majority of participants to the experiment said they are better than the average (Hoorens, 1993). The positivity bias, which can be also called confirmatory biased or illusory superiority (Hoorens, 1993) is strongly supported empirically. It is diagnosed especially when to the classical question "do you assess yourself better than the average in a particular domain", a more or less large majority of people answers "yes". It is well established that people tend to rate themselves as better than average across many domains. Only the size of the majority of people answering "yes" seems to change over the "domain". For example, it is well known driver rate themselves better as the average whatever their level of training and experience (Waylen et al., 2004). The same authors indicate us: "Grayson (1998) found that, in a sample of more than 1000 motorists, 80% considered themselves to have better than average driving ability". Many other examples of what it is also called self-serving bias are given in (Myers et al., 2009), as "90% of business managers rate their performance as superior to the average". This bias has been shown quite universal (Myers et al., 2009). Gossip from which the universality and the importance have been also shown (Foster, 2004; Conein, 2011; Beersma and Van Kleef ,2012) is said being a source of self-suffering as well as a way to punish the cheaters. It probably impacts onto the positivity bias since it seems able to decrease someone's self-opinion (ie the opinion people have of themselves).

8.2.2 The Leviathan model, the reputation and the positivity bias

The modelling approach

The Leviathan has been designed accordingly to a classical approach in the field of social simulation or in sociophysics. It consists in making a few simple assumptions about the rules of interactions between agents and the way they change their opinions. The aim is to study the obtained emerging behaviours. In some of these models, the agents have binary opinions (Sznajd-Weron, 2005; Galam, 2008), while in others the opinions are continuous (Deffuant et al., 2000, Fortunato et al., 2005; Deffuant, 2006; Lorenz and Urbig, 2007; Urbig and Malitz, 2007; Huet and Deffuant, 2008; Gargiulo and Huet, 2010; Huet and Deffuant, 2010; Gargiulo and Huet, 2012) (see Castellano et al., 2009 for a review). For some parameters, our model is also close to ones which include a set of affinities between agents, leading to emerging networks (Carletti and Righi, 2011).

The model is called Leviathan in reference to Hobbes (1651) who pointed out that the feeling to be undervalued is a major source of violence. In practice, the basic Leviathan model (Deffuant et al., 2013) assumes that each agent can have a continuous opinion about every other agent, truncated if necessary to remain between -1 and +1. In the initial state, the agents don't have an opinion about the others. The agents interact in randomly chosen pairs and two different processes apply. The first one supposes that during any interaction, each agent propagates her opinions about herself, about her interlocutor and about several randomly chosen other known agents. In this propagation, highly valued agents are more influential. The second process represents a vanity effect: an agent likes to be highly valued by the others, thus she increases her opinion on those who value her well. On the contrary, she decreases her opinion of those who undervalue on her. These assumptions are inspired by Hobbes (1651), but also by more recent experiments and observations from social-psychologists (Fein and Spencer, 1997; Buckley et al., 2004; Srivastava and Beer, 2005; Leary et al., 2006; Stephan and Maiano, 2007; Wood and Forest, 2011). Moreover, we suppose that the access to the opinion of the others is not perfect: people may not express exactly what they think and the listener may misinterpret these expressions. We consider such a defect as distorting the opinion of the speaker. To model this distortion, we add or suppress a random noise to the opinion to propagate.

The behaviour of the model

From its first study and despite its simplicity, the model shows a surprising variety of dynamic structures when changing the parameters. The following structures have been identified until now:

- Equality. Each agent **has a positive opinion about herself**; she is **connected by strong positive mutual opinions** with a small set of agents and has very negative opinions about all the others. All agents have a similar number of positive (and negative) links, called respectively friends (and foes). For some parameters, network of positive links shows the characteristics of small world networks.

- Elite. The pattern shows two categories of agents: the elite and second category agents. The **elite agents have a positive self-opinion** and **are strongly supported by a friend**, but they have a very negative opinion of all the other elite agents and of all the second category agents. The second category agents have a very negative self-opinion, they have a very negative opinion of all the other second category agents and their opinion about the elite agents is moderate.

- Hierarchy. **All agents share a similar opinion about every other agent** (called reputation) and the reputations are widely spread between -1 and +1. There are more agents of low reputation than of high reputation: this gives the image of a classical hierarchy with a wide basis and progressively shrinking when going up to the top.

- Dominance. As in the hierarchy pattern, **all agents share a similar opinion about every other agent,** but a single agent has a high reputation while most of the other agents have a very low reputation.

- Crisis. Each agent **has a very negative opinion of all the others and of herself.**

One can notice that these structures exhibit some properties that we relate to gossip in the previous section: agreement about opinions; positivity bias; ... The first study has mainly pointed out the importance of the propagation coefficient of the influence[2] comparing to the vanity one for explaining how these structures emerge. The particular impact of gossip has not been deeply investigated.

Two various forms of positivity bias have been identified in the first study of the Leviathan and linked to each other.

The first case of positivity bias shown in Deffuant et al., (2013) is associated to a value of the influence coefficient higher than 0 while the vanity coefficient is zero. This bias is not appreciated in terms of number of people held in low esteem, but in terms of the average self-opinion over the time compared to the average reputation (the average of all the opinions) over time. A small bias in favour of the self-opinion compared to the reputation is noticed by Deffuant et al., (2013). For these particular parameter values, the someone's self-opinion is very close to the opinion others have of the agent. The bias is due "to propagation coefficient ruling the influence. The higher is someone's self-opinion, the larger is her influence propagation coefficient" (since the other's opinion of her is very close to this self-opinion). This larger influence is due to the asymmetry of the propagation coefficient computation ruled by σ giving more influence to some agent held in high esteem. Because of this difference of influence, when an agent self-opinion is higher than her reputation, the others have less influence on the self-opinion than when the self-opinion is lower than the reputation (everything else being equal). However, the effect of this average difference between the self-opinion and the reputation depends on the value of the agent's reputation: ... Hence, highly valued agents tend to lead the other's opinions and, with the statistical bias for a self-opinion higher than the reputation, they tend to increase their reputation. This is the contrary for the badly valued agents who tend to naturally decrease their self-opinion, only by the effect of the propagation coefficient.

Below a threshold of the self-opinion, the reputations and self-opinions tend to be biased towards negative values, and above towards positive values. The value of this threshold depends on parameter σ determining the propagation coefficient and also on k the number of agents about whom the opinions are propagated during the encounters. Indeed, this number has an impact on how the agents propagate their opinion about the others."

These observations are useful to understand the processes when the vanity becomes higher than zero. First note that the vanity process enhances the tendency of self-opinions to be higher than the reputations. Indeed, the small statistical positive bias for self-opinion that is due to the opinion propagation leads, on average, the agents to consider themselves as more or less undervalued by the others, thus they devalue them by vanity. This explains the tendency of agents of the Leviathan model to get negative opinions.

Considering a larger vanity leads us to the second case of positivity bias shown in Deffuant et al., (2013) even if it has not been identified as such. It is associated to a very low propagation coefficient for a large vanity one. The reference paper (Deffuant et al., 2013) does not explicitly talked about positivity bias in this case but it is obvious from the analytical demonstration regarding how to compute the average number of agents positively assessed by an agent. Indeed, for this particular parameter values, the matrix of opinion is symmetrical around the diagonal representing the self-opinion of individuals. An agent can only be highly positively valued or highly negatively val-

[2] both in direct meeting and via gossiping

ued. The agents maintain themselves with a good self-opinion in a dynamic relational equilibrium between few friends which flatters them and which are flattered in return, and a large number of foes which punishes them and which are punished in return. For these particular parameter values, the number of friends and foes is similar for every agent. Foes are agents held in low esteem while friends are agents held in a higher esteem compared oneself. The number of foes can be computed analytically as shown in Deffuant et al., (2013). This number gives an indication on the strength of the positivity bias: having more than the (population size minus one) over two foes indicates a positivity bias. From their demonstration, the authors conclude about the effect of the main parameters for this particular set of parameter values (a very close to zero coefficient for the influence and a large coefficient for the vanity):

- 'Increasing δ (noise parameter) decreases the final equilibrium value of the self-opinion, and hence the final number of friends of each agent;
- Increasing σ (ruling the slope of the sigmoid function of the influence parameter) will decrease the difference of weights between friends and foes and therefore decrease the equilibrium value for a given number of friends. This will thus result in a larger number of friends at the stable state;
- Increasing the number of agents in the population decreases the value of the self-opinions for the same number of friends. Therefore, it will result in a larger number of friends at the stable state.
- Increasing ρ increases the fluctuations around the equilibrium self-opinion and hence will decrease the number of friends at the stable state. "

Regarding the "gossip" parameters we are interested in, we retain from the first case of positivity bias that increasing σ decreases the strength of the positivity bias while increasing ρ increases it. In the second case, we retain σ and k or an increase of vanity can change the observed dynamics. Moreover, from the previous work we also know that for these parameter values, and due to the vanity, the whole population is biased toward negative. We also notice here the presence of a global bias of the population toward the negative. This global bias to negativity seems to be a characteristic of the dynamics of the Leviathan model since it can come both from vanity and influence.

Overall, Deffuant et al. (2013) proposes the positivity bias is due to some particular *equilibria* associated to couples of the influence and vanity coefficients. However, a possible much more importance of the role of gossip in the emergence and the disappearance of the positivity bias deserves a specific investigation.

8.3 Material and methods

8.3.1 The model [3]

We consider a set of N agents, each agent i is characterized by her list of opinions about the other agents and about herself: $(a_{i,j}),\ \ 1 \leq i,j \leq N$. We assume $a_{i,j}$ lies between

[3]In this paper, the Leviathan model functions has been presented in a different order allowing to distinguish the direct experience of meeting a peer from the indirect contact with peer through gossiping. In practice, this means that the events do not exactly occur at the same time during the meeting and that the number of times the bounding feature of the opinion is checked is smaller. The model remains unchanged despite this small difference.

-1 and +1, or it is undefined (equal to nil) if the agent i never met j and nobody has talked to i about j yet. At initialisation, we suppose that the agents never met, therefore all their opinions are undefined. When opinions change, we always keep them between -1 and +1, by truncating them to -1 if their value is below -1 after the interaction, or to +1 if their value is above +1.

The agents interact in uniformly and randomly drawn pairs (i, j) and at each encounter, we apply two processes: the face-to-face management, implying influence attempts and vanity between the two agents meeting each other; and the gossip, consisting in influence trials about people they know (sometimes including themselves). Someone knows someone else if it has already met it or heard about it. Then in this case, the opinion of it is different from nil.

We follow the people's interactions considering a time range called iteration. We assume one iteration, i.e. one time step $t \to t+1$, is $N/2$ random pair interactions (each agent interacts N times on average during one iteration).

The following describes the processes occurring during a pair meeting with an incremental approach allowing understanding how they are coupled to each other. We start with gossip which allows us to explain how agents influence each other. Then we continue with the management of the face-to-face during which, not only influence, but also vanity occurs. We finally present the global iterative loop during which pair meetings occur.

Gossip: agents discuss their peers

Let us assume that agents$i$and j have been drawn. During an encounter, we suppose that agent j propagates to i her opinions about herself (j), about i, and about k agents randomly chosen among her acquaintances. Moreover, we suppose that if i has a high opinion of j, then j is more influential.

This hypothesis is implemented by introducing a propagation coefficient, denoted p_{ij} which is based on the difference between the opinion of i about j (a_{ij}) and the opinion$i$ about herself (a_{ii}). It uses the logistic function with parameter σ. If a_{ij} = nil (j is unknown to i), we assume that$i$ has a neutral opinion about $j$and we set a_{ij} to 0. Let us also observe that, at the initialisation, an agent has no opinion about herself (a_{ij}= nil), before she takes part in a first encounter, thus we also set a_{ij}= 0. Then we compute the propagation coefficient p_{ij}, which rules the intensity of the opinion propagation from j to i :

$$p_{ij} = \frac{1}{1 + \exp\left(-\frac{a_{ij}-a_{ii}}{\sigma}\right)}$$

The parameter σ defines the slope of the function close to $a_{ij} - a_{ii}$. Figure 8.1 represents the value of p_{ij} when the difference $a_{ij} - a_{ii}$ varies (between -2 and +2), for three different values of parameter σ. One can observe that p_{ij} tends to 1 when $a_{ij} - a_{ii}$ is close to 2 (i values j higher than herself), and tends to 0 when it is close to -2 (i values j lower than herself). Indeed, when σ is small, p_{ij} rapidly changes from 0 to 1. Whenσ is large, this change is progressive.

A parameter ρ controls the impact of the coefficient p_{ij}.

The agent i modifies her opinion about the agent z that i talked about applying the influence coefficient ρ by the propagation coefficient to the difference between what j told about z and what she thinks of z. However, i has no direct access to the opinion of j and can misunderstand j: for example j may not express exactly what

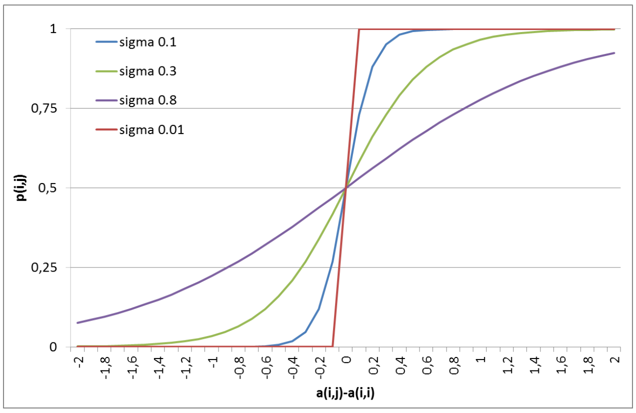


Figure 8.1: Examples of variations of the propagation coefficient p_{ij} when $a_{ij} - a_{ii}$ varies, and for four values of the parameter σ when σ decreases, this function tends towards a threshold function returning 0 for negative entries and 1 for positive entries.

they think and/or *i* may misinterpret these expressions. To take this into account in the model, the propagated opinions are distorted by noise. This noise is identical for every conversation and can also be seen as a difficult context not allowing the two partners to perfectly understand each other.

To take into account this difficulty, we consider the perception of i as the value a_{jz} more or less a uniform noise drawn between -δ and δ (δ is a model parameter). This random addition then corresponds to a systematic error the agents make regarding the others' opinions. More formally, the process can be written in pseudo-code as follows:

Gossip(i, j)
Repeat k times:
Choose randomly z taking into account $a_{jz} \neq$ nil, z /neq j.
If $a_{jz} =$ *nil*, $a_{jz} \leftarrow 0$
$a_{iz} \leftarrow a_{iz} + \rho p_{ij}(a_{jz} - a_{iz} + \text{Random}(-\delta, +\delta))$

Random (-δ, δ) returns a uniformly distributed random number between $-\delta$ and + δ, that can be seen as a noise that distorts the perception that i has about j 's opinions. The parameter δ rules the amplitude of this noise.

The face-to-face activates influence attempt and vanity

During their first meeting, i and j don't know each other and their opinions are nil. Then, they instantaneously become 0 which is the neutral opinion. This initiates the meeting dynamics and allows influence and vanity.

Indeed, when agents i and j meet, they talk about themselves: i talks about herself and j, while j talks about herself and i. This direct exchange implies two processes occurring at the same time: influence of each of them on what they think about themselves and the other, and a vanity process applied only by the listener to the talker. This vanity process expresses that agents tend to reward the agents that value them more positively than they value themselves and to punish the ones that value them more negatively than they value themselves. Then, added to the influence i received from j regarding what she thinks about j, agent i compares her self-opinion a_{ii} to the opinion j tells about her a_{ij}. If the perceived opinion of the other (j) is higher than her self-opinion, i increases her opinion of j (reward). Else i decreases her opinion of j (punishment).

Parameter ω rules the importance of the vanity process. The modification of i's opinion of j is assumed as simply depending on the difference between the opinion of i about herself and the opinion of j about i (modified randomly slightly).

The face-to-face can be formally described in pseudo-codes as follows:

```
Face-to-face(i,j)
    If a_ii = nil, a_ii ← 0
    If a_ij = nil, a_ij ← 0
    a_ii ← a_ii + ρ p_ij (a_ji − a_ii + Random(−δ, +δ))
    a_ij ← a_ij + ρ p_ij (a_jj − a_ij + Random(−δ, +δ)) + ω(a_ji − a_ii + Random(−δ, +δ))
```

During the interaction, face-to-face(i, j) and face-to-face(j, i) are successively applied.

Summary

Finally, the model has 7 parameters:

- N, the number of agents;
- δ, the maximum intensity of the noise when someone is alluded to;
- σ, the reverse of the sigmoidal slope of the propagation coefficient;
- ρ, the parameter controlling the intensity of the coefficient of the influence process (applied to the propagation coefficient);
- k, the number of acquaintances an agent talked about during a meeting - they are randomly chosen among her acquaintances;
- δ, maximum intensity of the noise when someone is alluded to;
- ω, the coefficient of the vanity process.

The following algorithm describes one iteration: $N/2$ random pairs of agents are drawn, with reinsertion, and we suppose that each agent influences the other during the encounter.

```
Repeat N/2 times:
    Choose randomly a couple (i, j)
    Save the opinions which are going to change in temporary variables to ensure the update
    during the i and j meeting is synchronous
    Face-to-face(i, j)
    Face-to-face(j, i)
    Gossip(i, j)
    Gossip(j, i)
```

The update is synchronous: every opinion changes occurring during a meeting are computed on the same value of opinions taken at the beginning of a pair meeting.

8.3.2 Hypothesis and methods

This section describes our hypothesis as well as the corresponding experimental design and the measured indicators. A following subsection describes the results.

Hypotheses

From our literature review, we formulate four hypotheses to test.

H1: In the Leviathan model, the gossip parameters have a strong influence on the consensus level of the population. In the previous study of the model, the appearance of consensus has been analyzed in terms of rapport between the power of the vanity and the power of the propagation of opinion. On the other hand, social psychology literature explains consensus emerge and are maintained through direct interaction and gossip - that would be relevant to explore and debate the specific role of gossip by considering it in the Leviathan model;

H2: In the Leviathan model, the gossip parameters have a strong influence in strength of the positivity bias. Previous study has mentioned some effect of the openness of people and sometimes of the number of discussed peer without really investigates them. Moreover, in the literature, gossip is at the same time considered as dangerous for someone's self-suffering from a bad reputation, and explained as a social way to control cheating. That would mean probably gossip decreases the strength of the positivity bias. Perhaps, it can lead a majority of people to undervalue them. Once again, the Leviathan model can provide elements to discuss;

H3: Positivity bias and consensus level of the population relates each other: it seems indeed counterintuitive the positivity bias and consensual reputation can be present conjointly. How a population judging themselves higher than the average can be agree on someone's value? We hypothesize there is a negative correlation between positivity bias and consensus;

H4: Positivity bias and bias to negativity simultaneous occurrence does not depend on gossip. The two biases have been conjointly observed in the previous study of the Leviathan model.

Three parameters of the model are involved in the control of gossiping: ρ, σ and k. While the impact of ρ has been already properly studied in regards of ω, only two values of k and σ have been tested (respectively 2 and 10, 0.3 and 0.5). Then, in order to conclude about the impact of gossip in the model, we have to vary more these two parameters.

To test our hypotheses, we elaborate the following experimental design.

Experimental design

The model includes 7 parameters and it is difficult to make an exhaustive study in the complete parameter space. While the study of the influence coefficient applied identically to the influence during the direct meeting and the influence through gossip, and the vanity coefficient, have been extensively experimented, the gossip process by itself has not been studied. Indeed, in the model, gossip intensity is controlled through three parameters: a coefficient of propagation, a number of agents someone talks about and a kind of openness to influence telling whose gossip is going to be considered by a listener. While the first study has varied a lot the influence and vanity coefficients, only two values have been tested for the other two parameters. To study the impact of gossip, we have now to focus our experimental design on these two parameters: k ruling the gossip intensity in terms of number of agents one agent talks about during a meeting; and σ, the level of openness to the influence depending on the level of esteem for the talker. We also decided to vary the noise δ, but not as much as k and σ. Also ρ and ω vary poorly since their co-variation has been studied in details. We fix N, the number of agents to 40, in order to make tractable results of our study.

In practice, we vary the other parameters as follows:

- k, the number of discussed acquaintances takes the values 0, 1, 2 , 3, 4, 5, 10, 15, 20, 25 and 30;
- σ, ruling the slope of the logistic function determining the propagation coefficients takes the values 0, 0.01, 0.02, 0.06, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0;
- ρ, ruling the intensity of the overall influence by being applied to the propagation coefficient takes on three values: 0.05, 0.5, 1;
- ω, ruling the intensity of the vanity : 0.05, 0.5, 1;
- δ, the intensity of noise disturbing the evaluation of other's opinions takes two different values: 0.1 and 0.3.

For each set of parameter values, we run the model for 201,000 iterations (one iteration corresponding to $N/2$ random pair interactions), and we repeat this 15 times.

Measuring indicators

From iteration 30,000 to 200,000, we measure every the 10,000 iterations a group of values allowing us to make conclusions about the impact of gossip. The measures, averaging over times of a run and over the 15 replicas gives us indicators. The indicators we build to test our hypothesis are the following.

The average disagreement to appreciate the consensus level
It is computed as the average over the population of the maximum difference of opinion on someone considering everyone except the agent herself. The average measure is finally called average disagreement. Disagreement varies from two to about δ (for remembering: we test δ equal to 0.1 and 0.3). The value two corresponds to the maximum difference between the minimum (-1) and the maximum (+1) opinion and δ to the average "noise" around the opinion on someone when everyone agrees on this opinion.

The average number of underestimated agents to appreciate the positivity bias
It is the average number of agents that each agent of our population assesses as lower than herself. Our experimental design considers a population of 40 agents. This means that if an agent considers that more than (40-1)/2=19.5 agents as lower than herself, she assesses herself as better than the average. Then, we decide diagnosing a positivity bias when the average number of underestimated (equal to "assessed as lower") agents is higher than 19.5. Indeed, it indicates than more than 50% of the agents assess themselves as higher than the average. When the average number of underestimated is close to 39, it means that almost everyone believes being the highest valued agent in

the population.

The average rate of positive opinion to appreciate the bias to negativity of the whole population
We measure the number of positive opinions and compute the average rate of positive opinions to assess the bias to negativity of the population. Indeed, this bias increases when the average rate decreases. It is valued 0 when the average rate of positive opinions is 0.5 and maximum when the average rate of positive opinions is 0.

8.4 Results of the study through simulations

This section presents the influence of gossip in the Leviathan model on various aspects and the results of the test of our four hypotheses. A first subsection shows its influence on the level of consensus. A second one deals with the positivity bias strength in regard to gossip. A third one shows how the level of consensus, the positivity bias and the bias to negativity identified in Deffuant et al. (2013) relate to each other.

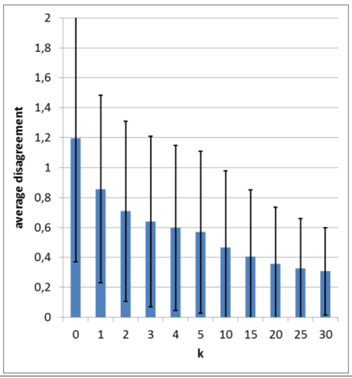
8.4.1 Gossip and the level of consensus

Our purpose is to understand the influence of gossip on the consensus level of the population on the value of each agent. To measure the consensus level, we compute the average level of disagreement which varies from two to about δ (see section 8.3.2 for more details).

Figure 8.2 shows that disagreement decreases with the intensity of gossip in terms of people someone talked about, k (on the top). Disagreement is particularly high in absence of gossip (ie $k = 0$). However, in the bottom panel of Figure 8.2 we can observe that consensus can be reached even in absence of gossip for some particular sets of parameter value. This occurs in two different cases: for $\sigma < 0.2$ and ρ=0.05 for ω = 0.5 or 1 and $\rho = 0.5$ for $\omega = 1$ in which the disagreement is zero; for $\sigma \geq$0.2 and $\rho = 0.5$ for $\omega = 0.05$ and $\rho = 1$ for $\omega = 1$ in which the disagreement roughly corresponds to the average value of tested δ (0.1 and 0.3). On the right part of Figure 8.2, we also observe that depending if the vanity is low or high, an increase of the level of openness can increase or decrease the level of disagreement.

Figure 8.3 on the left shows how these parameters change the average disagreement. For $\rho \geq 0.5$, the average disagreement tends to increase with ρ and ω and is not highly sensitive to σ. On the contrary, for ρ = 0.05, the average disagreement becomes very sensitive to σ when ω is larger than ρ (ω equal to 0.5 or 1). We observe a particular "threshold" behaviour occurring for the smaller value of ρ and larger values of ω (0.5 and 1), and depending on σ; a low disagreement for $\sigma < 0.2$, and a high disagreement for $\sigma \geq$0.2. We know this threshold behaviour is not explained by k since it always occurs. But even for this low ρ = 0.05, we can see on Figure 8.3 on the right that the average disagreement remains sensitive to gossip since the results for k=0 are different from the results for $k >$0 whatever σ. Also, on the right panel of Figure 8.3 we can observe, even in the conditions of high disagreement due to a low value of ρ and a high σ value (red bar), an increase of the gossip intensity. This means again an increasing of k decreases the average disagreement.

However, when the influence coefficient ρ is low (0.05) with a larger vanity ($\omega >$0.05), accepting to be influenced in face-to-face or in gossip by people held in lower esteem than oneself (ie. larger values of σ) is a source of disagreement between people. For



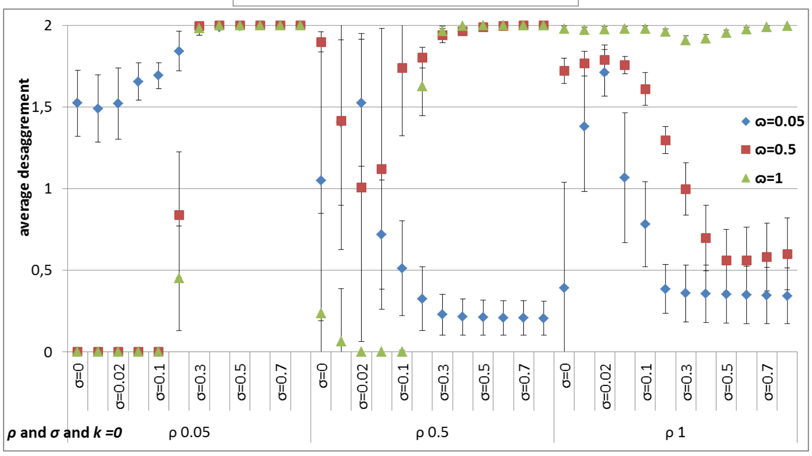


Figure 8.2: Average disagreement for various values of k (in abscissa of the graph on the top), and for $k = 0$ various values of ρ and σ) (in abscissa of graph at the bottom) and ω(= 0.05 blue diamonds; = 0.5 red squares; = 1 green triangles). Each bar corresponds to the average over all results obtained from every tested values for all the parameters considered in the experimental design. Error bars correspond to one standard deviation over these results.

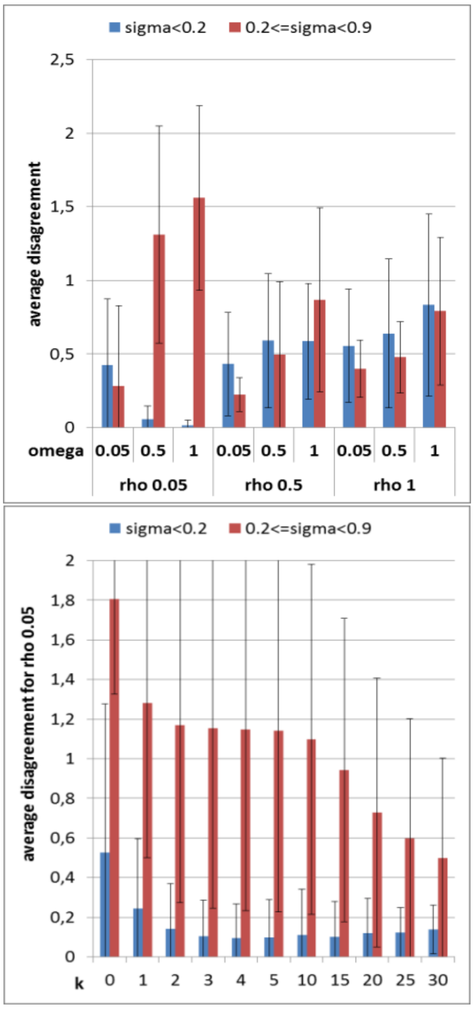


Figure 8.3: Average disagreement for, $\sigma < 0.2$ (blue bars) and $0.2 \leq \sigma < 0.9$ (red bars): on the left, for various ρ and for each value of ρ, various ω on the right, for various k (in abscissa) and ρ=0.05. Each bar corresponds to the average over all results obtained from every tested values for all the parameters considered in the experimental design.

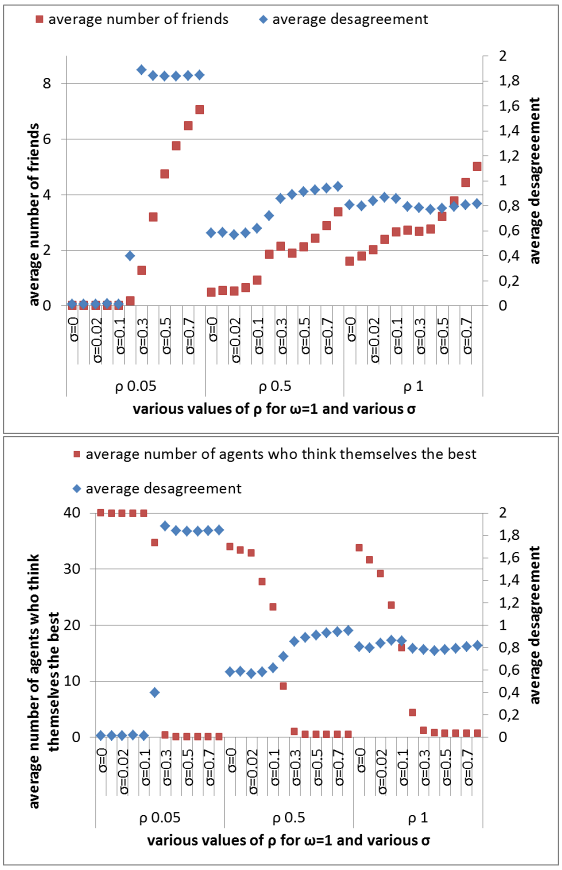


Figure 8.4: Average disagreement and average number of friends (on the top), and average number of agents who think being the best (at the bottom) for ω=1, various values of ρ and σ. Each dot corresponds to the average over all results obtained from every tested values for all the parameters considered in the experimental design.

these conditions, the behaviour is very particular since we observe a threshold:the level of disagreement is mainly driven by σ and depends if σ is lower than a threshold around 0.2. Under the threshold the disagreement is low while it is higher above the threshold. In any case, the average disagreement is decreased by the intensity of gossip (value of k) but if the influence parameter is low regarding the vanity, it can require a very high intensity of gossip (large k). This particular behaviour is partly due to the characteristics of our indicator. Indeed, as shown at the bottom panel of Figure 8.4, we can observe only for our critical small ρ=0.05 low in regards to ω (=1 in the Figure) that the σ values for which the average disagreement is the lowest corresponds to a zone where the average number of agents holding themselves in the highest esteem (ie they think they are the best) is equal to the population size. In this particular case, the average disagreement is valued zero since it corresponds to the average maximum difference of opinion on someone without taking into account the self-opinion. Then, as everyone is valued at worst, the difference is zero and the level of disagreement is assessed as null. This corresponds to the structure "equality" in which the agents have no friends.

For larger value of σ, we observe on the top panel that the number of friends (people held in a positive opinion by oneself) increases dramatically compared to the measures for the larger values of ρ. This set of parameter values corresponds to a particular equilibrium exhibiting a positivity bias identified in Deffuant et al. (2013) and called equality. This equilibrium between "friends and foes" (see section 8.2.2 for more explanations) only occurs when ρ is very close to be null and the vanity coefficient ω large in comparison. It considered a population of agents having friends held in a large positive opinion while they have the worst as possible opinion of all the others agents. Friends have a mutual positive opinion and reward each other. That is the way they are able to resist to a large set of "hated" agents who punished them and try to destroy the good opinion they have of themselves. For this equilibrium, the disagreement is close to the maximum since friends are close to have the best as possible positive opinion and foes has the worst one. Such a difference of opinions between people is not observable elsewhere in the parameter space. Overall, that explains why we observe a "threshold" behavior depending on σ for these parameters of ρ=0.05 and ω=0.5 and 1.

The main results of this section are**: no gossip, almost no agreement; increasing gossip decreases the disagreement**. A consensus can be hardly obtained when there is no gossip. It can emerges from the direct meeting only when the influence parameter is high for a very low vanity coefficient and agents are opened enough to each other. For other conditions and absence of gossip, the disagreement remains. When gossip is introduced, the disagreement decreases. More generally, the more people someone talks about, the more consensual is someone's value. **This confirms our hypothesis H1**: gossip have a strong influence on the consensus level of the population

8.4.2 Gossip and the positivity bias

This section aims to define if and how gossip participates from the emergence of the agents' positivity bias in order to test our hypothesis H2. To diagnose the positivity bias in the model, we compute the average number of agents that each agent of our population assesses as lower than herself. When this average number is higher than 19.5 (for our experimental design with 40 agents in the population), we diagnose a positivity bias (see section 8.3.2 for more details).

Figure 8.5 presents how the average number of estimated agents is sensitive to k, σ, ρ and ω. **The bias is almost always observable for** $k = 0$ (see the two panels) whatever ρ or σ except for ω = 0.05 and ρ=0.5 or 1 (at the bottom) except for very large values of σ (see Figure 8.7, σ=100). It is not observable for the same value leading to a consensus in the previous section (see Figures 8.2 and 8.5 at the bottom). On the other hand, we notice that **an increase of σ always decreases the strength of the positivity bias whatever the other parameters until it disappears** (a large increase of σ suppresses all the positivity biases as illustrated in Figure 8.7). **The bias always occurs for lower values of σ.**

Regarding k, when k is higher than zero, the impact is very complex and depends on the overall dynamics: from dynamics mainly driven by ω over ρ to dynamics mainly driven by ρ over ω. We can sum-up the sensitivity to k in three cases. Figure 8.6 shows these three cases. To represent directly the strength of the positivity bias, we compute the average number of underestimated agents $(N-1)/2$ with N the size of the population of agents. This "new" indicator is valued zero when there is no bias and 19.5 when the bias is maximum.

When ρ is small (0.05), two cases should be distinguished:

1. $\rho = \omega$ (0.05): **an increase of k decreases the strength of the bias until it disappears** or remains at the same level (Figure 8.6 on the top left panel).

2. $\rho \ll \omega$ (0.5 and 1): **an increase of k increases, and then decreases the strength of the bias** (Figure 8.6, top right panel).

When ρ is larger (0.5 and 1 in our experimental design), two regimes exist for a same couple of parameter value (ρ, ω) depending on the value of σ:

1. for large values of σ, **an increase of k decreases the strength of the bias until it disappears** or remains at the same level (Figure 8.6, bottom right panel) ;

2. for low values of σ, **an increase of k decreases at first, and then increases the strength of the bias** (Figure 8.6, bottom right panel and detail with a zoom in the bottom left panel).

The vanity coefficient ω plays an important role in absence of gossip (see on the right of Figure 8.5). It is **particularly strong when ρ is low** in regards of ω and leads to the largest positivity bias which can be observed in the model. This is this largest positivity bias identified in Deffuant et al. (2013) and explained as associated to a particular equilibrium between "friends and foes" (see section 8.2.2 for explanations) called equality.

The parameters corresponding to the equality are the only ones in our experimental design requiring a larger value of σ (than those of the experimental design) to suppress the positivity bias. Indeed, left panels of Figure 8.6 show top right corners totally empty indicating there is no positivity bias in these zones (on the contrary to the top right figures describing the case "equality"). However we are sure that a σ value close to infinite suppresses the bias. This is illustrated by the Figure 8.7 showing there is no more positivity bias whatever the parameters for σ = 100. Nevertheless, the particular equilibrium of equality makes the bias very robust to gossip.

Moreover, the sensitivity to k for these values of ρ and ω is very particular (see top right panel of Figure 8.6). An increase of k increases the strength of the bias at first and then since k continues to increase, the strength of the bias decreases. **This particular behavior is probably linked to the probability of a peer to be subject of discussion during a meeting**. This probability is ruled by k but a small population composed a large set of foes against a small set of friends is very sensitive to such a probability. As

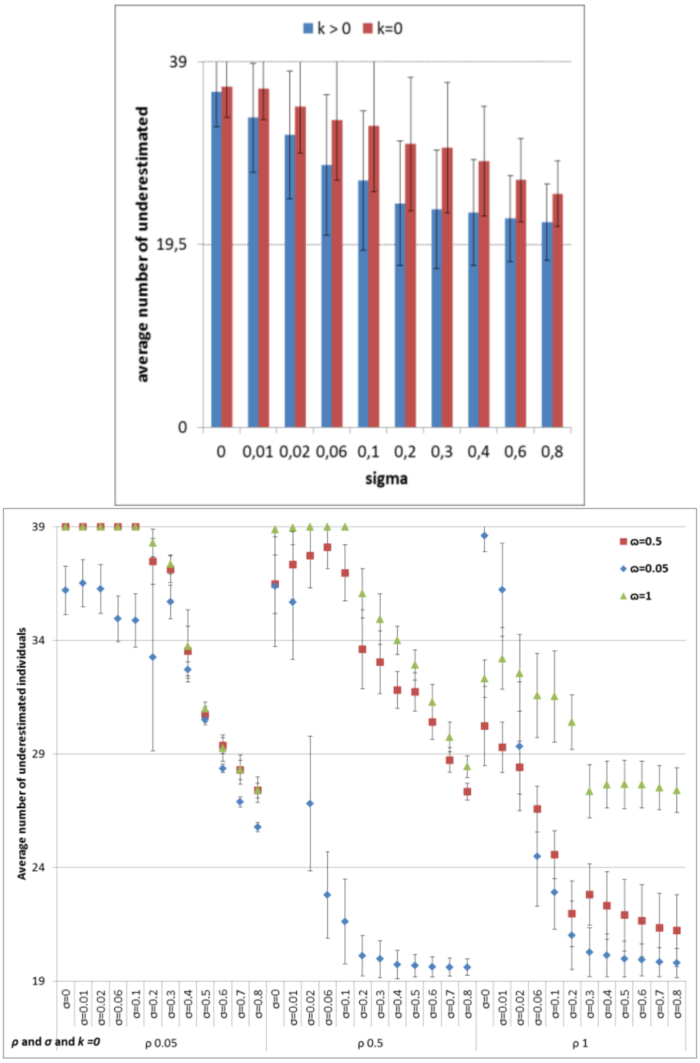


Figure 8.5: Average number of underestimated below oneself for various values of k: on the top, for various values of σ (in abscissa), k = 0 (red bars) and $k > 0$ (blue bars) and all values of all other parameters; at the bottom for $k = 0$ and the various ρ and σ values and ω =0.5 (red squares), ω =0.5 blue diamonds, ω =1 (green triangles. Each dot corresponds to the average overall results obtained from every tested value for all the parameters considered in the experimental design. Error bars corresponds to one standard deviation over these results.

a first step, an increase of k makes the probability of "friends" to be discussed by everyone higher, then agents who have a very strong negative opinion of them make those of them held in lower esteem more likely to be held in low esteem. This decreases the average number of agents held in low esteem, and thus the positivity bias. At a second step, a new increase of k is going to increase the number of evocation of "friends" by the minority of "friends" itself and "reinforce" them, decreasing the positivity bias at the same time. However, the bias remains since the difference of opinion between foes and friends are kept very large by the vanity process. This particular sensitivity has not been identified in Deffuant et al. (2013).

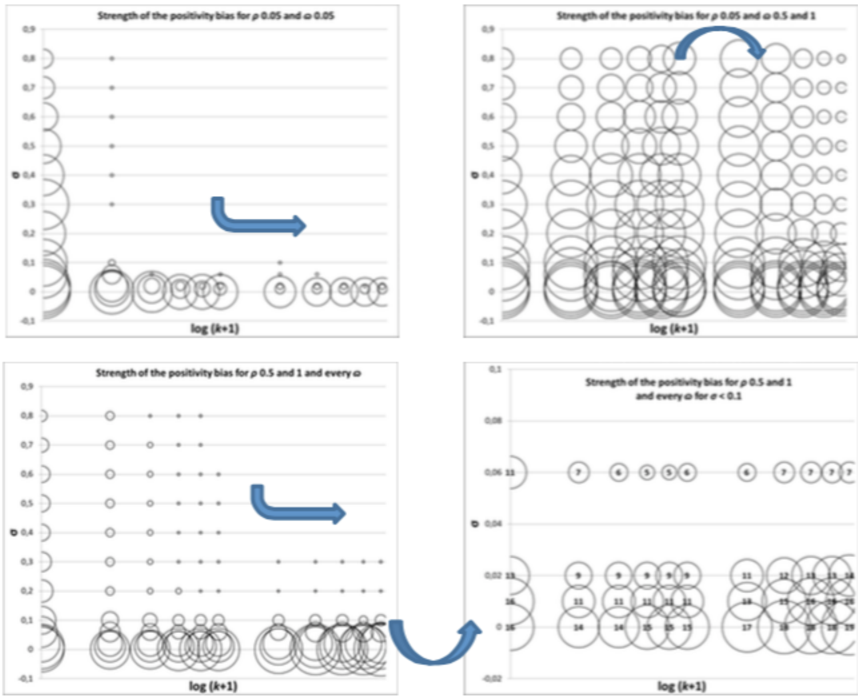


Figure 8.6: Strength of the positivity bias for: ρ=0.05 and ω=0.05 (on the top left); ρ=0.05 and ω=0.5 and 1 (on the top right); ρ=0.5 and 1 and every ω (on the bottom left) with a focus on small values of σ (on the bottom right). The size of the circle represents the strength. This strength is indicated in the centre of the circle in the zoom on the lower right panel. The blue arrows simply represent the way the strength changes with the increase of the value of k. For the lower left panel, there are two arrows since there are two different ways of changing depending on σ.

For larger values of ρ, the impact of vanity is not as high and the sensitivity of the bias to the intensity of the gossip in terms of the value of k depends on σ (see bottom panels of Figure 8.6). While an increase of k for large values of σ decreases and suppresses the bias, it decreases and increases the bias for small values of σ. **We have been unable to explain such a result thus far.** The second type of positivity bias identified in Deffuant et al. (2013) and occurring in absence of vanity, corresponds to the one observed for these larger ρ values. It has been assessed as weak in Deffuant et al. (2013) since it has been measured for a sufficiently large value of σ. However, we have showed that the positivity bias always occurs whatever ρ and ω for low values of σ. **This makes our knowledge about the emergence of the positivity bias more generic.**

To sum-up, the positivity bias always occurs for lower values of σ. An increase of σ always decreases the strength of the positivity bias until it disappears whatever the other parameters are. It is easy to understand since one agent held in low esteem has less chance to become held in high esteem than an agent held in high esteem to become held in low esteem. Indeed, the influence strength of the agent held in high esteem is very high, while the one of the agents held in low esteem is close to zero, especially for lower σ and large ρ. In case of low disagreement between people, it remains possible people held in high esteem think themselves lower and influence strongly the listener in this way. On the contrary, agents held in low esteem thinking themselves higher have a weak chance to change the listener's mind. When σ increases, the difference of influence between those held in high and low esteem decreases.

In absence of gossip (k=0), the positivity bias is very robust to the value of σ for large values of ω, and a very large value of σ is required to suppress the bias. When gossip is introduced ($k > 0$) and σ large enough, the positivity bias can be suppressed extremely quickly, especially when ρ and ω are low (see the disappearance of the bias in the top left Figure 8.7 (from k=0 to k=1 for $\sigma \geq 0.1$)).

All these results confirm our hypothesis H2 that the gossip parameters have a large influence on the positivity bias. Indeed, in the Leviathan model, the bias can be suppressed if agents are open enough to the influence of people held in low esteem, and not only to the influence of agents held in high esteem. In the absence of gossip, except for ω= 0.05 and ρ= 0.5 or 1, agents have to be almost open to the influence of everyone with the same sensitivity to suppress the positivity bias. Then, only the gossip is able to suppress the bias when the hypothesis of a difference of openness to agents held in low esteem compared to agents held in high esteem is maintained in the model. The intensity of gossip, in terms of number of people someone talks about, changes the strength of the positivity bias. However, the way this intensity changes the strength of the bias differs a lot depending on the coefficient ρ, σ and ω .

8.4.3 Positivity bias, level of disagreement and bias to negativity

We know from the two previous sections that disagreement level is driven by gossip controlled by k, the number of discussed peers during a meeting, and the positivity bias is driven by σ, the openness to others depending on the level of esteem for them. We try now to assess our hypotheses 3 and 4 regarding on the one hand the link between agreement and positivity bias and on the other hand, the link between the positivity bias and the bias to negativity diagnosed in the Leviathan model.

We hypothesized there is a global negative correlation between positivity bias and consensus. But we know now they are not driven by the same parameters: while the consensus is mainly driven by k and ρ, the biases, particularly here the positivity one, are mainly driven by σ and ω ! Thus it means in practice they can be both present as well as one present and the other absent. In Figure 8.7, we can observe the disagreement (green circles) tends slightly to increase by step with σ whatever k while the positivity bias (red squares) represented by the part of underestimated agents in the population tends to decrease. However, we have seen previously the first lowest step for small values of σ is only explained by the lowest value of ρ (section 4.1 and left panel of Figure 8.3) and characteristics of our indicator. Indeed, for ρ=0.05 and ω=1, the average disagreement is very low for small σ because all the agents hold themselves in the highest esteem and have the poorest opinion of the others. As our indicator do not consider the opinion of oneself for its computation, such a pattern implies a disagreement close to 0 (this corresponds to the average maximum distance of opinions on everyone except herself when everyone is assessed at the smallest opinion). Regarding the last step for very large values of σ, the increase of disagreement is simply due to sensitivity to the smallest values of k slightly higher than for lower values of σ.**Then we don't really confirm our hypothesis H3: there is not really a global negative correlation. Overall, agreement and positivity bias appears quite independently from each other.**

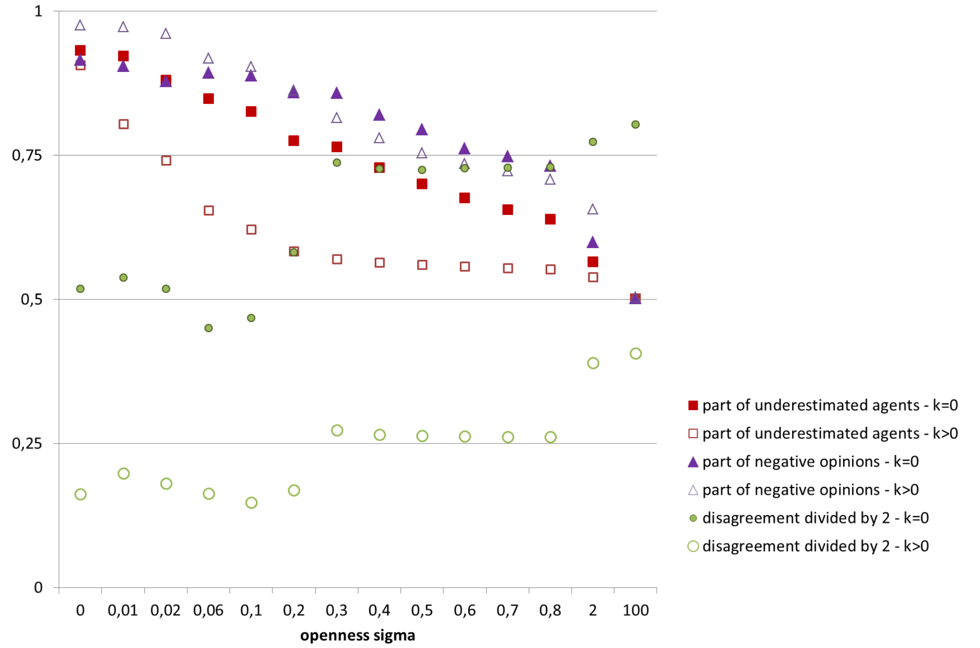


Figure 8.7: Part of underestimated agents (squares), part of negative opinions in the population (triangles) and disagreement (divided by 2 to be comparable to the two other measures), averaged over the various measures and values of parameters tested in the experimental design, for the case "no gossip" (k=0 in plain squares, circles and triangles), "gossip" ($k > 0$ in empty squares, circles and triangles) and the various tested values for the openness sigma (in abscissa). We have added two value for σ to our experimental design (2 and 100) in order to confirm the already observed tendency of evolution of our indicators.

This is now interesting to see how the bias to negativity identified in the Leviathan model evolves accordingly to the positivity bias. In Figure 8.7, we can observe that the part of underestimated agents (red squares for positivity bias) and the part of negative opinions (purple triangles) tend to evolve closely with the openness. The two indicators decrease as the openness increases until they reach 0.5 indicating there is no bias anymore for an openness equal to 100. This **disconfirms our hypothesis H4.** Indeed, even if as previously observed in Deffuant et al. (2013), **the positivity bias and the bias to negativity are both present for many values of σ, they both disappear for very large openness (σ=100) even if they are not equally sensitive to the vanity and the influence coefficient, as well as** k. Indeed, Figure 8.7 shows the bias to negativity seems on average poorly sensitive to k while it is not the case for the positivity bias.

Then, both these biases relate each other, particularly through the openness σ. The two apparently different positivity bias identified by Deffuant et al. (2013) are finally mainly grounded in the same mechanism. This sounds not so obvious and deserves some explanations.

The strength of the openness is very important: The biases are always present for a very low openness favouring almost only the influence of those held in high esteem. The difference in the consideration of the message about herself of someone held in high esteem compared to someone held in low esteem is responsible for every bias. It is not only it makes their influence different. **In any case, it also makes the vanity process more determining of what is thought of someone held in low esteem while the vanity and the influence rules what is thought of someone held in high esteem.** Thus, when the openness is low and the vanity is large, the biases are strong. However, even when the vanity is low, it still makes their influence different and the biases tend to remain until the difference of influence between agents held in low and high esteem becomes not significant for the dynamics, especially in regard of the value of the noise δ.

The explanation for the bias to negativity leads in the fact that the punishment of someone held in low esteem has a stronger impact than an equivalent punishment of someone held in high esteem: that is the major explanation for the bias to negativity. This is highly sensitive to the value of the self and of the vanity coefficient ω. When the openness is very large, the propagation coefficient tend to be a constant whatever the level of esteem for the speaker and only the influence and the vanity coefficients, as well as the self-opinion determines the evolution of the speaker (if we consider $k = 0$).

The explanation of the positivity bias leads in the fact that one agent held in low esteem has less chance to become held in high esteem than an agent held in high esteem to become held in low esteem. Indeed, the influence strength of the agent held in high esteem is very high, while the one of the agents held in low esteem is close to zero, especially for lower σ and large ρ. In case of low disagreement between people, it remains possible people held in high esteem think themselves lower and influence strongly the listener in this way. On the contrary, agents held in low esteem thinking themselves higher have a weak chance to change the listener's mind. When σ increases, the difference of influence between those held in high and low esteem decreases. This explains that this bias is sensitive to the vanity ω and the influence ρ coefficients.

When the openness increases, the suppression of the positivity bias occurs quicker than the one of the negativity bias. It is due to the complementary sensitivity to the influence coefficient ρ as shown in section 8.4.2. (see Figure 8.5).

From Figure 8.7, we can also **deduce the link between gossip parameters and emerging structures** (see 2.2.2 for their definitions)**.** The absence of gossip favours disagreement and positive bias. This means in terms of emerging structure that the structures **elite but mainly equality are favoured by the absence of gossip**. On the contrary, as **gossip** strongly decreases disagreement, it **favours dominance, and mainly hierarchy**, **even more for larger values of openness** favouring positive opinions. We notice that **counterintuitively, the hierarchy is favoured by openness to most people while equality is favoured by a population of very narrow people almost just influenced by people held in higher esteem.** Indeed, an increasing openness increases agreement and positivity, and decreases positivity bias (part of underestimated agents).

The suppression for large values of σ of the positivity bias and the negativity bias indicates that much of the known structures can't be observed for such a value of σ.

Indeed, regarding their definition, it seems only hierarchy remains.

8.5 Synthesis and discussion

This section synthesizes our results about the behaviour of the model and the gossip parameters. It considers at first the link between gossip and the emergence and maintenance of a consensus. Secondly, it deals with gossip and bias to oneself or to the others. These two properties, consensus and biases, defined in the Leviathan model the observed structures of opinions. Overall these three facts are useful to examine how our results can feed the debate of social scientists about the social functions of gossip.

We globally found that **the level of consensus is mainly driven by gossip**, especially by the number of peers discussed during a discussion. On the other hand, **the biases**, the positivity bias and the bias to negativity, **are grounded in the face-to-face and mainly explained by the openness depending on the level of esteem for the speaker**. The gossip has only a secondary effect on biases, quite complex and dependent from the vanity and influence coefficients.

8.5.1 Gossip and consensus

In the Leviathan model, the number of peer discussed during a meeting is the main parameter explaining the emergence of a global consensus about agents' values, especially when the influence coefficient is low. The main results are: (1) no gossip, almost no consensus about what to say or what to think about others; (2) increasing gossip decreases the disagreement. Indeed, a consensus can be hardly obtained in absence of gossip. It can emerge from the direct meeting only when the influence parameter is high for a very low vanity coefficient and agents are opened enough to each other. In other conditions and absence of gossip, the disagreement remains. When gossip is introduced, the disagreement decreases. More generally, the more people someone talks about, the more consensual is someone's value. This confirms our hypothesis H1: gossip have a strong influence on the consensus level of the population.

This is in accordance with the social psychology literature (Wert and Salovey, 2004; Foster, 2004; Emler, 1990). Similarly to what is outlined by these authors, gossip in the Leviathan model is a source of reputation, giving each agent a status structuring the population. It maintains the agent status and thus the group structure. It guarantees the connection between people and a sufficient level of agreement regarding the structure.

Following Wert and Salovey (2004), gossiping maintains the structure. For our model, it is not only responsible for maintenance: the structure emerges from gossip; it is different depending on the presence and the strength of gossip (measured as the number of peers discussed during a meeting).

Indeed, basically, without gossip, people structure themselves based on a very positive bias (very high self-esteem) while they despise others (tendency to negativity). This is the domain of the equality structure mainly driven by the openness of people to each other defining the number of friends of an agent. Regarding "real" groups of individuals, this result tends to confirm the importance, in absence of gossip, of the level of openness for the emergence and maintenance of a structure based on a network of friendships.

In the model and always without gossip, for high values of influence, other structures are susceptible to emerge but they are rare all over the parameter space. It tends to confirm the idea proposed by Hobbes that a strong power is necessary to organize the social space. But this is only true in absence of gossip in the Leviathan model. To sum-up, we can say that norms can't emerge without gossip, except if influence and openness are very large for a low vanity but the agreement is just based on face-to-face and can't be obtained if not everyone meet everyone!

This confirms gossip as a bonding mechanism as well as not only necessary for the maintenance of norms but also for their emergence. Indeed, even if the Leviathan model does not consider this case, gossip can link agents not talking each other directly.

But it is not only a bonding mechanism, it is also a way to build and transmit social representations. Some authors (Wert and Salovey, 2004) argue gossiping maintains the structure by sanctioning people who do not respect norms. From our results, we argue in a slightly different way since the structure is not only maintained by the ability of people to sanction or reward each other through gossiping. It is also because agents reinforce their position in the structure not only talking about themselves but also, from their point of view, relative to the agents they know. This allows the emergence of a consensus since, overall, people not only give one-by-one the opinion they have on a given person but of the structure from their own point of view. The more agents we gossip about, the more completely the description of the structure is discussed and the higher the agreement on the structure. Not only, as said in Foster (2004), the agent gets a map of his social environment, ... but he can, as outlined by Emler (1990) negotiate her own social identity by influencing her own ranking not only through direct interaction where each other talks about them, but also by directly influencing a large subpart of the ranking trying to transmit her own ranking. Then, finally defending her own reputation through gossip, the agent disseminates her view of the structure and help the emergence and maintenance of a global structure. This sounds quite in accordance with the literature and confirms the dynamic validity of the theory (Dunbar and Duncan, 1997; Conein, 2011).

In the model, in terms of structure of the population organized through opinions, while the introduction of gossip mainly favours an elite structure, a larger increase of gossip in terms of number of discussed peers favours finally a hierarchy. This can be diagnosed since the elite structure is associated to a high positivity bias and a strong disagreement while a low positivity bias and a high level of agreement characterized the hierarchy. In practice, increasing gossip allows passing from a structure based on relationships and lead by a network of friends to a structure based on norms and consensus about social representations.

In particular, gossip helps to the emergence of recognized leaders. In the Leviathan model, leaders are agents who have a positive reputation: everyone has a positive opinion of them with only small variations from an agent to another. From Deffuant et al. (2013), we know leaders only appear when reputations are consensual and the propagation coefficient sufficiently large compared to the vanity. It gives agents held in high esteem the opportunity to impose her point of view on everyone's value since everyone agrees on her higher status. In the social literature, if gossip has been often cited in terms of status maintenance, it has rarely been cited for high status emergence (to our knowledge, except Emler, 1990), even if the danger of gossip for the reputation have been often discussed (Foster, 2004).

In the Leviathan, the emergence of leadership is also strongly determined by the asymmetrical influence of people held in low and high esteem. It is probably the most important parameter in the explanation of the status emergence and maintenance, whatever the form of leadership style or the structure form. Huet (2013a) has shown in the Leviathan that, since the gossip is introduced in the dynamics for a sufficient level of openness, a leader is susceptible to appear in the population. Also, the number of leaders only depends on the level of openness since agents practice gossiping.

The question about the characteristics of the leaders and the various associated leadership style makes debate in social psychology (Hogg, 2001; van Knippenberg et al., 2004; Uhl-Bien, 2006; Martin, 2009; Huet 2013a). Investigating further the Leviathan model on this question would be interesting.

8.5.2 Biases and a "conditioned-to-esteem" openness

This section is much more dedicated to our study of the link between gossip and biases. We have investigated the relations between the gossip and the positivity bias, the positivity bias and the agreement level about opinions, the positivity bias and the bias to negativity of all opinions. Our study shows the great importance of the openness to the peer influence. The influence is partly ruled by a sigmoid function parameterized by an openness. This makes more influential an agent held in high esteem: The higher it is held in esteem, the more influential is the agent. In particular, when the openness is zero, only the agents held in high esteem are influential; those considered as lower than oneself are not influential.

The openness strength explains most of the biases strength. Indeed, our main results are: (1) the positivity bias and the bias to negativity decrease when the openness increases; (2) a very large openness makes the biases disappearing; (3) while the biases decreases with the increase of the openness, the disagreement increases; (4) the disagreement level, then the positivity bias, but not the bias to negativity, are sensitive to the absence of gossip (the introduction of gossip decreases the disagreement level and the positivity bias on average).

The value of the openness is very important. The vanity can be seen as a self-enhancement and self-protection mechanism which ensures by itself to an agent a preference for herself. Then the first intuition was to consider vanity as responsible for the bias to negativity as well as the positivity bias. However, following the Leviathan, it is only a reinforcing mechanism. The main cause of these biases comes from the way people are more or less open to the other's influence depending on their level of esteem for them.

When the openness is small implying the influence is very conditioned by the level of esteem for the speaker: (1) the punishment of someone held in low esteem has a stronger impact than an equivalent punishment of someone held in high esteem: that is the major explanation for the bias to negativity; (2) one agent held in low esteem has less chance to become held in high esteem than an agent held in high esteem, to become held in low esteem: that is the explanation for the positivity bias. Both these mechanisms are reinforced by the strength of the vanity which is harsher for people held in low esteem compared to people held in high esteem since it is not compensated by their influence about their own value. The openness makes the way people defined themselves in the dynamics. Especially, when it is small, people held in high esteem and people held in low esteem have a very different dynamics. People held in high esteem drives the opinions on themselves through their own influence and neglect what the other say about them. They are quite active in the formation and the maintenance of their self-opinion. On the contrary, people held in low esteem are very passive regarding their self-opinion. They are much more defined through the vanity process applied by their talker, especially through the punishment. It leads them to see themselves more and more negatively through the influence of people they held in high esteem.

When the openness becomes larger, everyone becomes equally influential regarding the propagation coefficient. This makes each agent more active in the definition of her self-opinion as well as in the definition of the opinion of others. In such situation, the biases to oneself (positivity one) and to the others (negativity one) disappear. However, these two biases are not equally sensitive to the vanity and the influence coefficient, as well as to k. So it is not possible from our experiments to observe a positivity bias without observing a bias to negativity. But it is possible to observe a bias to negativity without positivity bias, particularly for large openness and low influence coefficient. This remains an utopia considering the "real" world. Indeed the positivity bias is universal. Its effects can be temporary or locally decreased (Yaniv and Kleinberger, 2000) but remain overall.

The positivity bias and the bias to negativity have never been explained, to our knowledge in terms of openness to others or in terms of interaction with others. They take place in the need of two people to form an opinion of each other to be able discussing. This opinion is built from a mutual influence which a matter of esteem and from some self-enhancement or self-protection mechanism. In the literature, gossip is at the same time considered as dangerous for someone's self-suffering from a bad reputation, and explained as a social way to control cheating. That would mean probably gossip decreases the strength of the positivity bias to avoid the cheating. Perhaps, it can lead a majority of people to undervalue them. On the contrary, the Leviathan model argues gossip has only a small effect on biases and is not responsible for them overall. It can in fact increase or decrease slightly the biases depending on the vanity and the influence coefficients but very poorly compared to the impact of an openness conditioned to the level of esteem. This can explain the difficulty to conclude about the impact of gossip. This can also provide some clues to the apparently contradictory results showing gossiping can be either majorly negative (Wert and Salovey, 2004) or positive (Ellwardt et al., 2012).

Agreement, then the positivity bias, but not the bias to negativity, are sensitive to the absence of gossip (the introduction of gossip decreases the disagreement level and the positivity bias on average). However, agreement and positivity bias appears quite independent from each other. They are not driven by the same parameters: while the consensus is mainly driven by gossip and influence, the biases, particularly the positivity one, are mainly driven by the openness and the vanity! Thus it means in practice they can be present as well as one present and the other absent. We hypothesized there is a negative correlation between positivity bias and consensus since it seems counter-intuitive the positivity bias and consensual reputation can be present conjointly. How some agents judging themselves higher than the average can be agree on someone's value? Indeed, in the literature, gossip is at the same time considered as dangerous for someone's self-suffering from a bad reputation, and explained as a social way to control cheating (Foster, 2004) to protect norms. This means in practice positivity bias and consensus should be negatively correlated. This can be locally the case in the Leviathan model. But the model does not exclude intermediary situations which have been, even often separately, diagnosed in surveys and experiments. The noise occurring during discussion can also help reaching an agreement despite the universal preference for oneself.

Overall, the definition of the structures diagnosed in (Deffuant et al., 2013) has to be revised in the light of these results onto the gossip parameters effect.

8.5.3 Future works

Two types of future studies have to be considered: more studies of the Leviathan model; an investigation by the social psychology of the proposals emerging from the study of the model.

We have seen how gossip participates from the emergence and the maintenance of a structure. However, we can consider our population defines only one group of people. In the literature, structures relate not only to one group but mainly on several groups and how they interact each other, especially through stereotypes (which can be assimilated to the reputation of a given group). This is a particular issue for the Leviathan model which has to be investigated in the future. A possible solution is the modification of the heuristic of talking. At first in the current Leviathan model, everyone talk to everyone on average during one iteration and the interaction takes place in dyads. This is true that accordingly to (Conein, 2011), people gossip more often in dyads. However, this author also stress out some work showing gossip can occur during meeting composed from up to five people. This would be probably very interesting to add such a situation in the Leviathan model. We can also consider a different probability to talk or to meet someone else for agents. It can be through the introduction of a structure of interactions or of various communication apprehensions.

Regarding the social psychology, one of the main proposals of the model to investigate is probably the link between the strength of the gossip and the type of structure of opinions at the group level. Experiencing to define if such a result can be grounded empirically would be very interesting.

Bibliography

Arrow H., K. L. Burns, 2004, Self-Organizing Culture: How Norms Emerge in Small Groups, *The Psychological Foundations of Culture*, M. Schaller and C. S. Crandall, Lawrence Erlbaum Associates. Chapter 8, 171-199.

Beersma B., G. A. Van Kleef, 2012, Why People Gossip: An Empirical Analysis of Social Motives, Antecedents, and Consequences, *Journal of Applied Social Psychology*, 42(11), 2640-2670.

Buckley K. E., R. E. Winkel, M. R. Leary, 2004 texttt"Reactions to acceptance and rejection: Effects of level and sequence of relational evaluation, *Journal of Experimental Social Psychology*, 40(1),14-28.

Carletti T., S. Righi, 2011, Emerging structures in social networks guided by opinion's exchanges, *Advances in Complex Systems*, 14(1), 13-30.

Castellano C., S. Fortunato, V. Loreto, 2009, Statistical physics of social dynamics, *Reviews of Modern Physics*, 81(2), 591-646.

Conein B., 2011, Gossip, conversation and group size: language as a bonding mechanism, *Irish Journal of Sociology*, 19(1), 116-131.

Deffuant G., 2006, Comparing Extremism Propagation in Continuous Opinion Models, *Journal of Artificial Societies and Social Simulation*, 9(3).

Deffuant G., F. Amblard, S. Huet, S. Bernard, N. Ferrand, J. P. Bousset, G. Amon, J. Henriot, N. Gilbert, E. Chattoe, G. Weisbuch, 2000, Simulation de l'évolution des conversions à l'agriuclture biologique dans le département de l'Allier entre 1994 et 1999 par un modèle multi-agents de la population d'agriculteurs, Cemagref. Rapport intermédiaire du projet Européen IMAGES: 21.

Deffuant G., T. Carletti, S. Huet, 2013, The Leviathan model: Absolute dominance, generalised distrust and other patterns emerging from combining vanity with opinion propagation, *Journal of Artificial Societies and Social Simulation* 16(1/5), 23.

Dunbar R., N. Duncan, 1997, Human Conversational Behavior, *Human Nature*, 8(3).

Ellwardt L., G. J. Labianca, R. Wittek, 2012, Who are the objects of positive and negative gossip at work? A social network perspective on workplace gossip, *Social Networks*, 34(2), 193-205.

Emler N., 1990, A social psychology of reputation, *European Review of Social Psychology*, 1(1), 171-193.

Fein S., S. J. Spencer, 1997, Prejudice as self-image maintenance: Affirming the self through derogating others, *Journal of personality and social psychology* , 73(1), 31-44.

Fortunato S., V. Latora, A. Pluchino, A. Rapisarda, 2005, Vector Opinion Dynamics in a Bounded Confidence Consensus Model, *International Journal of Modern Physics*, 16(10), 1535-1551

Foster E., 2004, Research on gossip: Taxonomy, methods, and future directions, *Review of General Psychology*, 8(2), 78-99.

Galam S., 2008, Sociophysics: a review of Galam models, *International Journal of Modern Physics C*,19, 409-440.

Gargiulo F., S. Huet, 2010, Opinion dynamics in a group-based society, *Europhys. Lett.*, 91(5).

Gargiulo F., S. Huet, 2012, New discussions challenge the organization of societies, *Advances in Complex Systems*, 0(0), 1250033.

Hobbes T., 1651, *Léviathan. Traité de la matière, de la forme et du pouvoir ecclésiastique et civil*.

Hogg M. A., 2001, A Social Identity Theory of Leadership, *Personality and Social Psychology Review*, 5(3), 184-200.

Hogg M. A., J. C. Turner, B. Davidson, 1990, Polarized Norms and Social Frames of Reference: A Test of the Self-Categorization Theory of Group Polarization, *Basic and Applied Social Psychology*, 11(1), 77-100.

Hoorens V., 1993, Self-enhancement and superiority biases in social comparison, *European Review of Social Psychology* , 4, 113-139.

Huet S., 2013a, Formes de leadership, défense de soi et commérage, *Modèles Formels pour l'Interaction, PFIA 2013*, Lille (France),14.

Huet S., G. Deffuant, 2008, Bounded Confidence with Rejection: Clusters or Scattered Opinions? *ESSA, European Social Simulation Association* Brescia, Italy,12.

Huet S., G. Deffuant, 2010, Openness leads to opinion stability and narrowness to volatility, *Advances in Complex Systems*, 13(3), 405-423.

Kniffin K., D. Wilson, 2005, Utilities of gossip across organizational levels, *Human Nature*, 16(3), 278-292.

Leary M. R., J. M. Twenge, E. Quinlivan, 2006, Interpersonal Rejection as a Determinant of Anger and Aggression, *Personality and Social Psychology Review*, 10(2), 111-132.

Lorenz J., D. Urbig, 2007, About the power to Enforce and Prevent Consensus by Manipulating Communication Rules, *Advances in Complex Systems*, 10(2), 251-269.

Martin J. L., 2009, Formation and stabilization of vertical hierarchies among adolescents: towards a quantitative ethology of dominance among humans, *Social Psychology Quaterly*, 72(3), 241-264.

Moliner P., 2001, *La dynamique des représentations sociales,* Grenoble (France).

Moscovici S., 2000, *Psychologie sociale des relations à autrui*, Paris, Nathan Université.

Myers D., S. J. Spencer, C. Jordan, 2009, Social Thinking, *Social Psychology*, F. C. Edition. Canadian, 63.

Srivastava S., J. S. Beer, 2005, How Self-Evaluations Relate to Being Liked by Others: Integrating Sociometer and Attachment Perspectives, *Journal of Personality and Social Psychology*, 89(6), 966-977.

Stephan Y., C. Maiano, 2007, On the Social Nature of Global Self-Esteem: A Replication Study, *The Journal of Social Psychology*, 147(5), 573-575.

Sznajd-Weron K., 2005, Sznajd Model and Its Applications, *Acta Physica Polonica B*, 36(8), 1001-1011.

Tajfel H., 1978, *Differentiation between social groups: Studies in the social psychology of intergroup relations*, London: Academic Press.

Turner J. C., 1984, Social identification and psychological group formation, *The social dimension*. H. Tajfel. Cambridge, Cambridge University Press, 518-538.

Turner J. C., M. Hogg, p. J. Oakes, S. D. Reicher, M. S. Wetherell, 1987, *Rediscovering the social groups: A self-categorization theory*, Cambridge, MA: Basil Blackwell.

Uhl-Bien M., 2006, Relational Leadership Theory: Exploring the social processes of leadership and organizing, *The Leadership Quarterly*, 17(6), 654-676.

Urbig D., R. Malitz, 2007, *Drifting to more extreme but balanced atttiudes: Multidimensional attitudes and selective exposure*, 4th Conference of the European Social Simulation Association, Toulouse, 10-14 September.

van Knippenberg D., B. van Knippenberg, D. De Cremer, M. A. Hogg, 2004, Leadership, self, and identity: A review and research agenda, *The Leadership Quarterly*, 15(6), 825-856.

Waylen A. E., M. S. Horswill, J. L. Alexander, F. P. McKenna, 2004, Do expert drivers have a reduced illusion of superiority? *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4-5), 323-331.

Wert S. R., P. Salovey, 2004, A social comparison account of gossip. *Review of General Psychology* 8(2): 122-137.

Wood J. V., A. L. Forest, 2011, Seeking Pleasure and Avoiding Pain in Interpersonal Relationships. *Handbook of Self-Enhancement and Self-Protection*, M. D. Alicke and C. Sedikides. New York, London, The Guilford Press, 258-278.

Yaniv I., E. Kleinberger, 2000, Advice taking in decision making: Egocentric discounting and reputation formation, *Organizational behavior and human decision processes*, 83(2), 260-281.

Chapter 9

Discovering actors networks behind dynamics of opinion. A case study.

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Abstract

Text-mining analysis can describe evolutions of data, even big data, but between two points many curves can join them depending on the dynamics of the process. If statistics approximation can produce error estimation with tendencies, how modelling of dynamics opinion can produce networks estimations from the data ? This paper studies this research issue with the case study dealing with the controversy of abnormal death of bees among French speaking journalists during a period of 13 years. Articles are tagged with three stances to explain the phenomenon, a uni-factor cause, the use of pesticides, a multi-factor cause, including one other factor different than pesticides at least, or the absence of an understanding. On this basis, evolutions of the respective proportions of each category of agents are obtained. Assuming agents are either flexible or inflexible journalists about their respective reports of the facts, their associated networks are extracted from the data applying Galam Unifying Frame (GUF) of opinion dynamics. The variation of inflexible agents explaining the issue either with unifactor reasons or multifactor causes, is a result of the modelling. From those distributions the actual networks of agents can be inferred.

Keywords: formal modelling, sociophysics, sociology, opinion dynamic, daily press, text-mining, renormalization group, precautionary principle, bees colony collapse disorder.

9.1 Introduction

A good deal of publications has already been devoted to the theoretical study of public opinion, especially within the framework of sociophysics (Castellano et al. 2009, Galam 2008, 2012). This work analyzes the diffusion of two competing opinions whose dynamics leads to the success or the disappearance of one of the opposite view. Dynamics is a selection process seen as repeated local interactions between agents providing a new comprehension of social phenomena (Galam 2002).

But not many real cases have been investigated using real empirical data. The challenge is to compare descriptive data analysis with theoretical modelling. This paper presents a case study with a subject dealing with controversial environmental risks. In this case, public problems treatment in media makes the understanding of the public opinion mechanisms a great challenge. In our context, application of the precautionary principle is a sensitive issue. The precautionary principle states that if a given policy is suspected of a possible harm to either the public or the environment, in the absence of a scientific consensus about its risk status, implementing that policy is questionable and should be held on (French Constitution 2004, Galam 2005a).

Empirical data used for this paper deal with the abnormal bees' death, also called colony collapse disorder (CCD) in some countries including the US. This controversy is emblematic of the question of risks connected to the burden of making eventual mandatory arbitrage to ban the use of some specific chemical products. Real implementing of innovation leads to public debates which are inevitably driven by incomplete scientific data. The question arises on how possible risks are translated (Callon 1986) into solid (Tonnies 1922) facts during the ongoing associated public debate (Dewey 1927, Galam 2010)?

Our corpus is considering almost 1500 articles dealing with the topic of the abnormal deaths bees published in French newspapers during the period 1998-2010, i.e., thirteen years. With a text mining analysis[3] each article is categorized with one of three views about the possible explanation of this abnormal bees' disappearing. The first category gathers articles asserting the abnormal deaths is due to only one factor, the use of pesticides. At the opposite, other articles argue that many factors combined together produce the abnormal facts, it is thus a multi-factor cause. And a third category of articles states that the abnormal deaths is still an enigma without clear explanation.

Then, data are confronted with modelling in order to question back the social meaning of the dynamics. Our hypothesis asserts the evolution over the years of the importance of support among journalists for each view can be modelled as the result of interactions between journalists agents. Two kinds of agents are used in the model. Inflexible agents, those who never change their mind, and flexible agents, those who can change their mind (Galam and Jacobs 2007, Galam 2005b). The variations exhibited by the data suggest that the number of inflexibles vary from year to year. Those varying numbers of inflexibles are inferred applying Galam Unifying Frame (GUF), also denoted the Galam sequential probabilistic model of opinion dynamic or the majority model. Applying the model to the empirical data built from a corpus of published articles in newspapers provides a frame to go back to the data and question their social meaning with the eventual social mechanisms.

The rest of the paper is structured as follows. The problem is set in the second section where the dynamics opinion is quantitatively evaluated with empirical data. Third section highlights the newspaper level to show the inflexible or flexible agents profile. GUF is adapted to the problem in section four to extract inflexible agents proportions as a function of time in section five. The social meaning behind the data is addressed in section six enlightening the determinant role of lobbying and other externalities. The results are discussed in the last section.

9.2 Behind the dynamics there are many hypotheses

A boolean equation dealing with the abnormal death of bees in France during the period 1998-2010 has led to extract a corpus of almost 1500 French articles from Lexis-Nexis and Factiva databases. The collection of papers is taken from daily, weekly and monthly French speaking press. The annual distribution of the number of articles is shown in (Figure 9.1).

[3] An extensive text mining research program have been performed on the same corpus (Delanoe 2004, 2007, 2010) in order to extract the main terms that have a significant weight in the public debate. The text mining method used in this paper benefits from this series of works since it only categorizes articles if it does contain some specific terms at least.

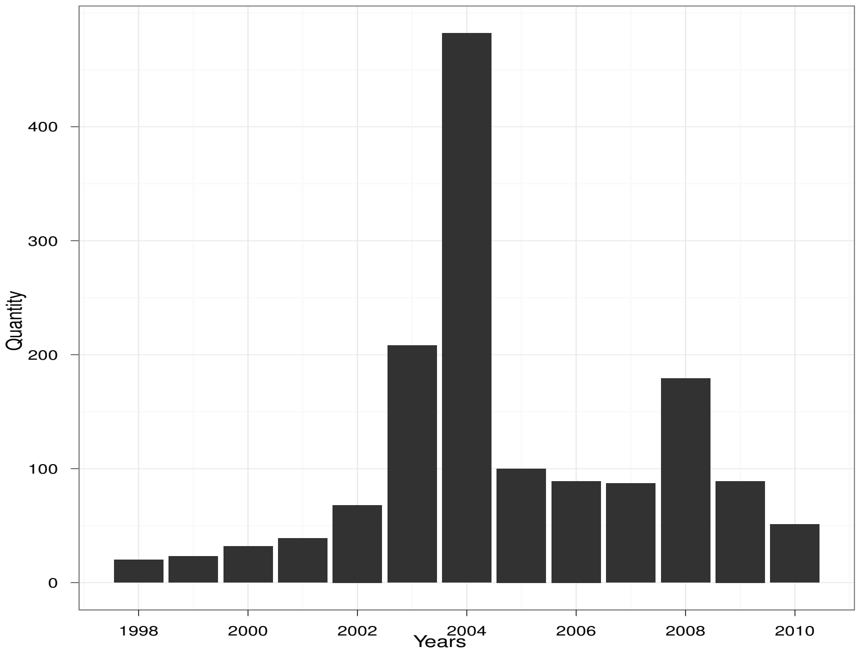

Figure 9.1: Number of articles published each year by French daily, weekly and monthly press dealing with the bee deaths from 1998 till 2010. Over the thirteen years the total amounts to 1467.

A systematic textual analysis of all the collected papers (Delanoe 2004, 2007, 2010), shows that within the articles dealing with the question of the abnormal bee deaths some pointed towards scientific results suggesting a single cause identified as the use of pesticides (Chateauraynaud 2004, Delanoe 2004), while others were emphasizing other results suggesting the combination (Chiron and Hattenberger 2008) of several different causes (Maxim and van der Sluiis 2010). A combination of words has been established to categorize each view.

1. Articles containing words as "pesticides" or "insecticides" or "chemicals" and without referencing others factors are categorized in the uni-factor class;
2. Articles containing at least one word in this list are put in the class of the multi-factors cause:
   - "Foulbrood" (it is a bacteria);
   - "Nosema" or "Nosemose" (it is a mushroom);
   - "Varroa" (it is a parasite);
   - "Virus" (it represents mainly the Israel acute paralysis virus);
   - "Predators" or "galleria mellonella" or "aethina tumida" or "Asian predatory wasp";
   - "Monoculture" or "natural toxin of sunflower" (which refer to agricultural practices);
   - "Pollution" or "climate change" or "meteorology" (which represent the external or environmental causes);
   - "Multi-factors" or "many factors";
3. Articles containing sentences as below are assigned to the class claiming there exists no understanding yet (sentences detected with qualitative reading):
   - "While it would be impossible to formally accuse the pesticide being exclusively responsible for the fall of the hive population";
   - "It is no element of new evidence of anything";
   - "All data analyzed does not criminalize formally and exclusively the treatment of sunflower seeds";
   - "The pesticide was evaluated on two occasions over the last three years, and we believe that there is no cause and effect relationship between our product and the problems of orientation of bees".

Semi-automatic textual analysis tools combined with human reading for validation has enabled to tag 84% of the corpus articles, leaving 16% of the articles untagged. Some articles do not infer any cause of the bees' death since authors have been mentioning general facts only. In this specific case these articles remain untagged. We have restricted the corpus to the tagged articles shown in Figure 9.2.

For the modelling, i.e. next figures, years will be numbered from $T = 0$ for 1998 to $T = 12$ for 2010. The corresponding proportions of articles for the uni-factor class denoted by U_T are respectively 0.500, 0.60, 0.677, 0.513, 0.627, 0.831, 0.769, 0.517, 0.540, 0.422, 0.544, 0.40, 0.255 with $T = 0, 1, \dots, 12$. A indicates the opinion of journalists who belong to the uni-factor class. Simultaneously, the opinion of journalists belonging to either one of both other two classes, the multi-factors and the no-proof ones, is noted B.

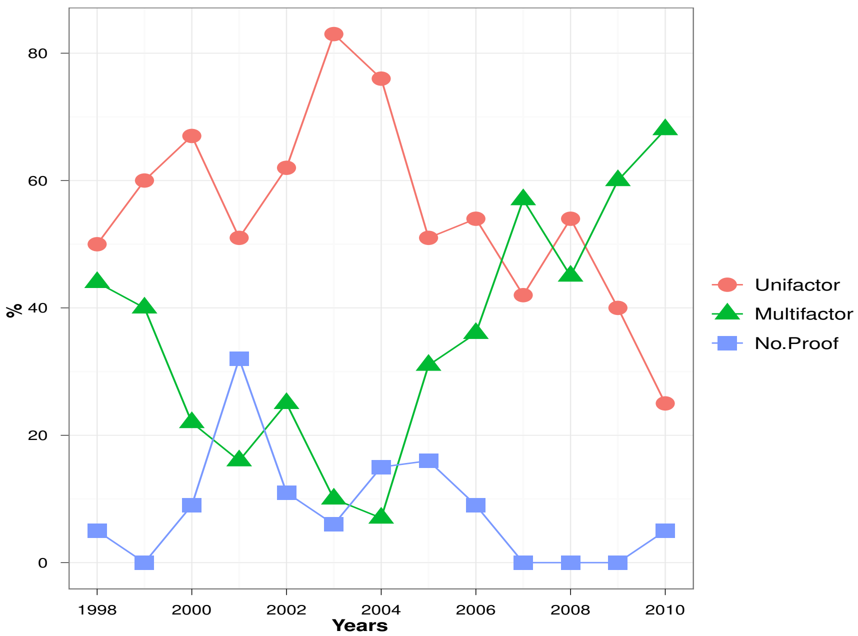

Figure 9.2: Proportions of articles published each year by daily press dealing with unifactor, multi-factors or no-proof categories. 84% of the corpus, i.e. 1233 articles, have been tagged.

9.3 The newspapers publications in time highlight the main profiles types

The corpus of selected articles is sourced from almost 60 different newspapers. Then to model dynamics of opinion we need to check if journal contributions exhibit different profiles. Looking at the contributions from "Le Monde" (Figure 9.3) we observe large variations. Indeed, some years present 0% of the articles for either A or B as respectively in 2001, 2006, 2007, 2008, 2009. Such facts mean that during those years all journalists were either all flexibles or flexibles with some inflexibles present only on the opinion side which has been advocated at 100%. In other words a 0% support for one opinion implies the absence of inflexibles on this side. Years for which the dynamics did not reach 100% for one opinion, inflexibles may have been present on both sides.

While 4 years 2001, 2006, 2007, 2008 are characterized by zero inflexibles for the uni-factor cause, only 1 year, 2009, feature zero inflexibles for the multi-factors cause. When the year contributions does not reach 100% and split over support of A and B, we can infer about a possible existence of inflexibles on one or two sides like for 1998, 1999, 2000, 2002, 2003, 2004.

The contributions from newspaper Sud Ouest (Figure 9.3) reveal the possible presence of inflexibles on each side every year. Contributions from newspaper "Le Figaro" (Figure 9.3) exhibit as for "Le Monde" several years with 100% polarization, namely 1998, 1999, 2001, 2005, 2007, 2008, 2009, 2010. These years are characterized by zero inflexibles for the uni-factor cause (while for "Le Monde" it occurs for both sides). This position was modified in 2000 and really reversed in 2002-2004, with a slight surge in 2006.

The results of Figure 9.3 hint at a key role played by inflexibles in the making of the data of Figure 9.2. Such a fact would question the social meaning of those results. Accordingly, it is of importance to extract the values of the proportions of inflexibles agents present at each year. Specifically the successive brutal changes of trends as exhibited by Figure 9.2 indicate a change of proportions of the inflexibles.

Since the goal is to build back the actors network from the dynamics, implementing GUF model appears appropriate as it does not infer structures of network *a priori*. Indeed, this model incorporates only the effect of inflexibles on the dynamics of opinion among flexible agents (Galam 2010, 2002, Galam and Jacobs 2007, Galam 2005b). Moreover, it has been shown that the size of the local updated groups does not modify the main results since increasing the group size reduces the number of updates required to reach the attractors (Galam 2002). To keep the equations analytically solvable, group updates of size 3 have been used.

9.4 Using a model to reinterpret the problem

9.4.1 The framework of basic GUF which depends on the group size distribution

The GUF model investigates the competition between two opposite opinions within a population of inflexible and flexible agents(Galam 2005a, 2002). Each agent has only one opinion. Rules of diffusion assert flexible agents can shift opinion. Indeed, within a group of agents, a flexible agent gets the opinion which has the majority. Then dynamics is implemented via repeated random meeting of agents within small groups

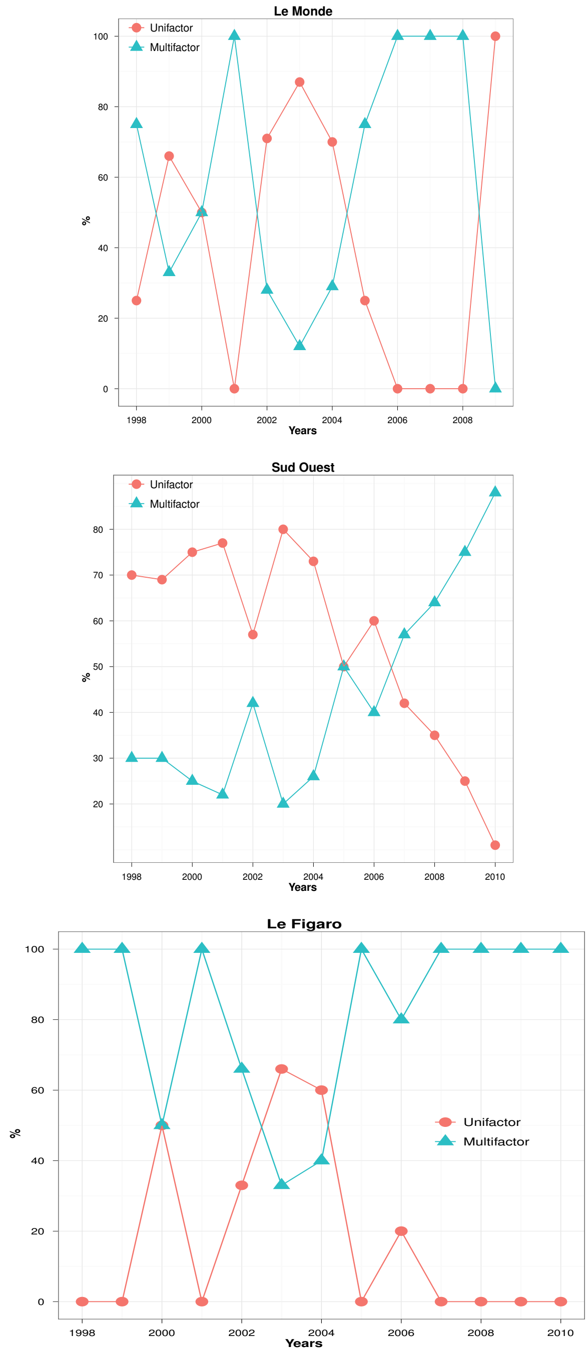

Figure 9.3: Proportions of articles published each year by Le Monde (total of 67 tagged articles), Sud Ouest (total of 209 tagged articles) and Figaro (total of 62 tagged articles) newspapers dealing with uni-factor and not-unifactors which includes both multi-factors and no proof papers.

of various sizes. For each distribution, agents' opinions are locally updated according to the respective local majorities in its own group. For even size groups in case of equality, agents preserve their current opinions.

In real life people meet and discuss in groups of different sizes. However these groups are usually small. In the case of journalists treated here, those meetings occur within the social network of journalists in which they can interact. To account for this reality the basic GUF can be extended to include a distribution of sizes leading to the general update expression,

$$u_{t+1} = \sum_{i=1}^{L} s_i \{ \sum_{j=[\frac{i}{2}+1]}^{i} C_j^i u_t^j (1-u_t)^{(i-j)} + \frac{1}{2} k(i) C_{\frac{i}{2}}^i u_t^{\frac{i}{2}} (1-u_t)^{\frac{i}{2}} \}, \tag{9.1}$$

where u_t and u_{t+1} denote the proportion of journalists in favor of A at times respectively t and t+1 and v and w denote proportions of A and B inflexibles. L is the size of the largest group, $C_j^i \equiv \frac{i!}{(i-j)!j!}$, $[\frac{i}{2}+1] \equiv$ Integer Part of $(\frac{i}{2}+1)$, and $k(i) \equiv [\frac{i}{2}] - [\frac{i-1}{2}]$ yielding $V(i) = 1$ for i even and $V(i) = 0$ for i odd. The proportion of groups of size i is defined by the probability distribution s_i under the constraint $\sum_{i=1}^{L} s_i = 1$. Including groups of size one accounts for the fact that not all agents discuss at the same time in local groups.

Although an infinite number of size distribution $\{v_i\}$ is possible in principle, it happens that the dynamics is qualitatively unchanged with the two attractors $u_A = 1$, $u_B = 0$ and the tipping point $u_t = \frac{1}{2}$ being invariant. The only difference is the number of required iterations to reach either attractor. Larger groups contribute to accelerate the polarization effect. Nevertheless, analytic solving of Eq. (9.1) is possible only up to $L = 4$, otherwise for $L > 4$ numerical solving is required. On this basis, to keep calculations simple and tractable we restrict the group sizes to 3 in this paper.

9.4.2 The heterogenous GUF mixing inflexible and flexible agents

The uni-factor distributions in Figure 9.2 reveal a series of brutal variations at years 2000, 2001, 2003, 2005, 2006, 2007, 2008. According to the model (Eq. 9.1), opinion reaching the majority is even more dominating. This result is incoherent with the empirical data evolutions. To counter this systematic increasing trend external parameters must be integrated in order to enable a topological modification in dynamics.

It is worth to stress that, in GUF model, inflexibles do not have more powerful arguments, they still have each one vote alike flexibles. They do obey one person one vote in a group discussion. However once every agent in the local group has written, they do not follow the local majority rule in case they are minority. In the present work we consider a population which is a mixture of flexible and inflexible agents. The proportions of inflexibles are external parameters while the respective proportions of flexibles in favor of A or B are internal parameters driven by the dynamics of local discussions. The possibility to make inflexibility an internal parameter has been studied in Martins and Galam (2013) but is not introduced here. Accordingly, Eq. (9.1) becomes

$$u_{t+1} = -2u_t^3 + (3 + v + w)u_t^2 - 2vu_t + v, \tag{9.2}$$

where v and w denote proportions of A and B inflexibles. Associated dynamics has been extensively studied in Galam and Jacobs (2007), Galam (2005b) where the various cases of flow opinion diagram have been obtained as a function of all combined ranges of values for v and w.

9.4.3 Fitting the model to data

Proportions of inflexible agents can be modified every year as a result of the activation of external pressures in favor of either one opinion. Then each year a flexible agent may turn to an inflexible status and vice versa. During each year, inflexible agents proportions are kept fixed for each successive update[4].

Then dynamics of opinion is implemented in two steps. First, some fixed proportions of inflexibles are given. And in a second step, n consecutive updates of flexibles are implemented keeping unchanged the inflexible proportions. Then the proportions of inflexibles are modified before n new updates are performed. This two steps dynamics is implemented by modifying Eq. (9.2) into

$$u_{T,t+1} = -2u_{T,t}^3 + (3 + v_T + w_T)u_{T,t}^2 - 2v_T u_{T,t} + v_T, \tag{9.3}$$

where $u_{T,t}$ and $(1 - u_{T,t})$ denote the proportions of journalists in favor of respectively A and B during year T and intra-time t. The associated proportions of inflexibles v_T and w_T are independent of the intra-time. They depend only on the year T. Given $u_{T,t}$, GUF determines $u_{T,t+1}$ obtained after one update of opinions for fixed values of v_T and w_T.

To account for the interplay between the two timescales we notice that since $T = 0, ..., 12$ for the years and $t = 1, 2.., n$ for the intermediate intra-time within a year, we have the congruence $(T, n) = (T + 1, 0)$.

In addition, we note that only the fraction $u_{T,t} - v_T$ is flexible, i.e., able to shift opinion under convincing local arguments. We thus have $u_{T,t} \geq v_T$ and $1 - u_{T,t} \geq w_T \iff u_{T,t} \leq 1 - w_T$, which combine to,

$$v_T \leq u_{T,t} \leq 1 - w_T, \tag{9.4}$$

with the constraints $0 \leq v_T \leq 1, 0 \leq w_T \leq 1$ and $0 \leq v_T + w_T \leq 1$. A detailed study of the properties of Eq. (9.3) has been performed in Galam (2010), Galam and Jacobs (2007).

9.4.4 Implementing model to rediscover the data

It is worth to emphasize that we do not aim at reproducing the data exhibited in Figure 9.2. The methodology aims at evaluating the minimum values of both the respective proportions of inflexibles v_T and w_T and the intra-time n, which are compatible with the data for every pair of successive years. Given a pair of values U_T and U_{T+1} we determine the minimum values v_T, w_T and n, which starting from $u_{T,0} = U_T$ reach $u_{T,n} = U_{T+1}$ with a precision of 10^{-3} after n successive iterations of Eq. (9.3). In a second step, writing $u_{T,n} = u_{T+1,0}$ we evaluate the minimum values of v_{T+1} and w_{T+1} which allow to get $u_{T+1,n} = U_{T+2}$ starting from $u_{T+1,0}$.

More precisely, we start from $u_{0,0} = U_0$ to evaluate v_0 and w_0 such that $u_{0,n} = u_{1,0} = U_1$. Then we evaluate v_1 and w_1 such that $u_{1,n} = u_{2,0} = U_2$. And so on and so forth up to the evaluation v_{11} and w_{11} such that $u_{11,n} = u_{12,0} = U_{12}$. Then, the end of each period of iterations is the beginning of a new period of iterations with new parameters.

[4]This constraint is necessary for modelling but questionable to meet real journalistic practices. Indeed, why should we slice the social phenomenon by year and fix the behaviour accordingly? In further research, the temporal parameter will be tested with different time slices.

Year	T	v_T^n	w_T^n	$u_{T,0} \to u_{T,n}$	Nb	ΔU_T	n
1998	0	0.091	0	$0.500 \to 0.600$	18	0.118	3
1999	1	0	0.080	$0.600 \to 0.677$	20	0.109	3
2000	2	0	0.285	$0.677 \to 0.513$	31	0.084	3
2001	3	0.081	0	$0.513 \to 0.627$	37	0.082	3
2002	4	0	0.019	$0.627 \to 0.831$	59	0.063	3
2003	5	0	0.169	$0.831 \to 0.769$	178	0.028	5
2004	6	0	0.225	$0.769 \to 0.518$	368	0.022	8
2005	7	0	0.015	$0.518 \to 0.541$	85	0.054	3
2006	8	0	0.169	$0.541 \to 0.422$	61	0.064	3
2007	9	0.209	0	$0.422 \to 0.544$	71	0.059	3
2008	10	0	0.121	$0.544 \to 0.400$	169	0.038	5
2009	11	0.033	0	$0.400 \to 0.251$	85	0.053	3
2010	12			0.251	51	0.061	

Table 9.1: Inflexible proportions at each year to reach the following one covering 12 annual intervals.

To determine which value n to use, we notice that the number of articles for each year period is distributed within 3 different groups with respectively less than 100 (10), between 100 and 300 (2), and more than 300 (1) as seen in Table (9.1). For each group we determine the minimum value of n which allows to implement $u_{T,n} = U_{T+1}$ starting from $u_{T,0}$ for all cases of each group. We found respectively, $n = 3, 5, 8$ as reported in Table (9.1).

From Table (9.1) it is seen that for any given year n, only one fitting parameter is used since always either v_T or w_T is equal to zero. The variation of $u_{T,n}$ as a function of successive iterations are shown in Figure 9.4. The error bars are also reported in the Figure although GUF values of the series of $u_{T,n}$ recover perfectly the data values U_T for all the 13 years. Figure 9.5 exhibits the simultaneous variations of v_T and w_T as a function of T.

9.5 Behind the data another sight on the networks

The picture drawn from the modelling leads to a reverse conclusion of what would have been expected. Proportions of categorized articles follow different evolutions than proportions of agents on each side. From empirical dynamics we are lead to question how journalists interact in the public debate.

If in the first year proportions are equally distributed ($U_0 = 0.50$) the uni-factor agents appear to be more inflexibles on its side while none was present on the other side. This result highlights the determinant advantage made by the first whistle-blowers about a new controversy.

Once the controversy was launched, the multi-factor inflexible agents happened while the uni-factor side turned down its pressure.

From high level of journalists against the use of pesticides, the industrial side launched a significant pressure getting up to $w_2 \approx 0.285$ inflexibles. The multi-factor expected right opinion was then achieved.

But, with the threshold nature of the dynamics (Galam 2002, Delanoe 2010), the next years brought back the uni-factor side to rather high values in 2002 and 2003 even

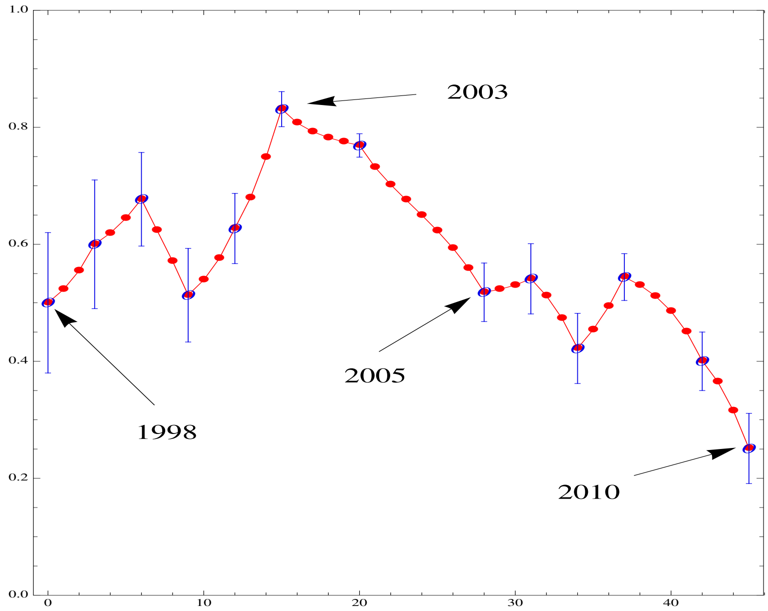

Figure 9.4: Evolution of the proportion of journalists advocating the uni-factor cause as a function of updates using Eq. (9.1) with $9 \times 3 + 2 \times 5 + 1 \times 8 = 45$ updates. Circles show the overlap with the data calculated per year and vertical lines indicate error approximation using the variance of a binomial generator.

if these values are lower than expected. Indeed, beekeepers' view has been translated in public media through political spokesmen during regional and European elections in 2004. Indeed, pesticides have been banned from sell that year.

With new scientific studies in 2005, the multi-factor side is relaunching the debate in the media.

9.6 Conclusions

This case study shows how empirical data and theoretical modeling can produce a heuristic framework to analyze a controversy. Starting from empirical data, the use of a model has allowed to go back to the data to question their social meaning.

First a text-mining analysis of published articles has been performed in order to categorize articles. Facts reports dealing with the causes of the critical phenomenon have been used to nest the papers. The first category advocates the opinion that the cause is uni-factor, namely the use of pesticides. The second category asserts multi-factors cause or the absence of an identified cause.

Second, the evolution of each proportion of categorized articles is assumed to be rebuilt with dynamics of interactions among journalists. Two types of agents are considered. Some never change their mind with a dispositional view: they are inflexible agents. Some have a positional view since they may shift their opinion. The respective proportions of agents follow a function of time and vary only on a year time scale. Between each pair of consecutive years, the fraction of journalists in each class is inferred from the distribution of opinions using GUF model of opinion diffusion (Galam

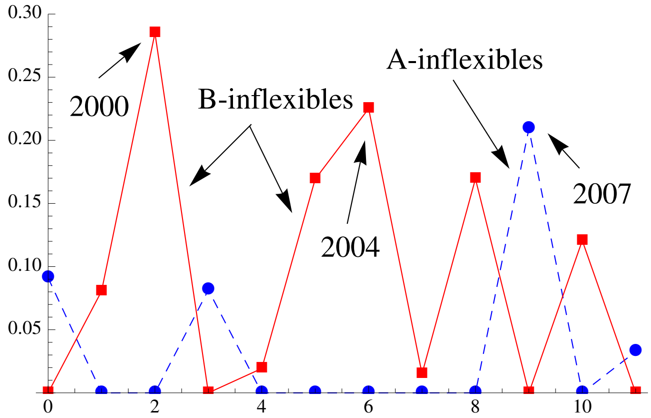

Figure 9.5: Variation of inflexible proportions v_T and w_T as a function of year.

2005b). The evolution of respective proportions of inflexibles is thus obtained for each year.

Third, those proportions of inflexibles extracted from the model, are turned back towards the empirical data to question the interactions between agents. For example we can question possible pressure on the journalists from the various involved parties.

The GUF model does not suppose any network *a priori* in order to question quantitative text mining evolutions with the results of the simulation. In that context, actors networks can be questioned with *scenarii* which include external pressure, social structure and frame of the debate.

Bibliography

Borghesi C., S. Galam, 2006, Chaotic, staggered, and polarized dynamics in opinion forming: The contrarian effect, *Physical Review E*, 73, 066118.

Callon M., 1986, *J. Law, Power, action and belief: a new sociology of knowledge?*, chapter Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay, 196-223. Routledge, London.

Castellano C., S. Fortunato, C. Vittorio Loreto, 2009, Statistical physics of social dynamic, *Reviews of Modern Physics*, 81, 591-646.

Chateauraynaud F., 2004, *La croyance et l'enquête*, volume XV, chapter L'épreuve du tangible. Expériences de l'enquête et surgissements de la preuve, Raisons pratiques, Paris.

Chiron J., A.-M. Hattenberger, 2008, Mortalités, effondrements et affaiblissements des colonies d'abeilles, Technical report, AFSSA, Novembre.

Delanoë A., 2004, Quand les abeilles meurent les articles sont comptés, généalogie et analyse sémantique d'une crise médiatique, *Strategic, Scientific and Technological Watch*.

Delanoë A., 2007, Analyse des dynamiques managériales face à la contestation sociale : éléments statistiques du cas "ni Gaucho, ni Régent", *Strategic, Scientific and Technological Watch*.

Delanoë A., 2010, Statistique textuelle et séries chronologiques sur un corpus de presse écrite. Le cas de la mise en application du principe de précaution, *JADT, Journées internationales d'Analyses statistiques des données Textuelles*.

Dewey J., 1927, *The public and its problems*, Holt, New York.

French Constitution, 2004, Article 5 - Charte de l'environnement.

Galam S., 2002, Minority opinion spreading in random geometry, *Eur. Phys. J. B*, 25, 403-406. Rapid Note.

Galam S., 2005a, Heterogeneous beliefs, segregation, and extremism in the making of public opinions, *Phys. Rev. E*, 71, 046123.

Galam S., 2005b, Local dynamics vs. social mechanisms: A unifying frame, *Euro. Phys. Lett.*, 70, 705-711.

Galam S., F. Jacobs, 2007, The role of inflexible minorities in the breaking of democratic opinion dynamics, *Physica A*, 381, 366-376.

Galam S., 2007, From 2000 Bush-Gore to 2006 Italian elections: voting at fifty-fifty and the contrarian effect opinion dynamics, *Quality and Quantity Journal*, 411, 579-589.

Galam S., 2008, Sociophysics: a review of Galam models, *International Journal of Modern Physics C*,19, 409-440.

Galam S., 2010, Public debates driven by incomplete scientific data: The cases of evolution theory, global warming and h1n1 pandemic influenza, *Physica A*, 389, 3619-3631.

Galam S., 2012, *Sociophysics, A Physicist's Modeling of Psycho-political Phenomena*, Springer, New York.

Gusfield J.-R., 1981, *Drinking-driving and the symbolic order. The culture of public problems*, The University of Chicago Press.

Katz E., P. Lazarsfeld, 1955, *Personal influence. The part played by people in the flow of Mass Communications*, Transaction Publishers, New Brunswick, New Jersey.

Martins ACR., S. Galam, 2013, Building up of individual inflexibility in opinion dynamics, *Physical Review E*, 87, 042807.

Maxim L., J. P. van der Sluijs, 2010, Expert explanations of honeybee losses in areas of extensive agriculture in france: Gaucho ® compared with other supposed causal factors, *Environmental Research Letters*, 5(1), 014006.

Tonnies F., 1922, *Kritik des öffentlichen Meinung*, Springer Berlin Heidelberg.

Part III

Interactions in social communication

Chapter 10

From Newton's cradle to communication using natural language: are human beings more complex than balls?

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Abstract

The simplest and best known models of interactions in classical mechanics are the ones which describe exchange of energy, of linear momentum or of electric charge between small macroscopic objects, such as balls. I will show that the set of principles classically used to account for what happens in Newton's cradle does not really account for what happens in Newton's cradle and that, moreover, it predicts possible behaviors that are never observable (this, obviously, is not an original contribution but the demonstration is not so old and is generally ignored in school books though it deserves being remembered, and will be useful for the purpose of this paper).

Simpler even is the model generally used when dealing with signal and its propagation; it is that model, however, that is almost universally used as a model of human communication. We will see some of the deplorable and piteous consequences of that carelessness on the way meaning is studied in linguistics and on the possible results of such studies. I will suggest a more serious, though more difficult, way to represent human communication and will examine its consequences on the linguistic approaches to describe the meaning of natural language expressions and account for the semantic phenomena.

10.1 From ball to balls: carelessness as a generalized intellectual system?

The simplest and best known models of interactions between material entities are the ones which describe exchange of energy, of linear momentum or of electric charge between small macroscopic objects, such as balls. Let us examine, for instance, the typical scenario of Newton's cradle, when only one of its balls is thrown, as illustrated in Figure 10.1.

The classical description of the observable interactions can be summed up as follows:

> "When the ball at one end is pulled aside and released it collides with the remaining stationary balls and the ball at the other end of the row moves off to reach what appears to be the same height from which the first ball was released. All the other balls are apparently at rest."

[Gauld 2006, p.597]

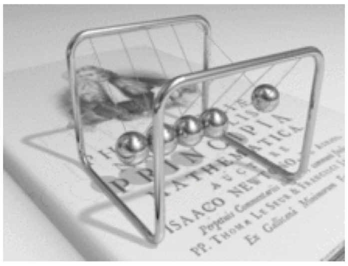

Figure 10.1: A material realization of Newton's cradle
A material realization of Newton's cradle. [2]

From this observation, many school books and didactic web pages (erroneously) conclude that "the effect of the collision simply consisted in the exchange of velocities between both balls"[3]. Considering the situation in which more than one ball is pulled and released allows to slightly better that conclusion, but, as we will see, not to correct it. The cases with more than one ball can be described as follows:

> If two balls are pulled aside and released, after the collision two balls move off - again apparently to the same height - with the rest stationary. Releasing three balls results in three balls moving off after the collision.

In those cases, clearly, velocity is not enough and school books are forced to introduce the notion of momentum conservation and, for some of them, that of energy conservation.

More precisely, the 'explanation' goes like this:

> *Ball A (system A) which was separated from the other four (B, C, B', A'), after being released, meets the remaining balls (system [B, C, B', A']), and transmits its momentum to the system* $[A,\ B,\ C,\ B',\ A']$. *In the theoretical conditions of the experiment, it is assumed that there is no loss of momentum or energy. System* $[A,\ B,\ C,\ B',\ A']$ *then transmits, energy and momentum to ball A' (opposite of A), which separates in turn; the system is thus in a position symmetrical to the initial situation, in which A' plays the role of A and vice versa.*

However, this reasoning does not explain why A' moves off alone (and, more generally, why the number of balls which move off after collision is equal to the number of balls which provoked collision). Gauld (2006) reveals an interesting but rather startling fact connected to this lack of explanation: none of the 40 scholar books he studied considers that question as requiring an explanation...

> "About one third of about 40 tertiary physics textbooks sampled contained some reference to Newton's Cradle [...] However, it is interesting to note that, in spite of the apparent simplicity of the demonstration, the behaviour of Newton's Cradle is not adequately explained in these textbook presentations *and there may not even be a fully adequate explanation available in the physics education literature*."

[2] This figure comes from `http://bestgifever.com/?yes=be6a165a2b5efd6d6e5e87362965fb6c`, under free Creative Commons License. Author: Dominique Toussaint; date: 2006/08/08.

[3] Translated from the French Wikipedia page on Newton's Cradle: `https://fr.wikipedia.org/wiki/Pendule_de_Newton` (still visible on February 25 2016).

[Gauld (2006, p.598); my emphasis]

Gauld wryly adds, further on:

> "One might excuse teaching which is ignorant of little known facts but it is less easy to excuse facts about the apparatus which are more easy to establish such as that the principles of conservation of momentum and kinetic energy are not sufficient, in themselves, to explain the behaviour of Newton's Cradle."

[*ibid.*, p. 615]

And this enormous cheating (if we may so call what Gauld pointed out) was so, in 2006, in spite of the fact that Herrmann and Schmälzle (1981) had shown that the use of the two usual conservation principles (momentum and kinetic energy) is not sufficient to describe the facts observed.

For instance, in the case of an initial impact with one ball (A), energy and momentum conservation would not prevent that A bounced with a speed equal to one third of the initial velocity, while A' and B' separate with a speed equal to two thirds of the initial velocity of A.

Indeed, as Herrmann and Schmälzle (1981, p.762) develops:

> "Imagine now the following final state: ball 1 moves to the left with $v = (-1/3)v_0$, balls 2 and 3 move to the right, both with the same speed $v = (2/3)v_0$. It is easy to confirm that the values of the kinetic energy $[Ek]$ and the momentum $[P]$ of this hypothetical final state are the same as those of the initial state:
>
> $$\begin{aligned} Ek &= (l/2)m\left[(l/3)v_0\right]^2 + 2(l/2)m\left[(2/3)v_0\right]^2 \\ &= (1/2)mv_0^2, \end{aligned}$$
>
> $$\begin{aligned} P &= m[(-1/3)v_0] + 2m(2/3)v_0 \\ &= mv_0. \end{aligned}$$
>
> Thus energy and momentum would be conserved. Nevertheless, the actual experiment always evidences another outcome."

The following fanciful illustration (Figure 10.2) gives an idea of the possible (but not actual, of course) behavior of the cradle when applying only momentum and kinetic energy conservation principles.

Since that behavior was never observed, there must be another constraint which the cradle must satisfy.

Herrmann and Schmälzle (1981, pp. 763-764) argue that "In a non-dispersion-free system, energy and momentum are distributed throughout the entire arrangement.", while what we observe is that the total energy and momentum of the incoming balls is transferred to the same number of balls at the other end of the chain. They thus propose a simple explanation involving a third conservation principle, shock wave energy conservation, allowing the kinetic energy transmitted by A to $[A,\ B,\ C,\ B',\ A']$ to be transferred without loss to A', through the initial shock wave. This constraint allows to take into account the propagation of the double perturbation wave due to the initial shock, perturbations which travel across the system in each of the two directions, and

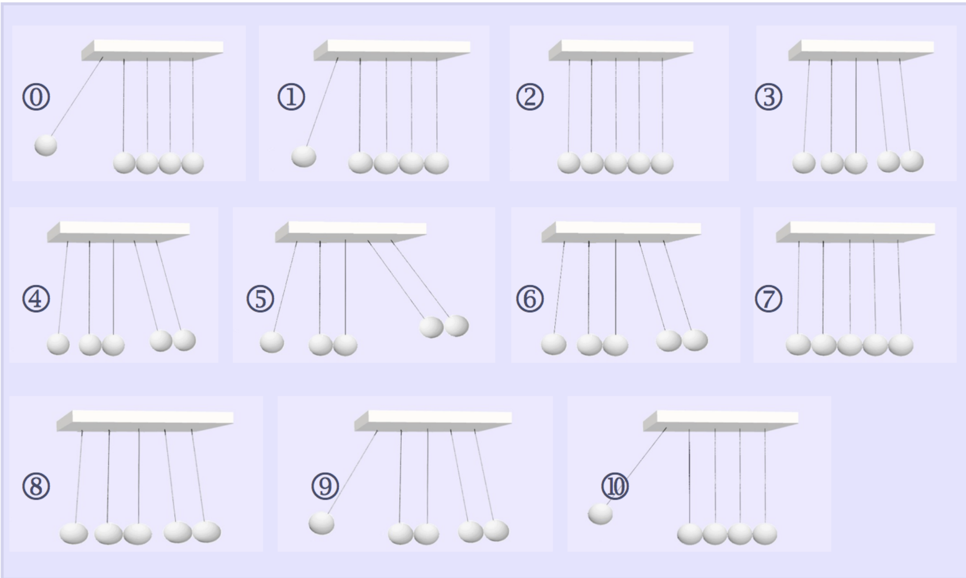

Figure 10.2: Fanciful non-actual behavior of cradle (compatible with the classical explanation).

move backwards after reaching the system ends, *without attenuation*, and therefore, at the same speed. It is at the point where the two wave packets meet that the balls separate; this point must be symmetrical to the point of impact in order for the two wave packets to travel the same distance before they meet. Figure 10.3 illustrates this point:

Extremely reassuring and fresh did I thus feel the proposal presented in 2010 by a group of secondary school students to the French Physics Olympiad, and... primed with the first prize. For they address that specific problem in a way that is both correct and amusing, and propose a solution which is both amusing and... correct.

In 2010, Nicolas BELIAEFF, Romain HEIMLICH and Baptiste JEANIN, from the Lycée Jean Eiffel (Dijon, France), formulate their conception of the problem in this way:

> "[Nous] nous sommes alors demandés comment la dernière bille, qui n'a pas assisté au cours de physique, a pu savoir qu'elle devait conserver énergie cinétique et quantité de mouvement."
>
> "[We] then wondered how the last ball, which did not follow the physics class, could know that it was supposed to preserve both kinetic and momentum"
>
> [Beliaeff *et al.* (2010)]

and they immediately propose a hypothetic answer, the validation of which is the object of their exposition:

> « Nous avons alors supposé que ces informations devaient être envoyées par la première bille et que le son ou la vibration due au choc devait contenir ces informations. »

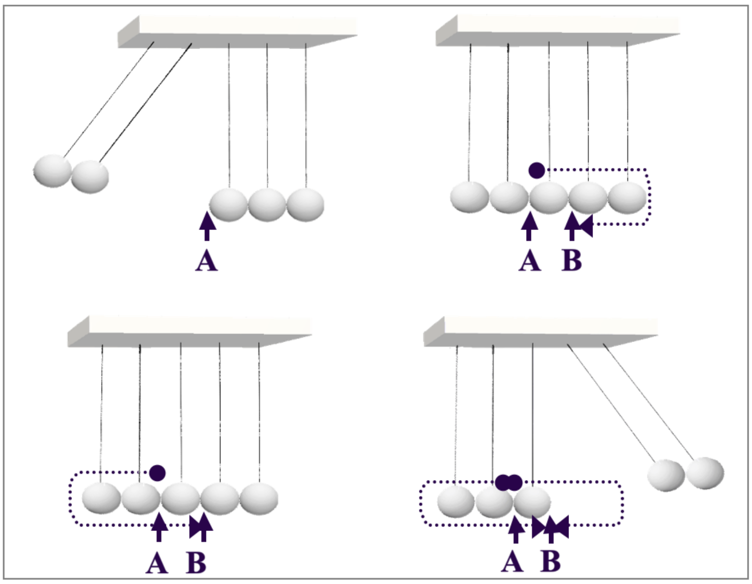

Figure 10.3: Explanation using the (additional) dispersion-free constraint.

> "We then made the hypothesis according to which this information was sent by the first ball and that sound or vibration due to the initial shock should contain this information"

[*ibid.*]

I cannot resist the temptation to show the way in which this hypothesis is discussed and illustrated in their work, where *ludic* goes together with *lucid, and 'ludicity'* seems to be a real warrant for *lucidity*... a brief sequence of schemata, shown in Figure 10.4, with their comments, will be enough to give an idea and, I hope, the intellectual pleasure.

10.2 From balls to Human Being: the... *impact* of communication

The standard communication model used for signal processing, since Shannon (1948) and Shannon and Weaver (1949), can be summarized in the following proposition:

> A *sender* encodes a message and emits the result of the encoding towards a *receiver*, which perceives it in an environment possibly disturbed by other transmissions (noise), and then performs the decoding.

That conception of signal transmission allowed to give an operational definition of *information*: *information*, within signal study, is the inverse of noise[4].

[4] Several cynical theorists argue that that is the reason why the century turn, with its ubiquitous glorification of public communication, has drowned information in an ocean of noise; in particular in the realm of scientific research, where the commandment "Publish or perish!" engulfs genuine scientific information in a tsunami of noxious waffle...

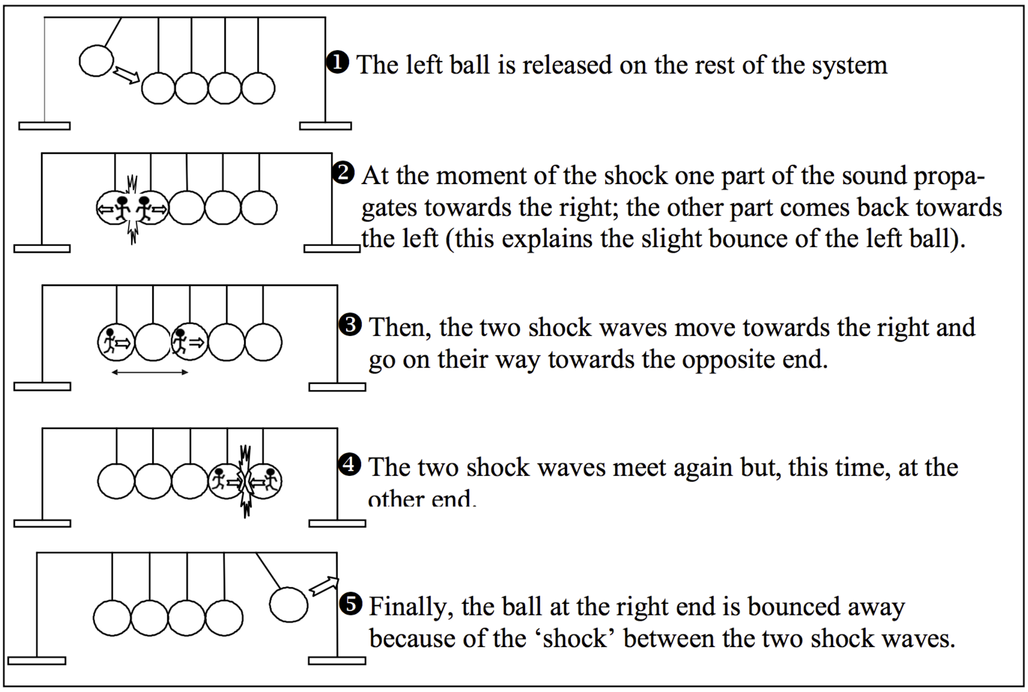

Figure 10.4: Explanation of the process involved in Newton's craddle using the hypothesis 'sound as a messenger' (adapted from Beliaeff *et al.*, 2010).

The communication model underlying that important work on signal was 'sold' to linguistics, though it was intended only for signal[5]. Roman Jakobson (1960) did feel the model was insufficient to account for human verbal communication but believed that, with a few 'patches'[6], it could be used as a first approximation. A version of Shannon and Weaver's signal model, 'patched' by Jakobson and simplified 'for didactic purposes' (henceforth: STD) is still constantly taught as *the* model of human communication 'discovered' by Jakobson...

Paying attention to the structure of the Signal Treatment Diagram (STD), as it is adapted for human communication (with 'patches' and 'didactic' simplification), one easily realizes that it is even simpler than the one which does not work for Newton's cradle. Figure 10.5 illustrates the model in question.

For linguistic studies, the transmission process is not an object of study; on the other hand neither the encoding and decoding processes, nor the original and 'reconstructed' messages (illustrated here by compositions of ❃,❋,and ❖) are observable... However, as any linguist is as good a speaker as any other speaker (which is certainly true), most of the linguists (mistakenly) consider that the non-observability of the processes, of the original message or of the 'reconstructed' message poses no problem: from the output of the sender, the linguist '*knows'* the message he/she (the sender) encoded; and, at the same time, '*knows'* what the receiver will get when decoding the

[5] It seems that the 'transaction' was done in spite of Shannon's doubts, for whom the signal model is not proper for anything else than signal.

[6] *Cf.* the six famous functions of languages he introduced in Jakobson (1960), and which are taught in practically all the classes of linguistics in France.

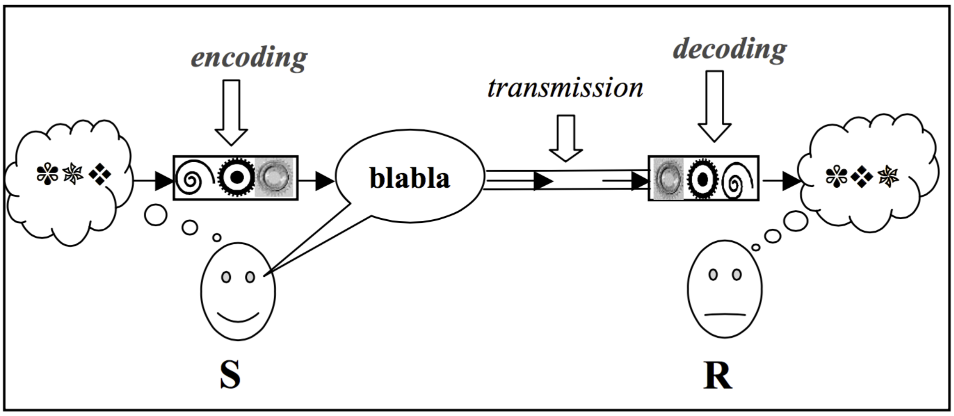

Figure 10.5: STD - an adaptation of the signal model *to human linguistic communication*

transmission and 'reconstructing' the message[7]. The discussion of this magic belief is not the subject of this paper[8] and I sufficiently suggested what I think of it (for some, even too much...): I only intend to show, here, that (independently of its magic touch) the model in question, STD, is a caricatural simplification of the one that does not work for Newton's cradle and, as such, is not likely to work for more complex interactions, such as human linguistic communication.

If we want to merge the description of what happens in Newton's cradle and the description of what, according to STD, happens in human linguistic communication, we get something that may look like Figure 10.6:

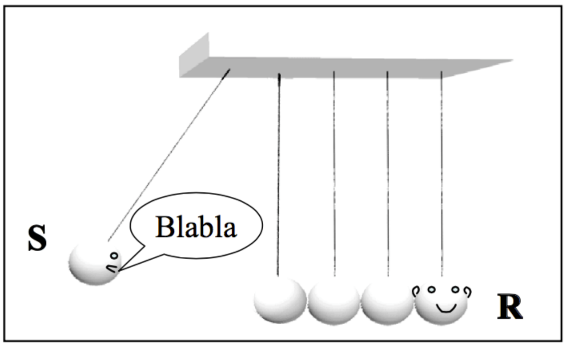

Figure 10.6: A cradle-like approach to the signal-like model of human communication.

where the impact of ball S corresponds to the transmission of the encoded message through the three balls in the middle, and the separation of ball R corresponds to the result of decoding the received encoded message. However, when observing the cradle, the separation of ball R *is* observable (and the properties of that separation -momentum

[7] This would seem absurd to any other researchers and, probably, to any other human being; but not for most linguists.

[8] For elements of that discussion, see, for instance, Raccah (2005), Raccah (2011a), or Raccah (2011b, pp. 154-161); those who read Russian can find in Raccah (2011c) a few proposals for a linguistic experimental approach to semantics.

and amplitude- *are* measurable), while, when observing human communication from the point of view of STD, as we saw it in the preceding paragraph, what R understands, which corresponds to the separation of the ball, *is not* observable. In addition, in the cradle, what caused the impact *is* also observable and its properties measurable, while, in the signal approach to human communication, again, what precedes the emission of the encoded message *is not* observable (let alone measurable).

To make a short story short, the scheme of human communication based on the signal model (STD) does not predict anything empirically observable: it cannot, thus, account for anything that would not be believed in advance (in particular, it does not say anything about how meaning or *what* meaning is constructed by the recipient); and, of course, it is immunized against scientific refutation.

In the next section, I will discuss several properties a model for human communication should show and, as a conclusion, I will propose a model of linguistic interaction which does show these properties and does not suffer from the weaknesses of STD.

10.3 From human being to human being: the... impact on communication

Regardless of nonsensical but abundant literature bad uses of good but limited models produce, there are

(i) Observable entities which are transmitted from S to R in a human communication between them (excluding meanings, intentions or messages), and

(ii) Possible observable reactions by R (excluding what R understood), which may allow an observer to produce hypotheses about how R understood S's communicative move.

Moreover,

(iii) a sufficiently large set of interaction instances *necessarily* gives the cues which allow to grasp the semantic rules of a human language; this is so because any dunce can acquire, *and does acquire*, a human language in 18-24 months, being exposed only to speech and human attitudes.

In addition, an acceptable conception of human communication has to take into account other problems that could not even be conceived within STD:

1. In human linguistic communication, the meaning of what the 'sender' is about to say is accessible to *no one* (not even him(her)self) before (s)he speaks.[9]
2. If *sound* is transmitted indeed (like in the school students conception of the cradle), meaning is not: it is constructed by the 'receiver' (in particular, on the basis of the stimulations that sound occasioned).
3. Understanding a discourse (or any utterance of a human language sequence) does not involve encoding or decoding[10]
4. Understanding a discourse (or any utterance of a human language sequence) is an irrepressible and unconscious activity[11].

[9] *Cf.* Raccah (2008), pp. 72-75.
[10] See Rastier (1995), Raccah (1998), and/or Grillo (2003).
[11] See Bruxelles and Raccah (1992).

If we go on exploring what is beyond the sole signal, it is clear that what S transmits to R (sound), (a) S too perceives it, (b) R (sometimes) reacts to it, (c) S too (sometimes) reacts to it, (d) S reacts to what she/he perceived of R's reaction, etc. The picture, thus, looks much more like the playful approach of the cradle, as presented by the high school students (with something running in both direction) than like the static simplification of the 'linguistic' model based on the *signal model.* Figure 10.7 is an attempt to include these considerations into Figure 10.6:

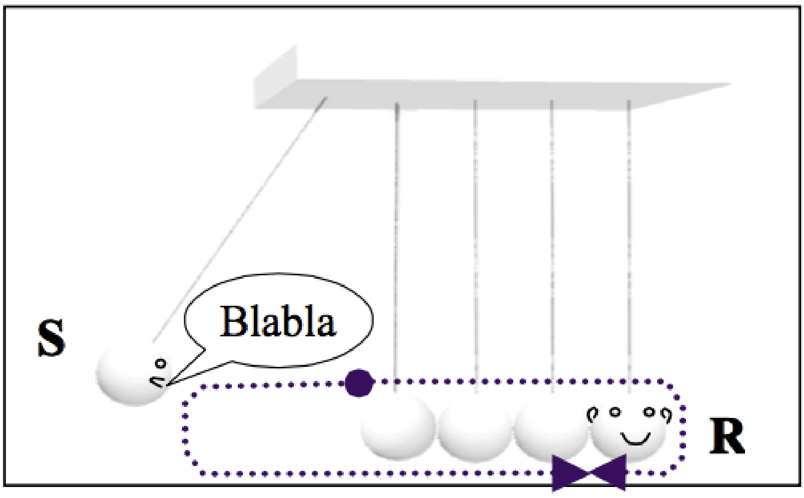

Figure 10.7: Figure 10.6 with feed back loop

The difficulty we underlined in the last section, the fact that *reactions* are not necessarily directly observable (in particular, *what is understood* by R is not directly observable), is not solved but, here, it is not hidden: R's reaction is present in the schema, and the experimentalist semanticist must design experiments which will allow to indirectly observe these reactions. The inclusion of the sort of feed-back loop in the presentation of what happens in communication allows to avoid two incredible mistakes, due to STD, which are quite often present in the implicit background of semantic work:

1. Discourse meaning, that the semanticist indirectly observes, and that will help him/her describe sentence meaning, is not the one (s)he him(her)self built, but one (s)he can show that this is what the receiver constructed: the last one requires arguments, while the first is based solely on intuition.

2. In order to be in the position to make (and argue) the hypothesis that the 'receiver' built utterance meaning S for discourse D, in the situation i, it is necessary to take into account the reactions of said 'receiver', and make abductive testable hypotheses about discourse meaning, which could explain these reactions.

Verbal reactions of R are not to be favored: they require interpretation by the semanticist, and thus introduce subjectivity in his/her observation. In the lack of better empirical material, one can be happy with them for a first approximation. However, this subjectivity regards the same area of research that we want to scientifically explore: there might soon be biases and conflicts of interest...

10.4 As a conclusion: a proposal for a model of human communication

We saw that the conception of human communication, STD, implicitly or explicitly used by most linguists all over the world is a simplified version of the model used for the treatment of signal. We also saw that that model is a simpler model of interactions with respect to the one mistakenly used to account for what happens in Newton's cradle: in addition to momentum and kinetic energy conservation, another principle is needed, namely what I called the *shock wave energy* conservation principle. I showed that the communication model STD, derived from the signal model, could make no empirical prediction, and I pointed out that several of its implicit assumptions are erroneous. I suggested that, modifying those assumptions implied a radical change in the conception of human communication, and adding an analogue of the shock wave conservation principle (which allows to take feedback into account) could yield to a much more interesting conception of human communication.

If I convinced the reader, I could be satisfied, even though one might argue that criticizing is easier than proposing... Luckily enough, I do have something to propose, which stems from all that critical work: a conception of *human communication using language*, which proceeds from a more general Communication Activity Representation conception (CAR). One of the advantages of this conception (from the point of view of the present paper) is that it does use the reflection developed here about Newton's cradle and the contrast between what is observable (for instance, the separation of the last ball) and what we use in order to account for it (principles), which is not observable. Another advantage (which might appear, at first, as an inconvenient) is that, once the proposal is understood, it seems to be so evident that it becomes difficult to envisage it as a real original conception of communication. This characteristic is an advantage because any move that is done to defend the idea that the said conception is too obvious to be a real original proposal is, *ipso facto*, an evidence in favor of that conception...

The proposal, called the *Manipulatory Conception of Human Communication Using Language* (in short, MCC) is presented in Figure 10.8:

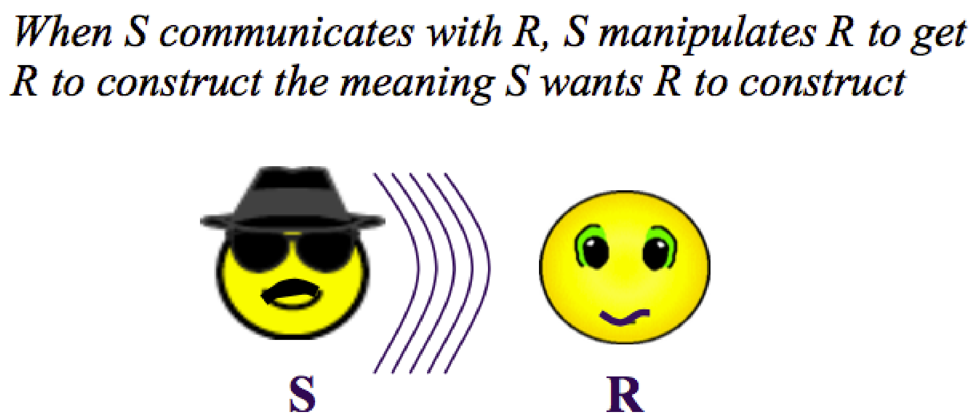

Figure 10.8: Illustration of the manipulatory conception of human communication using language.

The sounds emitted by S do not carry meaning, but act on R to make R construct a specific meaning for S's utterance. The meaning R will create is, as we said, influenced by S's utterance, but also depends on R's knowledge and beliefs: what S produces (S's utterance) functions as a set of instructions which R carries out or implement, and which have the effect of making him/her build this specific sense. R's internal process is not conscious: obviously, R may build a conscious *a posteriori* picture of 'what happened' in his/her mind, but the understanding process is not accessible while it takes place. The process itself is not directly observable: no one can access such internal processes (and, as we just saw, not even the person in which it takes place), but, sometimes, the outcome of the process provokes observable facts, which can be used to formulate abductive hypotheses about some aspects of the process. The process of meaning construction is also *irresistible*: the state of being a speaker of some natural language *forces* to understand any understandable utterance using that language.

For instance, about one half of the Anglophone American citizens might feel uncomfortable when hearing the following utterance:

John Doe is a Republican but he is honest

This is so because the hearers cannot understand the utterance if they do not -at least provisionally, during the time of the process - accept that there is some kind of opposition between being a Republican and being honest. Interestingly enough, the other half (if we except the few semanticists that might belong to it) usually do not even notice that they have to accept such a point of view on Republicans: the semantic instruction acts unconsciously and irresistibly until it eventually leads to a point of view which is inconsistent with the hearer's. When this contradiction does not occur, there is no reason for the hearer to be conscious of all the points of view (s)he had to accept in order to understand. When the contradiction does occur, the hearer often feels aggressed: for good reasons since (s)he has been forced to accept (even provisionally) a point of view which (s)he does not share.

What has just been said about the oral modality is relevant, with very little changes, for written material. This might surprise because oral and written material differ in nature: each time one reads a written segment, (s)he produces a new utterance, different from one produced by another reading, and which is usually treated as new oral material (a sort of *inner voice*). However biologically different might be the initial effect of real sound input from the more abstract effect of a reading, one of the very interesting properties of human language processing is that, at the level of complexity of semantic treatment, they should not, and *cannot*, be differentiated: as far as meaning assignment for natural language expressions is concerned, no distinction is to be made between *inner* voice and *outer* voice. This astonishing property, which is characteristic of a separate scientific field for the study of language, is certainly related to the level of abstraction at which the complex processes of understanding take place; it does deserve more investigation, but this aspect of the question is both outside the domain of researches on language as such, and outside the reach of the present work: we will have to limit ourselves to signal the question.

Although MCC is too general to be a model, it may yield to sound models of human communication, grasped through its interactive aspect (as we saw in section 2, this is not true about the conception based on STD): in MCC, there is an observable input (sound or written material) and there may be observable outputs (reactions), in such a way that the non directly observable intermediates (meanings, representations, points of view, beliefs, etc.) can be indirectly observed, in a way analogous to how momentum, for instance, can be indirectly observed. The relationship between the added value of MCC and the correct account for Newton's cradle is the fact that, in MCC, S knows whether his/her action on R succeeded by interpreting R's reactions: the global effect of the interaction lies thus on the meeting point between the two actions packets.

Clearly STD and MCC are two incompatible competitive CARs. Now why should you buy the new CAR I propose? The first reason is, obviously, because your old CAR is out of order... More seriously, STD blocks the evolution of the accounts of human communication and of human language semantics because the oversimplified concepts it uses presuppose, as we have just seen, facts about communication and about language that we now know wrong. It may have been useful when the tracks leading to findings about human languages were narrow; but the map of knowledge on this subject has evolved since that time and you should not use your old CAR in the expressways that are available for scientifically exploring this territory.

Bibliography

Barthes J., 2010, La pétanque de Newton. BUP 926 (*Bulletin de l'Union des professeurs de physique et de chimie*), 877-884. (Compte-rendu d'enseignement expérimental, à partir des travaux de Beliaeff et al. (2010)).

Beliaeff,N., R.Heimlich, B. Jeanin, 2010, La pétanque de Newton. Mémoire de concours : 1er prix de Olympiades 2010 ; 2ème prix - au concours CASTIC à Canton (Chine) en août 2010. Lycée Eiffel (Dijon).

Bruxelles S., P.-Y., Raccah, 1992, Argumentation et sémantique : le parti-pris du lexique. *In* W. de Mulder, F. Schuerewegen et L. Tasmowski (eds) *Enonciation et parti-pris*. Amsterdam, Rodopi.

Gauld C. F., 2006, Newton's Cradle in Physics Education. Science & Education, 15, 597-617.

Grillo É., 2003, Parler la même langue. *MAG Philo*, revue électronique, 9 *: Langages*.

Herrmann F., P. Schmaälzle, 1981, Simple Explanation of a Well-known Collision Experiment, *American Journal of Physics*, 49(8), 761-764.

Jakobson R., 1960, Closing Statement: Linguistics and Poetics, *in* Thomas Sebeok (ed.) *Style in Language*.

Raccah P.-Y., 1998, L'argumentation sans la preuve : prendre son biais dans la langue. *Interaction et Cognition* , 2 (1-2)

Raccah P-Y., 2005, What is an empirical theory of linguistic meaning a theory of? *In* Zygmunt Frajzyngier *et al.* (eds.). *Diversity and Language Theory* Studies in Language Companion Series, John Benjamins.

Raccah P.-Y., 2008, Contraintes linguistiques et compréhension des énoncés : la langue comme outil de manipulation. In Entretiens d'orthophonie, 61-90 ; Paris, Expansion Formation et Éditions.

Raccah P.-Y., 2011a, Linguistique critique : une exploration cognitive. *Intellectica* 56, 305-314. Special issue: *Linguistique cognitive : une exploration critique*, dir.: Jean-Baptiste Guignard.

Raccah P.-Y., 2011b, Les questions de rhétorique sont-elles des questions sémantiques ? Réflexions sur une théorie de la signification, informées par des études de sémantique contrastive. *RSP* 29-30, 151-173.

Raccah P.-Y., 2011c, A semantic description of lexicon: a means to efficiently assist intuition?, Presses de l'Université d'État de Novossibirsk ; Série : Linguistique et Communication interculturelle, 9(2) , 96-120.

Rastier F., 1995, Communication ou transmission ? Césure, n° 8, 151-195.

Shannon C. E., 1948, A Mathematical Theory of Communication. *Bell System Technical Journal* 27 (3), 379-423.

Shannon C. E., W. Weaver, 1949, *The Mathematical Theory of Communication*, Urbana. University of Illinois Press.

Chapter 11

Human interactions modeling : a tool for training. A case study with social-sport educators.

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Abstract

Being an educator or teacher has become a very exacting job. This study explores the complexity of these professions (Perrenoud, 1999). This complexity can generate suffering and even lead teachers to abandon the profession, especially in socially and economically deprived areas (Ria, 2009). The root cause of some of this complexity comes from interactions with young people who are often violent and unpredictable. Thus the activity of social-sport educators is particularly interesting to study because unstable behaviors and reactions are amplified. The aim is to demonstrate that the intervention itself is complex. This comprehensive approach could provide content for the training of future educators. University-based training that includes the complex content found in the social sport intervention may be an interesting target. The future educators would thus be better prepared for real-life professional activity. Modelization tests provide an analysis tool for the daily hazards of the profession. We explore the nature of interactions, their characterization and the events that lead to instability. Contradictions and alternatives are also explored as well as the ways educators respond to these situations.

11.1 Introduction and context

Intervening with problematic young people in the area of training and education currently appears difficult and unforeseeable (Johannès, 2013). For professionals, uncertainty and the lack of motivation can generate suffering on the job, which results in educators quitting the job and a high turnover rate. Interaction with a public with special needs (young school drop-outs, with social and/or family difficulties, deprived inner-cities sometimes under judicial warrant) cannot be envisaged without a rigorous professionalism of the social-sport educators (SSE). Our exploratory study attempts – through modeling - to clarify the complexity of the various interactions during sport interventions. We advance the hypothesis that the environment composed of the situations where the educators intervene could be considered a complex system.

11.2 Sport social interactions, a complex system

We consider that the interventional situation, subject of our study, is a complex system (Bonami et al., 1996; Clergue, 1997; Le Moigne, 2002; Morin, 2005). In each situation, we have the actors, the stakes, the obstacles, the resources, the tools and the temporality which give a dramatic dimension during a crisis and for the results. In a paper, Lave

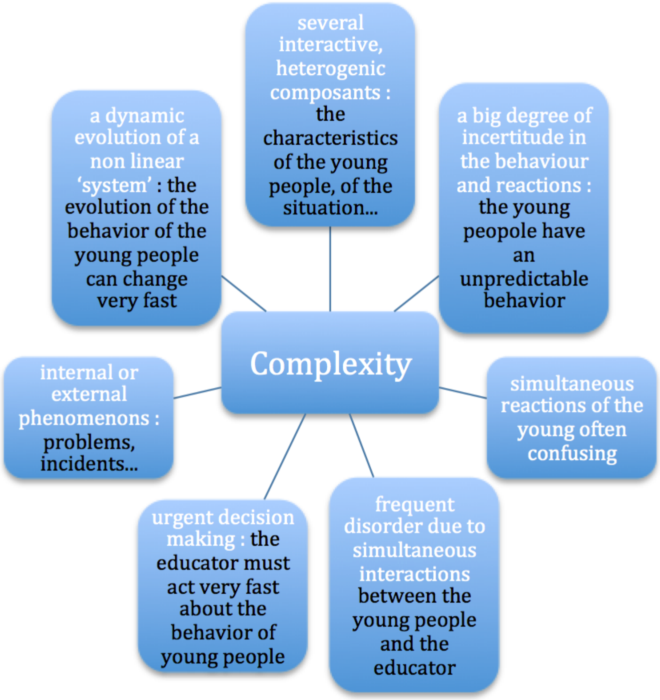

Figure 11.1: Representation of a complex system

1988, p.150) proposed two dimensions to describe the environment. The “Arena", which is the objective aspect, permanent of the situation and the “Setting", which = is the singular, subjective dimensions of the situation, the point of view of a actor. In this paper, we focus on the “arena".

Figure 11.1 illustrates the complex nature of interventional situation.

Our study takes into account the role of the SSE exposed to a complex environment. During the decision making process, the SSE composes with contextual constraints, available resources (his/her level of expertise) and his/her conception of the appropriate reaction (moral and educative values). The educator must also employ self-preservation when confronted with the pressures in this complex environment (Granon and Changeux, 2011). The educator has a balancing role, maintaining the link that will enable the situation to remain viable.

11.3 Question for the training course

How to train and prepare to act in a difficult context? The training of educators can only rely on the predictive model: even a very thorough and rigorous planning of the activity cannot evacuate hazards and uncertainties. The development of routines – even numerous ones - will be insufficient in absorbing daily issues (Barrère, 2002; Tardif et Lessard, 2000). A professional training, which prescribes predefined solutions, will not allow the educator to adapt ideally to incidents and hazards. In order to deal efficiently with disruptions, the active strategy must be adapted and transformed (Gelignier, 1979).

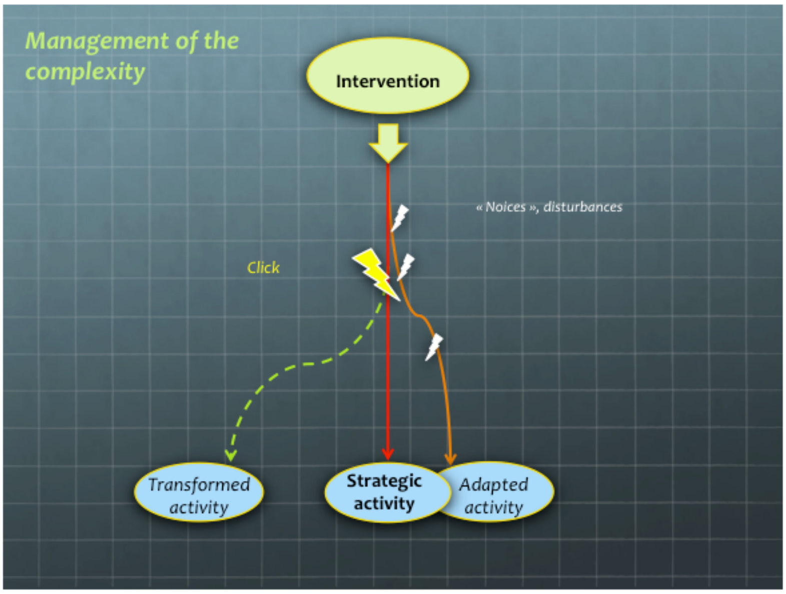

Figure 11.2: Transformed activity

Figure 11.2 shows that the intention of the intervention is an arrow pointing towards the planned activity. Some 'noises', disturbances disorganize the activity. The actor must simply change his activity (adapted activity) or redefine his activity completely (transformed activity).

"The action depends on the complexity, that is to say, hazard, chance, initiative, decision... "(Morin, 1990, 2005) Training within a complex environment and including complex tools might be a solution. How can a training module provide a real complex educational situation? How can the student educator be confronted with and understand the risks, dysfunctions, surprises linked to the context? How and with what limitations can this complexity be used for professional development?

11.4 Typical environments which generate tensions and complexity

The law for freedom and autonomy of the French universities ("LRU" in French) of August 2007 redefines the public service missions for higher-level teaching (or university level teaching) by including the orientation and professional insertion of the students. Diplomas must now be in phase with the needs (Gayraud et al., 2011).

Clergue (1997) suggests to educate "with and by complexity". The "mobilization of complex educational situations: that is situations where the causes tangle and accumulate like in reality and so reinforce the motivation of the student by transforming the immediate failure into reasons for inventing new solutions" (...). "Every time new needs emerge from his or her environment, the student progresses" (Clergue, 1997 p.14). In this article, we propose to adapt this view to SSE training, which means to account for interactions between the different actors.

The analysis of interactions is at the center of our study. The definition of the word *interaction* is the action of entering a situation with the intention of influencing on how it plays out or to engage an action, an authority, to play a role in the situation, to act deliberately. The French etymology of the verb "intervenir " dated in 1363 ("intervener", "interagir » in French langage) explains that it means to "entrevenir" ie "to go out and meet other people" (Bloch and Von Wartburg, 1986). Also, intervention (dated 1322), a word borrowed for the latin entevenire, is considered in the legal area to be a 'mediation'. De Montmollin (1977 pp. 20-21) defines social interactions as the sum of effects that result from the use of words or the actions of others on individual answers to one's environment. In this definition, reciprocity is discussed within the answer of the individual to the social environment.

11.5 Theoretical frame: a systematic approach, complex and situated actions

Professional didactic theories (Samurçay and Pastré, 2004) and the situated action (Suchman, 1987) are mobilized in order to chart the exercise of the SSE profession. It is necessary to examine the activity in a given situation, in a familiar environment in order to diagnose the needs for the training. The activity and technical registries (Martinand, 1994; Glomeron, 2001) provide us with an analytical activity grid with the limitations and effects.

The activity is not detachable from the context in which it has occurred and is the proof of the adherence of the actor to his environment The complex approach sheds light on the actor's decision process. The precise moment that marks the arrival of the disturbances signals the start of the actor's capacity to adapt (Bénaïoun-Ramirez, 2013).

In order to clarify our postulate, it is possible to introduce into the training the complexity of the real life situations. This apprenticeship in complexity (Clergue, 1997) seems possible if the reality of the interactions is correctly and systematically interpreted. This is why it is necessary to fully understand the interactions in real-life situations and in their evolutions. We seek the appearance of the release mechanisms and analyze them. We identify the breaks, intermittences and changes which arise from disorders in the situation. In other words, we ask the question: what is the state of the system?

Our hypothesis is that the analysis of the situation, its dynamics, the disturbances and the reorganizations that occur in response could allow a better understanding of the adaptation and the regulation of the SSE's competencies. The transformations are proof of the professional apprenticeship of the future educators.

11.5.1 Methodology

The activity in reference is the socio-sports intervention. The physical activity is organized by the SSE in such a way that the level of performance is not the only objective. Sport here is a tool, an object, a social practice, a way to allow these young people, which lack social and relationship skills, to progress. The SSE is constantly aware of the need to deal with these vulnerabilities during sport activities. The SSE's educational choices are guided by this end point. In the complex, educational interaction situation, priorities are thus defined. For the actor (SSE) the social-sport intervention is characterized as a complex system, as represented in Figure 11.3.

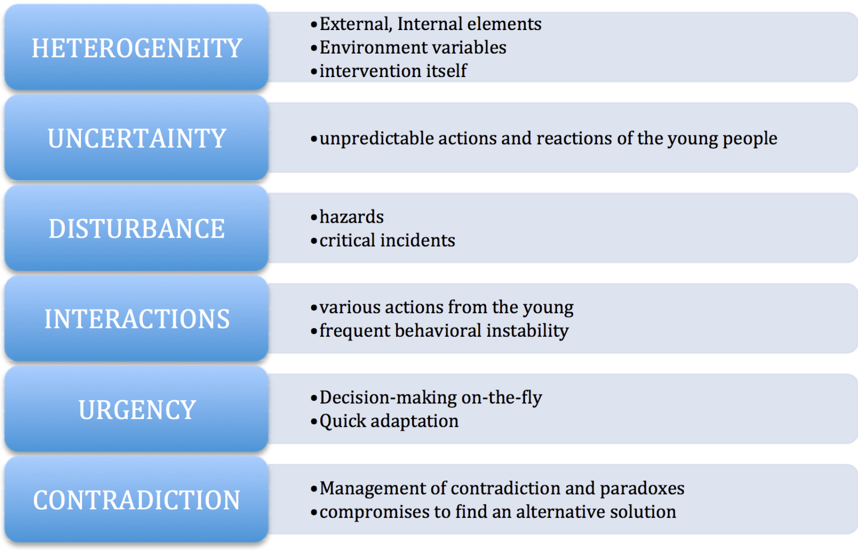

Figure 11.3: Social-sport intervention as a complex system

Our real-life study led us to make observations in those social areas targeted by the training (Martinand, 1994). These areas are legal youth protection centers, detention centers, children centers, local associations and regional government bodies. The professional activity of 5 educators during 10 sport sessions is the basis for this study.The observation grid used for the data collection includes the following guide points:

- The elements being interacted
- Type of interactions
- Luck, incident
- Mark of destabilization of actor (attitude, visible emotive expression)
- Alternative decisions: paradox, contradictions to be resolved
- Decision made on the action
- Effect on the action

The educators being observed filled in their own worksheets. Their notes related to the ongoing intervention or were filled in a while afterwards. They were used in the modeling of the complex systems: the components, the links identified, the interactions and events of the actions, etc. The interviews with the 10 educators provided further notes for the worksheets; During each interview, 2 or 3 significant situations were discussed. The critical moments such as destabilization, incidents or hazards (Glomeron, 2001) were chosen to observe the professional ability of the SSE in action. From the actor's point of view, these critical moments reveal a specific part of the system that should be modeled and so, we obtained an instantaneous modeling at the desired time. This is valid to the analysis of interactions, evolutions and the parts of the targeted system .

The analysis is based on the data collected. The components are identified. The interaction network is constructed. The disorders are characterized. The alternatives and decisions of the actor are presented. The evolution of the system is identified.

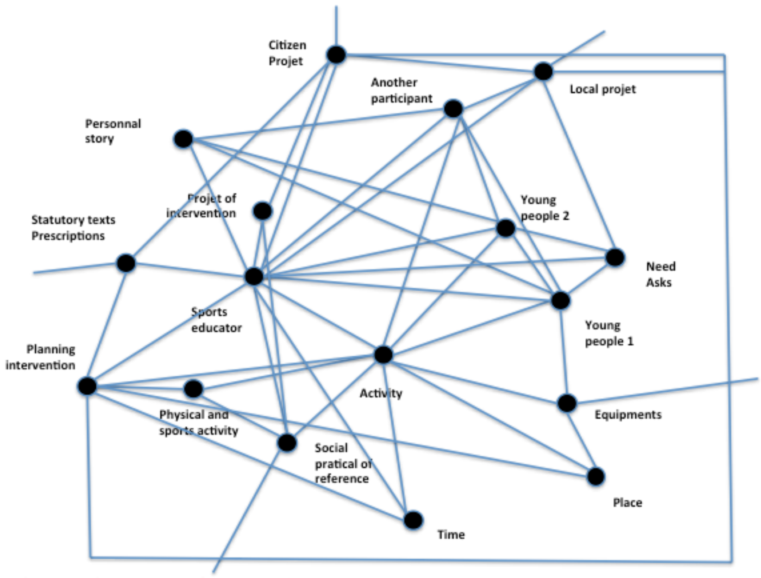

Figure 11.4: Intervention, a complex system

11.5.2 Results

We were able to analyze the modeled interventional situations and to identify the moments, triggers that led to destabilization. The analysis of the interactions and the evolution of this complex system supplies elements about the abilities used in the form of an “organized improvisation” (Perrenoud, 1999). This provides professionals with the capacity to make decisions rapidly:

- Type of interactions and the “trigger”events
- Contradictions and alternatives that have to be managed
- Characterization of the interactions
- Technical actions types in interactions

Our study illustrates the different phases of decision-making during a volley ball session. The components are depicted in Figure 11.4 by points while their active interactions are shown as lines. The components are important elements for the actor (observed or evoked). The system is an open one and certain components are linked to outward elements. For example, the equipments can be shared with another actor. The local project can be linked with other projects. The “citizens’ agenda” is at the heart of the projects objectives. It is linked to other aspects for the young i.e. good health. Figure 11.4 includes components that are related to and which are important for the actor. The actor appears in the heart of the action. We can observe interactions with the various components of the situation.

Let’s apply this model to sports through the example of Volley ball.

Figure 11.5 represents the different phases of decision-making during a Volley ball session:

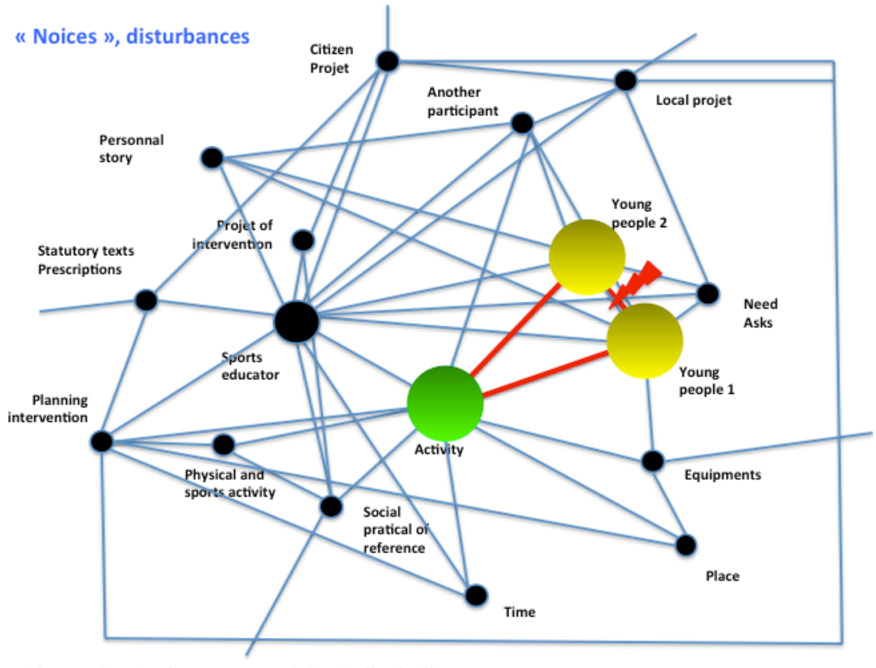

Figure 11.5: Altercations in sports: volleyball example

1. In red the main interactions. SSE focuses his/her attention on the activity of 2 young people. There is a risk of a sudden altercation between them
2. The central elements of the interaction represented with the large circles
3. SSE increases his/her attention on this interaction : focus
4. The public becomes tense. The initial situation is now perturbed. The relationship installed up to this point is broken. This is a key moment for the evolution of the system

It thus becomes necessary to reorganize the structure of the situation in order to keep moving on.

We identify this as a decisive moment in the decision making process. The SSE has to rely on educative tools systems. A choice must be made between:

1. Maintaining the progress of the session and staying in conformity with what was planned. Risk: could be contagious and increasingly disturbing
2. Stopping the progress of the entire group in order to deal with the two perturbing elements
3. Reorganizing then resuming the activity.

The observational answer is the following one: the situation is reorganized in its normal context and the incident replayed. This incident becomes the basis for a new activity. It can be said that some elements of the system are inhibited, others liberated. The

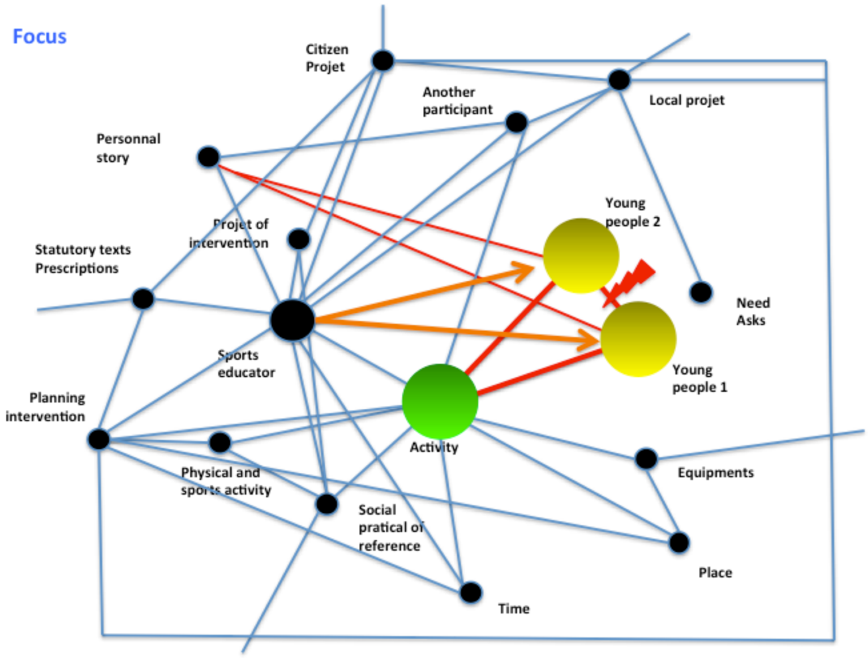

Figure 11.6: Conflit regulations and inhibitions

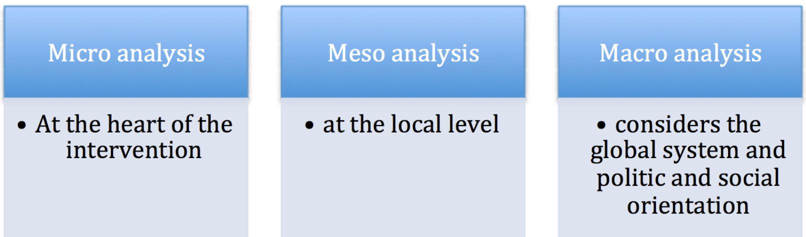

Figure 11.7: Different analytical levels of the SSE activity

strategy consists in changing the direction of a given situation without stopping it. A secondary complexity emerges, shown in Figure 11.6.

The objective of this first study is to describe and explain this complex system with its interactions, issues and schedule reorganizations. While observing a social sport exercise orientated towards a fragile public, several analytical levels of the SSE activity can be perceived, which can combine and influence each others, as shown in Figure 11.7. However, while this analytic division is easy to understand, it does not function so well when applied to the decision making process. Even for a local level decision, the SSE must take into account the interactions between the different levels. Appropriate decisions must be made within a systematic and multi-layered network. In order to illustrate this, we have attempted a multi-layered approach, as presented in Figure 11.8. Even if the links between the levels are taken into consideration, the analytical approach does not adequately reflect reality. These different levels are constantly and simultaneously inter acting. We comment on the repetitive structure at the different

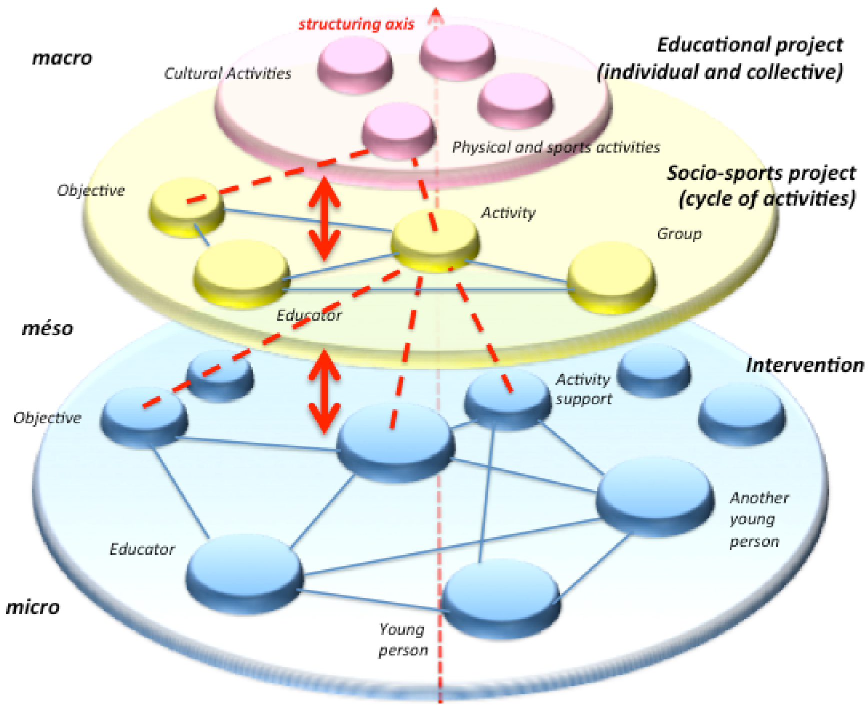

Figure 11.8: Intervention analysis layers

levels. “We can characterize the complexity such as the emergence of different levels within the same system’ (Clergue, 1997, p. 18). Thinking should systematically be organized from micro to macro and vice versa.

One method could be to focus on one level. However, when concentrating on the macro level, we would ignore elements from the micro level that might affect the macro level. Thus in our comprehensive method we must analyze the system entirely. A structuring axis exists that organizes all levels so that they coherently perform. This axis represents the endpoint of the SSE’ profession i.e. the ability to educate and reintegrate the young minors. We perceive the different levels to be coherent. The micro level is the situation proposed by the educator. The “meso” level is the group of activities with an objective leading to transformation for the young (a sport project). The macro level is the educative project for the young (individual and group). In the previous example, the incident observed at a micro level (altercation between two of the young people) is the beginning of the activity rebuilding by the SSE who keeps in mind the educational objectives while concentrating on some of the young people. The ability of the SSE is reflected in the capacity to face and manage these incidents. His/Her decision takes into account several factors as discussed below. He/She may intervene and maintain an equilibrium while protecting himself / herself. No renouncement of values and bearing in mind the feasibility and compatibility of the educative target. In this work, we focus on the “trigger" moments. These are the moments when a change of direction, disorder, destabilization but also creative adaption appear. “we are always tempted to control through order but disorder allows for creative activity” (Le Moigne,

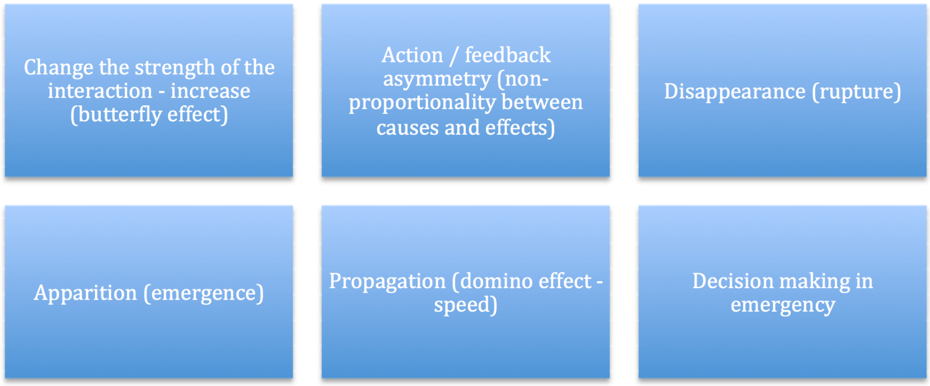

Figure 11.9: Modeled complex system

Table 11.1: Opposite feeling an SSE has to face

Commitment - Pleasure	vs	compliance - constraint
Opposition - individualism	vs	cooperation - Shared
Urgency - immediate - pulse	vs	long term
Contingency - uncertainty	vs	adaptation planning - anticipation
take care of one person	vs	assume collective project

1999).

11.6 Typical events

We have identified temporal and functional markers of the decision-making process. These "triggers" generate a need for adjustment, adaptation, decision making, action in context. The triggers identified in this study are the following: altercation - conflict; resistance to the action - inertia - refusal to share - fold; Non-compliance - inappropriate action; risk taking (for self and / or others); questioning of authority; form of "anomie" (foiling rules - social disorder). We also found different types and mode of interactions: verbal and non-verbal modes (gestures, eye contact), close to the point of conflict or with distance (inter-individual distance).

Human interactions in the sports situation comply with the nature of the actions described in the life of a modeled complex system, shown in Figure 11.9.

In fact, the actor manages the contradictions and paradoxes depending on how he experiences opposite feelings presented in Table 11.1.

In making a decision, the SSE is exposed to contradictions and antagonisms. This is another element to consider in training. Clergue (1997, p.131) wonders whether "learning, which is essentially a nonlinear dynamic phenomenon, could not also find these state changes involving profound changes?" We believe that these bifurcations are elements favoring change and adaptation.

11.7 Action registers, registers of technicality

The action in these situations requires some technical interactions. They are technical (Combarnous, 1984) when three interacting elements are present: a technical rationality in process, the actor taking a role, a specialization, and the use of machinery (equipment, appliances). This technicality is implemented in different registers of action (Martinand, 1994). More precisely, four technical action registers can be used:

The register of control is represented by the professionals. The register of participation is the ability to play a guided role; for example a beginner, novice. The register of reading and interpretation is the ability to "read" the practice, to identify indicators. The register of modification implies innovation, transformation, invention.

This should be kept in mind while building the training session. However, the results of the characterization of registers (Glomeron, 2001) show that a training that insists on control of the action is not the most relevant, this register being not sufficient. The SSE action is often composed of several registers. To this end, extracts from interviews speak by themselves: The register of control: *“However, it is a sport that I have practiced for a long time at the club and I felt at ease, probably too much so. Finally, I was not able to handle the situation”.*

That is a good example of control and planning that is not efficient.

The register of participation: *“Young people do not want to participate. However, afterwards with the speaker, I gained confidence. I saw that I could regularly intervene with young people, even to change their positions”.*

The register of reading and interpretation. *“Even when I’m not near the action I constantly monitor and listen. As soon as I feel it, I can intervene very quickly. That is what is most important to me”.*

The register of modification: *“We have changed roles and I made concessions regarding compliance to the rules. If I don’t act as is, the whole group will disagree with me. On the contrary, they were ok with my decisions. As they have really made an effort, I think next time I will be able to come back to the real rules”.*

In teaching physical practice, a continuous and strict control of rules and technicals is not relevant because of uncertainty and difficult settings. The tool used, i.e. the sport, even when perfectly mastered by the teacher, does not absorb hazards generated by an audience of young offenders, within the socio-sporting interventions. The same study shows that technocratic rigor can block the overall project. A too rigid strategy can inhibit planned action, stop the operation. The efficiency of the SSE to maintain the viability of the system depends on its ability to manage different registers of technicality.

11.8 Discussion

Some principles of action appear repeatedly in these cases and these contrasting situations and are summarizes in Figure 11.10. This is the reason why professional’s actions are often “ do-it-yourself actions", and appear to come from “controled improvisation” (Perrenoud, 1983). This “ controled improvisation" is a contextualization, a possibility of action in a personal adaptation to the situation. It is based on constructed, organized but flexible principles.

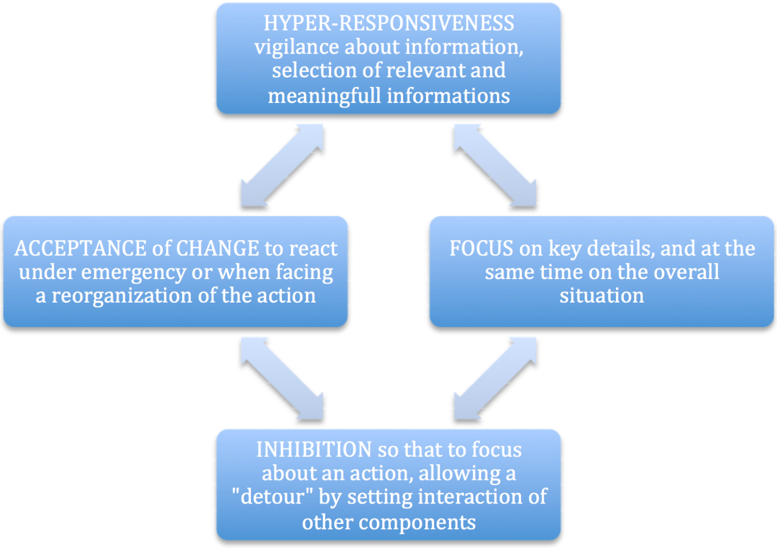

Figure 11.10: Common principles of action

11.8.1 Modes of action and decision-making

The management of uncertainty in professional situations requires the ability to think at several technical levels. The SSE must be able to adapt himself to the environment and has to be flexible. It also seems that this kind of flexibility helps to keep some "clarity" and ability to "think" adaptation. This is the reason why the analysis of decision-making is done at different levels of the system (micro, "meso" and macro) and in various time frames.

11.8.2 How to train in the complexity of the interactions

We were able to identify the criteria of "authenticity" and relevance of the situations that will expose students to the complexity of reality. Some examples are listed below:

- Confront the students with professional problems;
- Allow triggers, bifurcations, emergence;
- Enforce the treatment of contradictions and decision making;
- Need the commitment of the actor;
- Provoke reactions, emotions to be managed;
- Put the player in a dynamic adaptation;
- Avoid blocking or permanent withdrawal;
- Seek collective commitment (support, resources, complementarity);
- Solicit qualities of "hyper-responsiveness" and upper vigilance;
- Develop the acceptance of test and error;

11.9 Conclusions

Through this study, we have verified our hypothesis : the complex approach provides valuable elements for training. Therefore we can say that the SSE can be confronted to the complexity of reality in workshops. It showed major benefits for their training. Situation modeling, or interaction modeling in a multi-levels approach provide keys for training. In training, the system of interactions in sports clearly shows the importance of the work in an environment made of complexity. It is useful to expose future educators to these environments so they can learn the many factors influencing the sequences of actions.

The multilevel modeling reveal the need for joint actions who incorporate the concerns of other professionals. Once shared between professionals, the structuring axis gives coherence to all the actions of the various actors, and fits into decision-making at this level.

11.9.1 To open up new horizons

Beyond this study, this is a new challenge for training the SSE : to accept, integrate uncertainty in initial training. Thus, the professional specialized in difficult publics will be able to adapt. This uncertainty, that is wished and mobilized by the trainers, can contribute to building large skills to overcome the difficult environments.

By analyzing the activity of professionals, action logics can be characterized with some degree of "authenticity". These modeling actions can contribute to the situations of training and help to become aware of the complexity of the reality. To intensify this point of view, Rogalski and Leplat (2011, p.24) show *"the importance of the variability of situations and disruptions in (the acquisition of) basic skills"*. For the future, we hope to validate the findings of this study in two different manners: by testing them with more cases, and with different contexts. We may want to transpose to other work environments facing the same issues, that is to say intervention in schools. We can also think about the existence of the typical profiles of the actors and/or the existence of the preferential registers of action which show a trend the more important flexibility and adaptability in emergencies in a complex system.

Bibliography

Barrère A., 2002,*Les enseignants au travail. Routines incertaines*, L'Harmattan, Paris.

Benaioun-Ramirez N., 2013, *Traitement d'imprévus et incidents par un enseignant expérimenté, extrait d'une étude de cas*, Congrès AREF, Montpellier.

Bonami M., B. De Hennin , J.-M. Boque, J.-J. Legrand , 1996, *Le management de la complexité*, De Boeck, Bruxelles.

Bloch O. W. Von Wartburg, 1986, *Dictionnaire étymologique de la langue française*, Presses Universitaires de France, Paris.

Clergue G., 1997, *L'apprentissage de la complexité*, Hermès, Paris.

Combarnous M., 1984, *Les techniques et la technicité*, Messidor / Editions sociales, Paris.

De Montmollin, G., 1977, *L'influence sociale. Phénomènes, facteurs et théories*, Presses Universitaires de France, Presses Universitaires de France, Paris.

Gayraud L., G. Simon-Zarca, G. Soldano, 2011, Université : les défis de la professionnalisation, NEF, 46.

Gelinier O., 1979, Nouvelle direction de l'entreprise, Editions Hommes et techniques.

Glomeron F., 2001, Unité et cohérence de la formation des professeurs de technologie - Contribution à la définition des registres de technicité, Thèse de doctorat de l'ENS Cachan.

Granon S., J-P. Changeux, 2011, "Deciding between conflicting motivations: what mice make of their prefrontal cortex", *Behavioural Brain Research*, 229, 419-426.

Johannès F., 2013, *Le lent naufrage de la Protection judiciaire de la jeunesse*, Journal Le Monde du 09.02.2013.

Lave J., 1988, *Cognition, practice*, Erlbaum, Hillsdale.

Le Moigne J.-L., 1990) *La modélisation des systèmes complexes*, Dunod, Paris.

Martinand J.-L., 1994, La didactique des sciences et de la technologie et la formation des enseignants,*Aster*, 19, 61-75.

Morin E., 1988, *Le défi de la complexité*, Chimères, 5-6, 79-94.

Morin E. 1990, *Science avec conscience*, Seuil [Points - Sciences], Paris.

Morin E., 2005, *Introduction à la pensée complexe*, Paris, ESF Edition.

Perrenoud P. 1983, La pratique pédagogique entre l'improvisation réglée et le bricolage, *Éducation & Recherche*, 2, 198-212.

Perrenoud P., 1994, *La formation des enseignants entre théorie et pratique*, Paris, L'Harmattan.

Perrenoud P., 1999, *Enseigner : agir dans l'urgence, décider dans l'incertitude. Savoirs et compétences dans un métier complexe*, ESF, Paris.

Ria, L., 2009, "De l'analyse de l'activité des enseignants débutants en milieu difficile à la conception de dispositifs de formation", in M. Durand, L. Filliettaz (Eds.), *Travail et Formation des Adultes*, 217-243, PUF, Paris.

Rogalski J., C. Leplat, 2011, "L'expérience professionnelle : expériences sédimentées et expériences épisodiques", *Activités*, 8(2), 4-31.

Samurçay R., P. Pastré, 2004, *Recherches en didactique professionnelle*, Octarès, Toulouse.

Suchman L., 1987, *Plans and situated actions : the problem of human-machine interaction*, Cambridge University Press, Cambridge.

Tardif M., C. Lessard, 2000, *Le travail enseignant au quotidien*, De boek-Westmael, Bruxelles.

Chapter 12

Modalizing the teacher's evaluative speech in order to study the student's position[1]

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Abstract

Teachers' speech is a professional gesture based on a certain design idea of the profession ethic and a certain way of seeing pupils. This is especially true for assessment, firstly because it's a powerful indicator of the teacher's professional identity, and secondly because it has a powerful impact on pupils, the image of themselves and therefore the resources they have to make progress. School issues seem important.

We wish to analyse the interactions in class, words that teachers use to address to their pupils, to highlight a number of linguistic elements to define the positions of teachers, knowing that these positions have consequences in terms of learning, in terms of language but also cognitively.

The research presented is based on the analysis of five marking sessions conducted by five different teachers third grade of primary school. It seeks to highlight some pragmatic and linguistic elements, to build a first categorization of teachers' postures to model interactions.

12.1 Introduction

The vast amount of research focusing on the movement of speech at school all agree on one point: the teacher speaks a lot, and the student mostly listens. The teacher speech is estimated from 60 to 80 % in an oral classroom context (Dolz & Schneuwly, 1998; Bucheton, 2009; Mercier-Brunel & Jorro, 2009). The remaining time is then shared between pupils, depending on their abilities and on their status in class (Sirota, 1988). These linguistic dimensions, as well as anchoring identities and the values and plans that are affiliated to them, are too often left implicit and related to the teacher's skills and charisma (Bucheton, 2008).

Our aim is to analyze the language used by teachers when talking to their pupils, in order to highlight a certain number of linguistic elements (De Nuchèze, 2001) and to suggest modelization of interactions in class, knowing that these interactions have repercussions on learning, as regards to a linguistic but also a cognitive aspect (Guerin, 2011). School-related issues seem to be considerable.

12.2 To think speech in class

12.2.1 From the institution's point of view

Since the early 20^{th} century, curriculums have significantly evolved in regard to the role of oral communication in class, expressing the fact (or not) that school used to consider that it was part of its duty to teach pupils how to communicate orally. Studying the last hundred years alone, it appears that the teaching of French in the 1923 and 1938 curriculums was aiming at "a beautiful language and a beautiful literature", as well as a strengthening of national unity. The 1971-1972 curriculums appear to be exceptions, for they define oral according to oral exchanges deriving from "real experience situations, or game situations", highlighting a kind of speech authenticity. The 1985 curriculum backtracks on this progress and lapses into a form concern, to the detriment of substance. In 2002, 2007 and 2008, official instructions gradually placed oral at the service of disciplinary fields - within the framework of the triptych speak/read/write, where the speech of pupils had to be useful and obey precise school models. The common core of competences leads teachers to split off between an oral taught in a syntaxic aim (competence 1), and an oral instructed in a discursive purpose (competence 5 and 6), "as if, from all eternity there had been language first, and then the ways of using it" (François, 1998).

12.2.2 About research

Research contributions to oral in class have also significantly evolved. In the 1970s, researchers like H. Romian and the *Groupe Langue Orale* tried to develop the problematic of oral at school. In the 1980s, several linguists worked to renew the approach of verbal exchange, by no longer considering oral as a degraded written form (Peytard, 1970), but as a specific object (Culioli, 1983) inducing another way to mean (Blanche-Benveniste & Jeanjean, 1987; Gadet, 1989). Analytical tools were created (Kerbrat-Orecchioni; 1986, 1990), and corpus analyses were made (Bange, 1987; Cosnier & Kerbrat-Orecchioni, 1987).

However, educational sciences really started focusing on pupils' speech in the 1990s. For example Nonnon's numerous works whose analysis has continually evolved, from verbal interaction (1986 & 1990) to discursive behaviour (2001). She studied closely the existing links between speech and cognition. Halté and the CRDF team from the University of Metz also analyzed classroom interactions based on the hypothesis of a language activity constituent of learning, and observed that "oral was less taken into account" (Halté, 2006). The Geneva Schneuwly team built a paradigmatic classification of didactic situations relating to oral, and suggested a series of pedagogic devices (Dolz & Schneuwly, 1998), as interview and radio programs. These ones are based on Piaget and Vygotski 's language development theories, as well as on Bakhtin's secondary speech genres. Finally, there are also the INRP works, with its two main research teams: one of them based on the corpus analyses collected in classroom, and suggesting various conclusions (Grandaty & Turco, 2001), the other addressed to teachers in order to show them the importance of working on oral skills in the classroom, in the final aim of offering them sessions, as well as offering them some thoughts on discovery learning, assessment and remediation (Garcia-Debanc & Plane, 2004).

All of this research enabled, among other things, to show that it is in the course of actual exchanges - i.e. with actual issues, other than those implied by answering a teacher's questions about the current lesson, or by mechanically repeating a sentence - the development of language know-how is at stake, and that the latter has real consequences on the developing of knowledge in general, as well as on language mastery, but also on the way of comprehending the world.

12.3 Teacher's speech

12.3.1 Evaluative speech

We are interested in the analysis of teachers' speech regarding its relatively stable aspects, and because it influences pupils' positioning.

The first point is about finding the element of this speech which calls out to the listener's singularity regarding his referential, emotive and conative functions at the same time. Indeed, we decided to focus on this subject since "the individual is recognizable by its elocutions which can be qualified as evaluative" (Ricoeur, 1990), and the evaluative utterances are ubiquitous in classroom situations.

There is no doubt that this evaluative speech has a strong influence, whether because academic functioning implies a dialect relationship between assessment by teachers and the leaner's self-regulating process (Allal, 2007), or because academic judgment has undeniable psychological consequences on pupils (Barlow, 1992; Bressoux & Pansu, 2005).

Actually, evaluative utterances seem to be heterogeneous in the classroom's daily context with rather immediate consequences but varied forms, from the closure or verdict, to an index, evocative or inchoate appearance (Jorro, 2003). The question of the teacher's efficiency seems to hinge on this kind of feedback on pupils' action, depending on their contingency, targeting and corrective dimension in case of a student's mistake (Carhay, 2007).

12.3.2 Definition of the selected linguistic indicators

Based on what was stated above, we took an interest in the nature of contingency of evaluative feedbacks and the way of approaching it. The first studied indicators in the teacher's speech are the types of statements corresponding, according to Benveniste (1966), to "three fundamental behaviours of speaking and acting through speech": the assertive, the interrogative and the imperative (injunctive).

These types then raise the question of certainty (Ducrot & Schaeffer, 1995), introducing three modalities: the possibility/capacity or apodictic truth - alethic modality -, what the teacher faces during the exchange or what he or she is sure of because it falls within his knowledge in the field - epistemic modality, and what he or she allows and what he or she imposes - deontic modality.

But other than these aspects that could be defined as illocutionary, there are indicators referring to perlocutionary values present in the utterances, that is to say the perlocutionary effect intended and/or reached by the teacher's speech, in terms of demand, persuasion, induction and guidance, according to which effect is observed in the behaviour, the beliefs, the feelings (Vermersch, 2007) or the cognitive processes of the pupils respectively.

From there, we have established a first series of elements that aim towards a pre-categorization of the teachers' evaluative utterances studied here and presented in Table 12.1.

12.3.3 Complementary enunciative indicators

One of the interesting aspects of evaluative utterances lies in the strong enunciative dimension that cannot be perceived by the previous pre-categorization that is more directed towards other functions of language. We thus suggest returning to look at some

Table 12.1: Categorization of teacher's evaluative uttertances

Indicators concerning the teacher's utterances	Types	Assertion
		Question
		Injunction
	Modalities	Alethic (*apodictic vs hypothetical*)
		Epistemic (*knowledge vs supposition*)
		Deontic (*right vs duty*)
	Perlocutionary values	Demand (*order, request*)
		Persuasion (*argumentation, demonstration*)
		Induction (*manipulation, rhetoric*)
		Guidance (*support, inquiry*)

of Kerbrat-Orecchioni's works in which she tries to explore the traces of the utterer's subjectivity in his or her words using what she calls *subjectivèmes* (subjective markers) (Kerbrat-Orecchioni, 2006). To do so, she relies on the *affective* and *evaluative* dimensions - in qualitative and quantitative terms and she notices amongst others three types of indicators.

Deictic markers make it possible to place the action on a self-centered spatial-temporal level. We will study *personal pronouns*, subjects or complements that make it possible to place the process in terms of its author and its object. Here we will focus on a pragmatic dimension, especially in the context of exchange situations in the classroom, that is to say the type of address and the way the teacher creates a link with the group. The differences are noticeable between a general and a targeted *you* is: "You didn't learn that lesson" addressed to the whole class or just some of the pupils? Similarly, is the use of *we* in "Do we agree?" purely rhetorical or does it really speaks to the pupils? Amongst the deictic markers, there are also *spatial demonstratives* which are often responsible for the difficulties pupils have when decoding: in "This isn't correct" or "You made a mistake here", the reference is often about a sum of elements that pupils have difficulties distinguishing. *Temporal demonstratives* also raise a problem: "What did I tell you last week?" does not help the pupils who know precisely what they will learn and who establish links with the previous lessons - which is rarely the case with pupils in difficulty to whom these questions are often addressed.

Affective markers are another kind of *subjectivèmes* that mark an emotional commitment from the speaker towards what he or she is referring to. It should be noted that if certain types of speech claim they proscribe these kinds of terms, notably because they aspire to a form of neutrality, they remain in fact very present in evaluative synthesis - "Disappointing results" - and in dialogues - "I really like your text", "Your test turned out terrible". The matter is less about the evaluated object strictly speaking than it is about what it provoked in the assessor, while a competent assessor goes unnoticed (Jorro, 2000).

Non-axiological evaluatives have a qualifying aspect in respect to a certain scale. They rely on a double norm inside the object and specific to the speaker. In other words, the use of an evaluative adjective is related to the idea that the speaker has of the evaluative norm. For instance, "There are too many mistakes" typically refers to the acceptable amount of mistakes that can be made while doing a given task, according to the assessor.

Finally, *axiological markers* bring a value judgment to the evaluative utterance and pupils rarely put enough space between performance and capacity. It is thus common that pupils go from “Your maths test was bad” to “I am bad at maths”. One can wonder if a “It is very poor”, thrown out while giving back a test, is in fact addressed to the performance or to the pupil? (Barlow, 1992). The field observation shows the importance of the axiologicals in the teachers’ evaluative utterances, often supported by non verbal actions - a hand on the shoulder versus arms crossed, an open and smiling face *versus* eyes lifted towards the ceiling. “Congratulations” and “well done” are not as clear as they seem either: if they refer to a *good* action, the question is then *good for whom*? For a teacher that has set himself or herself objectives, good might refer to everything that helps him or her reach them (Mercier-Brunel & Jorro, 2009). Now, not all these objectives are oriented towards the quality of the learning.

12.4 Application to a corpus

12.4.1 Research site

The data was collected in 2008 in four CE2 classes (3^{rd} grade) from the same school in order to minimize the *institution effect* (consequences of the sociological context). The pupils were between 7 and 10 years old - most of them were 8. It was decided to work at this level because the Official Instructions are more precise regarding (oral practices) within various frameworks and they impose a precise definition of school subjects (for instance history, geography and science belong to a field called “world discovery”).

The school is located in a rather privileged neighbourhood in the centre of Nice. Half of the pupils have a rather wealthy background - children of middle management and liberal professions -, the other half come from more modest or even precarious environments - social housing or emergency shelters can be found in the same area where the school is located. Two thirds of the more modest families belong to the working class and are of foreign origin.

These four classes have 26 to 28 pupils, which is a lot for primary school. On average, the school has classes of 25.5 pupils. As the school is not in a deprived area, this is a standard rate for a city as important as Nice.

12.4.2 Data collection process

The five filmed sessions all followed identical protocols: a 20-minute correcting session after lunch. The corrected exercises had to correspond to the classes’ daily work. However, the duration of each session differs for practical reasons - breaks, teachers’ wishes - and for consistency - longer or shorter activities, faster-working or slower-working pupils. The five sessions below were recorded between the end of October and the end of November, 2008.

The profile of each teacher is quite different and summarized in Table 12.2. **Christine** was filmed during a 34-minutes group correcting session. For a grammar exercise, the pupils had to find individually “what the pronoun referred to”.

Mathieu was filmed for 44 minutes during which time he and his class corrected several exercises related to types of sentences and conjugation of the verbs ‘have’, ‘be’ and ‘go’ in the present.

Geneviève corrected exercises on the value of numbers and the various figures composing numbers following decimal systems. Her session lasted 31 minutes.

Viviane corrected mathematics for 36 minutes: in the various exercises, pupils had to find a specific number in a list following given instructions such as parity or the

Table 12.2: Teacher's profile

	Christine	**Geneviève**	**Léa**	**Mathieu**	**Viviane**
Age	45	52	29	35	48
Experience as a teacher	17 years	10 years	5 years	12 years	17 years
Experience teaching CE2 (3^{rd} grade)	13 years	4 years	4 years	4 years	11 years
Number of pupils	26	27	26	27	26

figures composing it.

Léa corrected three geometry exercises for 22 minutes. The pupils had to find right angles in various geometric shapes, using a set square.

12.5 Categorization of the teacher's discourses

Although each teacher cannot be defined as using a single type, modal construction or *subjectivème*, we noticed some unexpected combinations, sometimes with alternations between two combinations.

During the first part of her session, **Christine** is characterized by her use of several injunctions, a few highly inductive questions and more and more axiological markers. This seems to put a correcting routine into place, each questioned pupil being firmly guided to give answers in a specific order. This discourse has been identified as "*routine creating*".

Teacher (T): (to Anouar) So, have we to read the *one* ?
Anouar: No
T: No we haven't / it will be for doing exercice you're right / good / we ?

A little while after that, Christine starts to speak less but gets into longer dialogues with the pupils she is questioning (reaching 4 to 6 Q&A with a single pupil). Her questions become more about guiding than inducing an answer (i.e. the pupils can no longer guess the answer because of the question, but they know where to look), the affective subjective markers are more numerous and the personal pronouns are in the singular.

T: She / the teacher / it's feminine / and so ? / it was good what you've just tell before
Angelo: She is alone
T: So you've chosen ? /
Angelo: The / the / singular
T: Right / very good / thanks

She also seems to focus on a selection of pupils, guiding them both to find the answer and to secure them emotionally using a *supervising* discourse.

Genevieve alternates two types of combinations during the entire session. The first one is based on injunctions and a few highly inductive assertions, a lot of axiological markers and deontic modal constructions. Her discourse is about "imposing a routine". Contrary to Christine, this routine is previously created instead of being co-built during the sessions.

T: So / how many one hundred euros bills would you give / for nine hundred and twenty nine ?
Emie: Nine
T: Nine / how many ten euros bills / Steven / for nine hundred and twenty nine ?
Steven : Two
T: Two / and how many one euro coin will you give ?

The second combination is essentially made of highly inductive questions (the pupils guess the answer half the time), numerous deictic markers indicating the key elements to solve the problem and alternations between personal pronouns in the singular (student being questioned) and in the plural (class being questioned).

T: So / who doesn't agree ? / (to interrogated pupil) how do you read that / the number you wrote ? / where have you to place the decade ?
Margot: Six hundred and one
T: (to Solène) Wait / she realize she was wrong

Her discourse is about "taking charge of the procedure".

Léa, the youngest teacher, seems to be using a single combination made of injunctions (personal pronouns in the singular and deontic modal constructions) and interrogations (personal pronouns in the plural and epistemic modal constructions). Her speech is only slightly inductive and contains just a few affective and axiological markers.

T: Elyes / how do you put your template ?
Elyes: Well like this
T: You put the corner / on the angle's corner / you put a side / on the figure's side

It seems like she wants to firmly regulate the pupils' position individually and their procedures collectively using a *normalizing* discourse.

Mathieu is the one who uses the highest number of assertions, with many alethic and epistemic modal construction aimed to guide. His feedbacks are not very explicit, which means there are few subjective assessment markers and many inductions.

T: Yes rather it's an order / it could be an advice / depending of the context [. . .]
T: Yes it's right / it's right they resound / how could I explain / there are verbs / which are / euh / which you didn't use / with every person / so / it's tricky

He seems to present himself as owning the knowledge, using an *apodictic* discourse. Then, as he is pressed for time by the end of the session, he uses more evaluative axiological markers, inductive injunctions and a lot less guidance, therefore opting for a *session leading* discourse.

Viviane started her session with many highly inductive questions, a few injunctions and very short assessment markers. She focuses on the pupils' theoretical knowledge about which she asks for explanations through an *epistemic* discourse. Later on, her speech becomes shorter, the pronouns in the singular are replaced by plural and she focuses more on the rest of the class than on the pupil who is correcting to validate or invalidate the answers. Her questions are very slightly inductive and can sometimes guide but are mostly neutral.

T: I'm odd / so it's 63 / do you agree with him / others ? [...]
T: Kevin doesn't / who is wrong ? / could you explain to me where it come from ? one of the two who are wrong ?

It becomes difficult for the pupils to know what she wants and if their answers are right, and they have to build their approach with the class rather than with the teacher. Her discourse is based on *postponed assessment*.

12.6 Synthesis and perpespectives

This categorization of teachers' evaluative speeches, that we chose not to develop any further, enables us to rebuild a certain pedagogical intentionality and find a way to involve the pupils through the words of the teachers. Consequently, we can see positions developing, with a withdrawal in supervision encouraging the pupils' investment with Viviane, securing and targeting for Christine, turned towards leadership with Mathieu and towards correcting with Léa and Geneviève.

These various discourses allow the pupils to be part of the exchange in different ways. For instance, we have noticed that pupils tend to simply answer the questions with Mathieu or Léa, while they try to verbalize their intellectual approach with Geneviève or Viviane. In the first case, the method is pre-established, but in the second the method is created on the spot. Furthermore, we have noticed that the secure feeling felt with Christine allows inferences that are not always relevant to the exercise but interesting for the understanding of the thought process.

The data exposed here is part of a wider set of results and shows why a linguistic categorization of the teachers' evaluative discourse is necessary to reveal its effects on the implication of pupils in the class exchanges, which we know to be at the basis of school education. In relation to this subject, we only refer to the socio-constructivist works in didactics done on mathematics and French. This data is therefore an interesting tool for research as well as training - teachers can understand the impact of their evaluative comments on their pupils' education.

Bibliography

Allal L., 2007, Régulation des apprentissages : orientations conceptuelles pour la recherche et la pratique en éducation. In L. Allal (Ed) *Régulation des apprentissages en situation scolaire et en formation* (pp. 7-23). Bruxelles : De Boeck Université.

Bange P., 1987, *L'analyse des interactions verbales. La dame de Caluire : une consultation*. Berne : Peter Lang.

Barlow M., 1992, *L'évaluation scolaire, décoder son langage*. Lyon : Chronique sociale.

Benveniste E., 1966, *Problème de linguistique générale*. Paris : Gallimard

Blanche-Benveniste C., C. Jeanjean, 1987, *Le français parlé : transcription et édition*. Paris : Didier.

Bressoux P., P. Pansu, 2005, Quand *les enseignants jugent leurs élèves*. Paris : PUF.

Bucheton D., 2008, Professionnaliser ? Vers une ergonomie du travail des enseignants dans la classe de français. In D. Bucheton & O. Dezutter (Eds), *Développement des gestes professionnels dans l'enseignement du français* (pp. 15-27). Bruxelles : De Boeck Université.

Bucheton D., 2009, Le modèle de « l'agir enseignant et ses ajustement ». In D. Bucheton (Ed), *L'agir enseignant : des gestes professionnels ajustés* (pp. 25-68). Toulouse : Octarès.

Cosnier J., C. Kerbrat-Orecchioni, 1987, *Décrire la conversation*. Lyon : PUL.

Crahay M., 2007, Feedback de l'enseignant et apprentissage des élèves : revue critique de la littérature de recherche. In L. Allal (Ed), *Régulation des apprentissages en situation scolaire et en formation* (pp.45-70). Bruxelles : De Boeck Université.

Culioli A., 1983, Pourquoi le français parlé est-il si peu étudié ? *Recherches sur le français parlé, 5*, 291-300.

De Nuchèze V., 2001, Sémiologie des dialogues didactiques. Paris : L'Harmattan.

Dolz J., B. Schneuwly, 1998, *Pour un enseignement de l'oral*. Paris : ESF

Ducrot O., J.-M. Schaeffer, 1995, *Nouveau dictionnaire encyclopédique des sciences du langage*. Paris : Editions du Seuil.

François F., 1998, *Le discours et ses entours*. Paris : L'Harmattan.

Gadet F., 1989, *Le français ordinaire*. Paris : Armand Colin.

Garcia-Debanc C., S. Plane, 2004, *Comment enseigner l'oral à l'école primaire ?* Paris : Hatier

Grandaty M., G. Turco, 2001, *L'Oral dans la classe. Discours, métadiscours, interactions verbales et construction de savoirs à l'école primaire*. INRP.

Guérin E., 2011, Sociolinguistique et didactique du français : une interaction nécessaire. *Le français aujourd'hui, 3*, 139-144,

Halté, J.-F. 2006, Entre enseignement et acquisition : problèmes didactiques en apprentissage du langage. *Mélange CRAPEL*, 29, 13-28.

Jorro A., 2000, *L'enseignant et l'évaluation. Des gestes évaluatifs en question*. Bruxelles : De Boeck Université.

Jorro A., 2003, L'évaluateur est un autre ! In J.-P. Astolfi (Ed), *Education et formation : nouvelles questions nouveaux métiers*. Paris : ESF.

Kerbrat-Orecchioni C., 1986, L'implicite. Paris: Armand Colin.

Kerbrat-Orecchioni C., 1990, *Les interactions verbales*. Paris: Armand Colin.

Kerbrat-Orecchioni, C., 2006, *L'Énonciation*. Paris : Armand Colin.

Mercier-Brunel, Y., A. Jorro, 2009, La parole évaluative de l'enseignant. *Les dossiers des Sciences de l'Education*, 22, 9-24.

Ministère de l'Education Nationale, 2002, *Qu'apprend-on à l'école primaire ?* Paris : CNDP.

Ministère de l'Education Nationale, 2005, Loi No 2005-380 du 23 avril 2005 d'orientation et de programme pour l'avenir de l'école. *Bulletin Officiel No 18*, 5 mai.

Ministère de l'Education Nationale, 2008), *Bulletin Officiel No 3*, Hors-série du 19 juin.

Nonnon, E., 1986, Interactions verbales et développement cognitif chez l'enfant : aperçu des recherches psycholinguistiques récentes en langue française. *Revue Française de Pédagogie*, 74, 53-86.

Nonnon, E., 1990, Est-ce qu'on apprend en discutant ? Un exemple d'interaction maître-élèves en Section d'Education Spécialisée. In F. François (Ed), *La communication inégale* (pp. 147-212), Neuchâtel : Delachaux et Niestlé.

Nonnon, E., 2001, La construction d'objets communs d'attention et de champs notionnels à travers l'activité partagée de description. In Grandaty, Ph. & Turco, G. (Eds), *L'Oral dans la classe. Discours, métadiscours, interactions verbales et construction de savoirs à l'école primaire* (pp. 65-102). Paris : INRP.

Peytard, J., 1970, Oral et scriptural. Deux ordres de situations et de descriptions linguistiques. *Langue française*, 6, 35-48.

Ricœur, P., 1990, *Soi-même comme un autre*. Paris : Editions du Seuil.

Sirota, R., 1988, *L'école primaire au quotidien*. Paris : PUF.

Vermersch, P., 2007, Approche des effets perlocutoires : 1/ Différentes causalités perlocutoires : demander, convaincre, induire, *Expliciter*, 71, 1-23.

Chapter 13

The self-organized situation, a challenge for physical education teacher training: a complex system of ritualized interactions and proxemic distances.

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Abstract

The reform of teacher training called in French "masterisation" implies a reflection on teaching disciplinary situations during the initial training and leads to a new analytical focuses on the interactions between the teacher and his student's framework. The question of complexity is an essential issue and we are confronted to a real problem of didactics. "Building Teachable" raises the question of training situations proposed to students, allowing them to encounter a part of the reality of their future occupation. The disciplinary orientation used is that of "situated action". This approach will be complemented by the theoretical framework of symbolic interactionism and by a proxemic analysis. Seven students of 5th year supervise a gymnastics lesson. This lesson is completely filmed and provides support to analyze the activity of the trainee teacher. Three registers of analysis will be used for this exploratory study: (1) planning lessons, (2) the video, (3) collective post activity discussions. The results show three major points: (1) trainee teachers have built a planned design "teachable", (2) teachable is an unfinished construction, (3) trainee teachers build strategies to control some variables of the "education" system. Changing the posture of the student in a self-organized situation generates a dynamic engagement. The workshop of professional practice is a tool to build the "teachable" in a training framework that integrates complexity.

13.1 Introduction

In his letter from October 5 2010 (see Appendix 13.8), the Minister in charge of Higher Education and Research wished that the initial training teacher education would be further developed, more particularly by insisting on how this reform could be implemented in higher education institutions. The importance of teacher training for any nation does not need to be reminded. Similarly, it would be an illusion to believe that this training could follow an immutable pattern which we alone could define contents and modalities. Society is evolving and changing, so it is essential that teacher training integrates these changes (Lessard, 2000). Moreover, international experience clearly shows that all nations are also involved in the recurring process of reform of initial training without an ideal solution to make consensus among all stakeholders (Jolion, 2011). Therefore reforms are not to be questioned.

Moreover it seems a pity that, although the competitive exam (to become a teacher) is a necessity, no one has imagined a system which would allow to measure the number of students, the relative flux of the various sectors, the monitoring student profiles whether in degrees preparing for the exam or without preparing.

This feeling of disconnection between competitive exam and teaching is unanimously felt and criticized by students when they prepare themselves to become primary school teachers or secondary school teachers (Jolion, 2011). This point will be widely commented upon as it is the major pitfall of this reform. Contest requirements sometimes seem distant from what is required as a teacher. Teaching is interacting with students. Teaching is transmitting knowledge and making sure that students learn something. The competitive examination does not prepare for this interaction.

The aim of the reform is to improve the training of future teachers and enable them to acquire a greater vocational qualification.

Teaching is not an art but a profession (Mérieu, 1989) that can be learned and the practice must be accompanied. Who can doubt that today's pupils, living in a culture of immediacy, who are both at the center of the world and more isolated than ever, require a renewed pedagogy that cannot be reduced only to the individual charisma?

The "masterisation" involves changes in the implementation of teaching and in the reflection skills to be acquired. A new analytical framework is born around interactions as the basis for the training of future teachers. It's all about innovation and helping futures physical education teachers use problem-solving skills to figure learning situation out on their own. The question of complexity (Clergue 1997, Morin, 2005) is an essential issue and we are confronted to a real problem of didactics. The framework of complexity highlights the fact that is not only a sufficient conceptual idea, but it calls for major developments towards the analysis of the activity in a training situation: what we call here the construction of "Teachable". "Building Teachable" raises the question of training situations proposed to students (spatial and temporal organization, interaction with pupils, choice of teaching contents, provide feed-back to students), allowing them to encounter a part of the reality of their future occupation (Blanchart-Laville, 1998). Figure 13.1 represents this analytical framework.

The complexity lies in the interaction between the implementation of training situations, didactic obstacles arising, the institutional framework and the construction of professional skills.

In their face-to-face relations in the public arena human beings are engaged in scanning or reading each other and, in turn, presenting themselves through externalization so that they are read in appropriate ways by others who are scanning them. Frame analysis reveals the complexity of social activities and it brings out the arbitrary nature of any fixed, social-domain or activity-based dichotomy between what is "staged" and what is "real". The teaching profession shows the presence of a complex system. This system is built by interactions through a proxemic space , ritualized and temporal (Baeza, 2012).

Symbolic interactionism is a micro-level perspective which focuses on how daily interactions create and maintain social order. Social interaction generates the order that changes adaptively to internal and external constraints, resources, and power. Complex adaptive transformation focuses on the self-organizational behavior of complex, dynamic systems, and the interaction of such systems with each other. "Complex systems have a self-organizational process that emerges out of the nature of the properties of

Figure 13.1: Analysis model of physical education teacher training.

their component parts" (Siegel, 2003).

The aim of this article is to demonstrate that the establishment of self-organized situations generates among students, future Physical Education teachers, a real dynamic of change. Self-organized situation allows to built the "teachable".

13.2 Framework

The disciplinary orientation used is that of "situated action" (Suchman, 1987) that underlies the idea that any action is highly dependent on material and social circumstances in which it takes place. The actions are still socially and physically situated and the situation is essential to the interpretation of the action. Suchman (1987) insists on the changing complexity of situations and on the "opportunistic" reactivity of the actors to environmental contingencies.

This approach will be complemented by the theoretical framework of symbolic interactionism. Interactionism and especially the paradigm developed by Goffman (1974) focuses on the rituals of interaction and face to face interaction. From the different types of rituals proposed by Goffman, it is possible to transpose in a constraining school context:

- **"Presentation Ritual"**: Our behaviour enables our pupils to perceive how we consider them and how we will deal with them in the next classes. The distance between the teacher and his pupils reveals the presence of this ritual. In order to belong to the space of the group, the teacher must come in.

- **"Confirmation Ritual"**: Conveying an image of ourselves to others as well as emphasizing the attention we pay to others. The teacher has some obligations (pedagogical and institutional). For that purpose, he uses pedagogical and didactic strategies and tools.
- **"Reparation Ritual"**: It takes place when some incidents may damage the pedagogical relation. It is all the more important when the teacher wants to build a dynamic by meeting the expectations of pupils and making the group work. When people are together, unexpected events may occur that can break the initial balance within that group. Under those circumstances, the teacher will have to restore the balance in order to maintain his authority.

Goffman (1974) has assumed that this maintenance activity constantly occurs in ordinary interactions since it is the foundation of encounters. Thus the word « ritual » is used because this activity -though very simple- represents the effort we make in order to give a symbolic image to others, i.e, pupils.

Communication is an activity regulated by rules and set standards for collective interaction. Finally, we will complete the theoretical framework by a proxemic analysis. Proxemics (Hall, 1966), or the study of the perception and use of space by humans, is defined as the physical distance established between the people caught in an interaction, an exchange of communication. Hall discusses the structure of conditioning experience by studying the culture and the cultural dimension in a vast communication network with multiple levels. Four interpersonal distances are highlighted and presented in Figure 13.2: the intimate distance (7-45 cm), personal distance (45 to 125 cm), social distance (from 1.25 to 3.60 m) and public distance (from 3.60 to 7.50 m).

13.3 Hypothesis

The construct of "teachable" implies a new perspective from the trainers. The interaction between the trainer, the student, knowledge and context is a process to study. We need to emphasize what it escapes the constraints of interaction (environmental constraints, communicational constraints) rather than the constraints themselves (the interaction order) (Goffman, 1974). We make the hypothesis that observation of proxemics phenomena (Hall, 1966) to interactions rituals is likely to enhance a didactic approach in the training of future teachers. The proxemic phenomena result in the measurement of distances between actors. These distances reflect the nature of rituals and their contents are shown in Figure 13.3.

This model shows a new form of complexity. Students, knowledge, context of training and trainers are interwoven. These four categories operate together and are in direct interaction.

13.4 The situation of intervention

The trainee teacher is subject to fixed constraints in a self-organized situation of training. The environment will be used for situation of professional practice (see Figure 13.4).

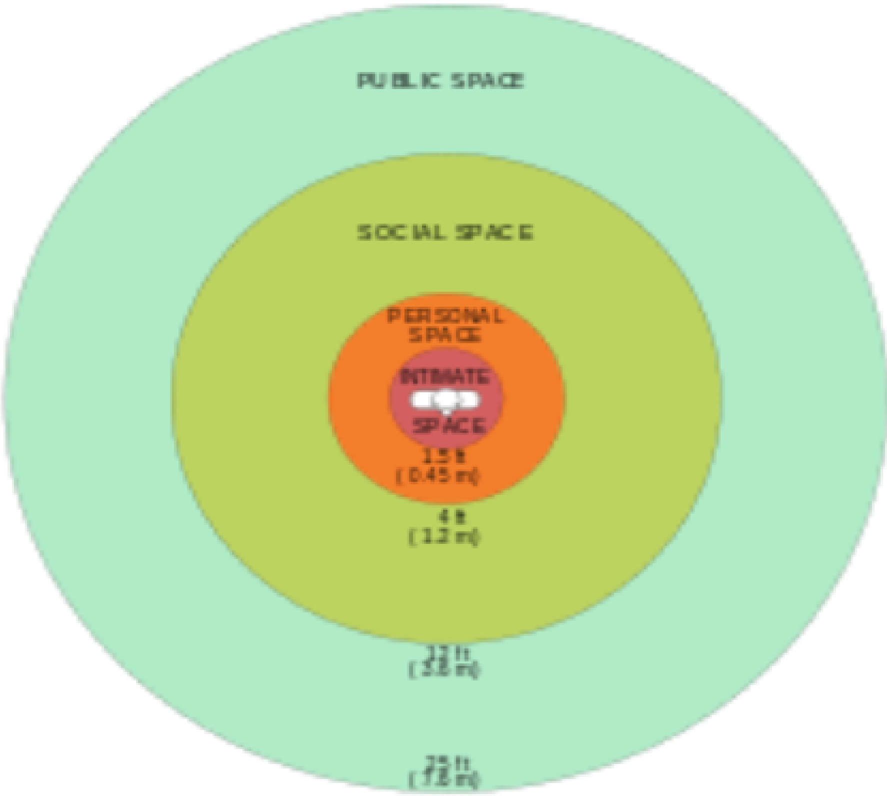


Figure 13.2: Proxemic's distance (Hall, 1971).

The aim is to present a lesson from a theme imposed by the trainer. It is considered that these requirements operate as didactics variables (Robin, 2012). The context plays the cognitive artifact role: envisage the action as a self-organized coupling involves considering the context, and its properties, such as offering "resources for action" available to the actor according to his intentions (Norman, 1993).

13.5 Population

Seven students of 5th year supervise a gymnastics lesson. This lesson is completely filmed and provides support to analyze the activity of the trainee teacher.

13.6 Methodology

Three registers of analysis will be used for this exploratory study: (1) planning lessons for understanding how the trainee teacher structures self-organized situations, (2) the video to read the activity of the trainee teacher in situ. The collection of field data will be analyzed from a proxemic analysis grid, (3) the collective post activity discussions to understand the analysis made by the trainee teacher on its action in situation.

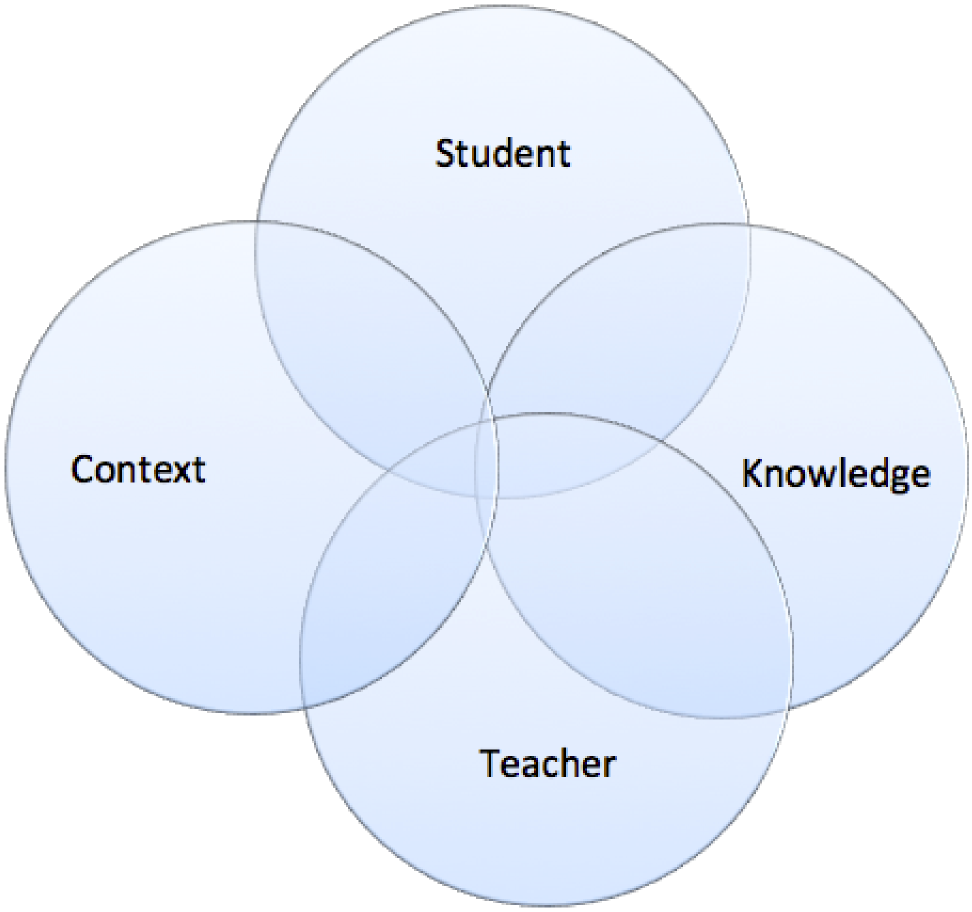


Figure 13.3: New model of physical education training teacher.

Here we only consider the "space" that will be analyzed from the point of view of proxemics studying the signifying structure of human space. We observe the proxemic distances established between the actors during interactions in gymnastics lessons in physical education.

13.7 Results and discussion

13.7.1 Space in the planning

Planning allow to see that as workspaces located and organized according to professional prerogatives (spatial organization, temporal organization, methods of grouping students, implementation of several learning situations). Space is controlled by the student. The use of media, the materialization workspaces before the beginning of learning is reflected. Each student group is confronted with a specific learning situation with media to consolidate the instructions given by the teacher-student. The space

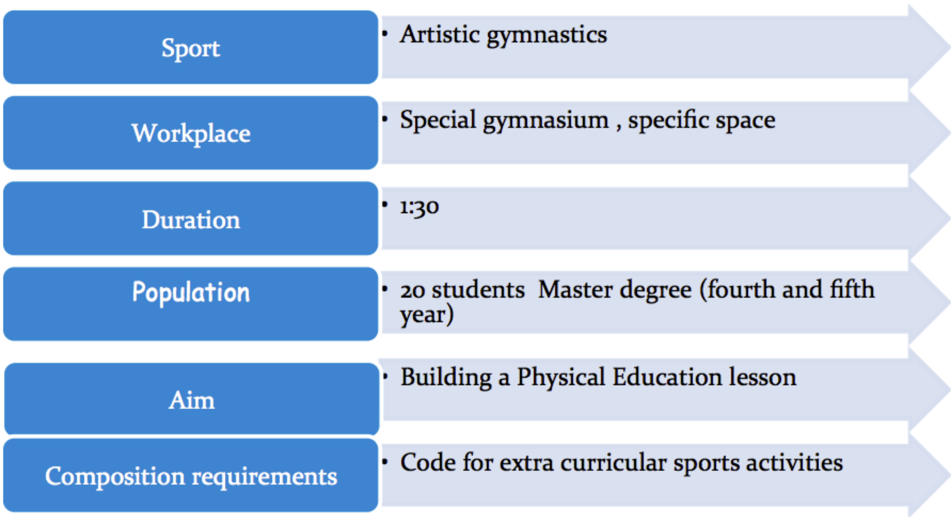


Figure 13.4: Self-organized situation of teaching.

is arranged to constrain specific motor skills.

13.7.2 Space in the lesson

The results are presented in Figure 13.5. Regarding the ritual of presentation, the distance is 2.50 meter for 100% of the population. This social distance permits to deliver general instructions for lesson.

Relating to ritual of confirmation, we can observe: 29% use private distance, 57% personal distance and 14% social distance. These distances differ depending on the interaction between pupils and teachers.

Concerning ritual of reparation, two types of distance appear: 86% use personal distance and 14% social distance. When there is a contract breaking-off, teacher prefers to keep the distance in interactions with students.

13.7.3 Space in collective debriefing

The feedback highlights three key points:

- The workshops are located in the workspace,
- Students are divided among the workshops,
- The workshops are organized according to the activity and needs of the pupils.

The results show three major points:

1. Trainee teachers have built a planned design "teachable" taking into account the institutional, pedagogical and didactic requirements.

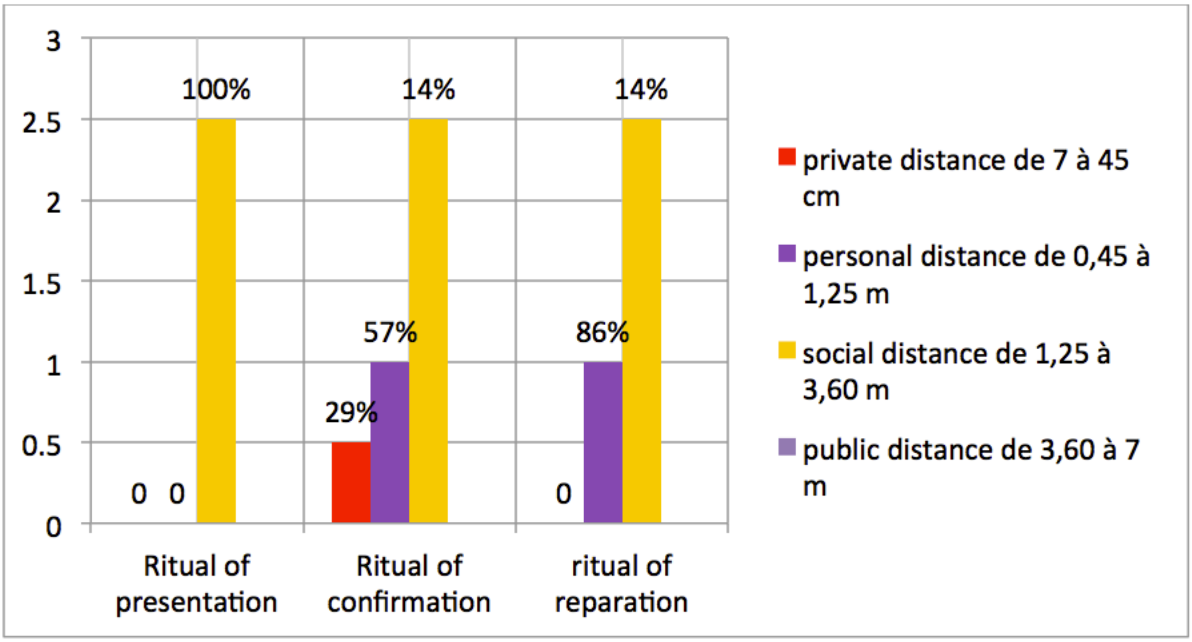


Figure 13.5: Space in the gymnastic lesson (Video results).

2. Teachable is an unfinished construction because institutional, pedagogical and didactic requirements are realized in interaction with students. Requirements implementation raises a problem for the trainee teacher. He must learn to manage the complexity of the act of teaching, to think of the properties of the transmission process. It is implementation of "teachable" that remains to be built.

3. Trainee teachers build strategies to control some variables of the "education" system. What seems to raise a problem is the instability that could result from the interaction between the variables (institutional, teaching and learning). The "teachable" is accompanied by a change in posture and acceptance of some kind of disorder.

13.8 Conclusion and perspectives

Changing the posture of the student in a self-organized situation generates a dynamic engagement. The interaction between trainee teacher, pupils, knowledge and the trainer generates the construction of a balance, a "middle ground" between adaptation to the constraint of the task and stability built in self-organized situation.

The workshop of professional practice is a tool to build the "teachable" in a training framework that integrates complexity. By adopting a pedagogy of simulation, the workshop turns into a self-organized situation where we will put forward the necessary cooperation of the actors; the goal is to build and bring out a changing reality through interconnected variables (institutional, pedagogical and didactic) that create or oppose change. This cooperative game is indicative of the process of interaction (Figure 13.6). This new reference is a true interaction model in complex system.

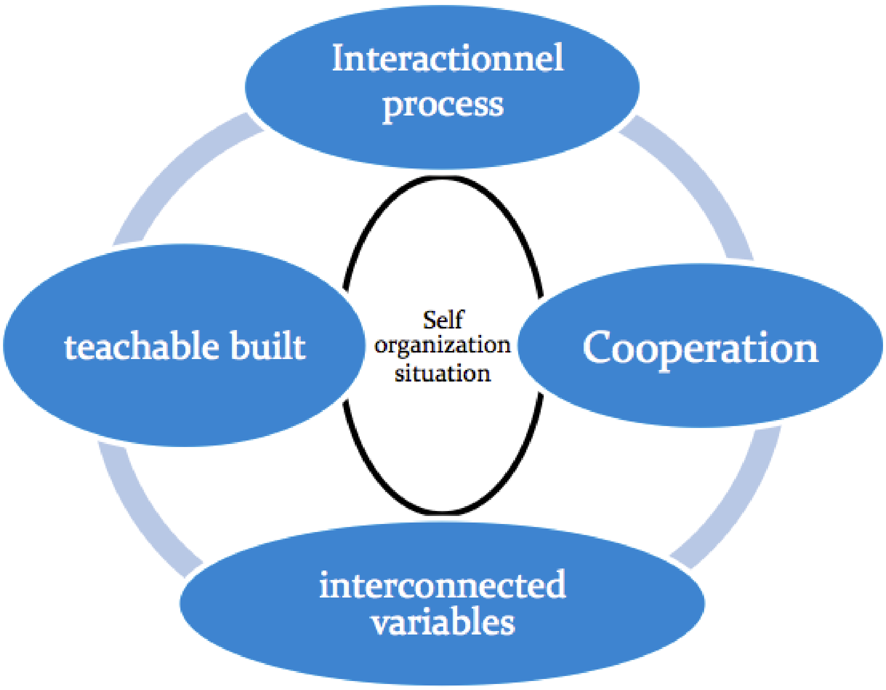


Figure 13.6: Professional situation, a real organized-situation.

Bibliography

Baeza N., 2012, *Interaction ritual, proxemic: two paradigms to teach formation*. Seminar AMISC .

Blanchard-Laville C., D. Fablet 1998, *Analyser les pratiques professionnelles*, L'Harmattan, Paris.

Clergue G., 1997, *L'apprentissage de la complexité*, Hermès, Paris.

Goffman E., 1974, *Interaction ritual*, Minuit, Paris.

Hall T.E., 1966, *The Hidden Dimension*, Doubleday, New York.

Lessard C., 2000, Evolution du métier d'enseignant et nouvelle régulation de l'Education, *Recherche et Formation*, 35.

Mérieu P., 1989, *Enseigner, scenario pour un autre métier*, ESF Editeur, Paris

Morin E., 2005, *Introduction à la pensée complexe*, Points, Paris.

Norman D.A., 1993, *Things that make us smart*, Addison Wesley, New York.

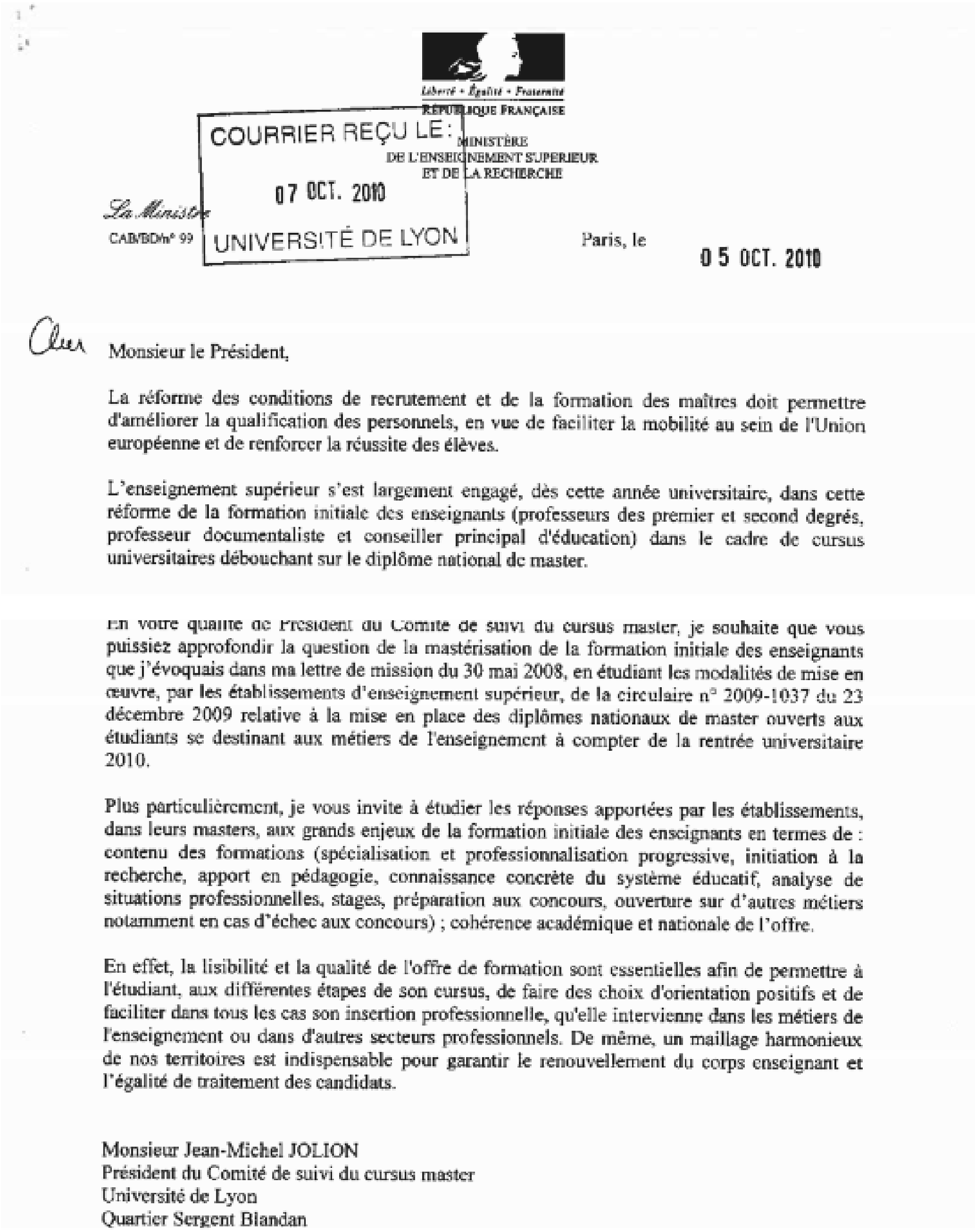
Rapport Jolion, 2011, *Masterisation de la formation initiale des enseignants*.

Robin J.F., 2012, La gymnastique : un jeu de règles, *e-JRIEPS*, 25, 27-42.

Siegel A., 2003, Représentation des Systèmes Dynamiques substitutifs non unimodulaires, *Ergodic Theory and Dynamical Systems*, 23, 1247-1273.

Suchman L.A., 1987, *Plans and Situated Actions*, Cambridge University Press, Cambridge.

Appendix A Letter from the minister in charge of higher education and research



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RÉPUBLIQUE FRANÇAISE

MINISTÈRE
DE L'ENSEIGNEMENT SUPERIEUR
ET DE LA RECHERCHE

COURRIER REÇU LE :
07 OCT. 2010
UNIVERSITÉ DE LYON

La Ministre

CAB/BD/n° 99

Paris, le 05 OCT. 2010

Cher Monsieur le Président,

La réforme des conditions de recrutement et de la formation des maîtres doit permettre d'améliorer la qualification des personnels, en vue de faciliter la mobilité au sein de l'Union européenne et de renforcer la réussite des élèves.

L'enseignement supérieur s'est largement engagé, dès cette année universitaire, dans cette réforme de la formation initiale des enseignants (professeurs des premier et second degrés, professeur documentaliste et conseiller principal d'éducation) dans le cadre de cursus universitaires débouchant sur le diplôme national de master.

En votre qualité de Président du Comité de suivi du cursus master, je souhaite que vous puissiez approfondir la question de la mastérisation de la formation initiale des enseignants que j'évoquais dans ma lettre de mission du 30 mai 2008, en étudiant les modalités de mise en œuvre, par les établissements d'enseignement supérieur, de la circulaire n° 2009-1037 du 23 décembre 2009 relative à la mise en place des diplômes nationaux de master ouverts aux étudiants se destinant aux métiers de l'enseignement à compter de la rentrée universitaire 2010.

Plus particulièrement, je vous invite à étudier les réponses apportées par les établissements, dans leurs masters, aux grands enjeux de la formation initiale des enseignants en termes de : contenu des formations (spécialisation et professionnalisation progressive, initiation à la recherche, apport en pédagogie, connaissance concrète du système éducatif, analyse de situations professionnelles, stages, préparation aux concours, ouverture sur d'autres métiers notamment en cas d'échec aux concours) ; cohérence académique et nationale de l'offre.

En effet, la lisibilité et la qualité de l'offre de formation sont essentielles afin de permettre à l'étudiant, aux différentes étapes de son cursus, de faire des choix d'orientation positifs et de faciliter dans tous les cas son insertion professionnelle, qu'elle intervienne dans les métiers de l'enseignement ou dans d'autres secteurs professionnels. De même, un maillage harmonieux de nos territoires est indispensable pour garantir le renouvellement du corps enseignant et l'égalité de traitement des candidats.

Monsieur Jean-Michel JOLION
Président du Comité de suivi du cursus master
Université de Lyon
Quartier Sergent Blandan

Figure 13.7: Letter from the Minister in charge of Higher Education and Research

Chapter 14

The hazard and discomfort in complex situations: resources for the training of social sports educators

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Abstract

This contribution is part of a finding based upon research, crossed by a social, economic question: how to improve teaching in University, when this institution has to form professionals with a great challenge to achieve. They have to teach to everyone, everywhere, in a economic crisis context, and a heated French National Education debate. Teachers, educators have to be efficient as soon as possible, need to work in networks, must create new solutions. This contribution focuses on social sports educators (SSE), which takes care of offenders, or people who can't stand school, or young people whose family failed to educate them. For developing the efficiency in such a professional context special workshops simulate the dimensions of these jobs, during the initial formation. In these workshops, future educators experience tensions, discomforts and dilemmas and by the fact seem to improve their professional identity construction. They could increase their adaptation abilities when faced with complex situations. Two frameworks provide the opportunity to report this development of adaptation into these workshops: cognitive anthropology (Suchman, 1987) and the course-of-action (Theureau, 2004). The discomfort and dilemmas seem to be parameters of control in the initial formation process.

14.1 Introduction

This contribution is related to a university training course for a job we named "social-sport educators". These professionals work in complex environment, primarily because the public, which they take care of, accumulates many problems: social, psychological and medical needs, with intricate dimensions. To overcome these needs, socio-sports educators support these people through sports and arts practices. The pedagogy has to fit very finely to this unsteady public. Many factors come into account in the daily decisions of these professionals, so they are exposed to extreme stress, associated with these particular areas in which they are involved. These special "schools" accommodate young people, who present different levels of social and physical deprivation Consequently, these educators often act in emergency, at the crossroads of various influences. Actually, they must constantly evaluate the priorities, according to their own sensibilities, to their own experiences too. They have to admit that the only certainty they might have is that nothing can be entirely planned in advance. They must admit they will have to create solutions that nobody could teach to them. To manage such complex situations, newcomers in education have to develop competences. For example, *"the capacities of problem-solving, risk taking, trust in collaborative process, ability to cope with change and commitment to continuous improvement as organiza-*

tion" (Hargreaves, 2003, p.3) are necessary qualities to teach, educate in the society 21st century.. In fact, they have to take into account a major parameter of the situation they are involved in: themselves. Here we speak about their own feelings, their own sensations that will have a major impact on the decision process, especially in the start of their career. The complexity of situation, all interactions between many parameters, the unpredictability of these contexts are some of the characteristics of what some well-known scientists such as Edgar Morin (1999), Didier Delignières (2009), Jean Louis Le Moigne (1999) call "complex systems". In this contribution we focus on the impact of discomfort and the hazard in the simulated teaching process, and we examine how these troubling sensations seem to participate in the development of qualities of adaptation, which could be a kind of *"elegance in action"* (Berthoz, 2009).

University of Orléans forms professional educators who intervene through sports with "fragile" publics in institutions professionally harsh (Homes for people with social problems, homes for young offenders, prisons). These audiences are known to practice the concept of "teaching misunderstanding" (Garnier, 2003), inducing the speaker, the teacher, the adoption of "survival strategies"(Woods, 1990, p.96). In the professional context, the socio-sports educator adopts a state of alertness that allows for the correct and competent reaction when confronted with these moments of rupture. All day long, they are under pressure to take decisions, and must stay efficient to manage tensions: it's a matter of sustainable career, often at a risk to their own health.

This paper is part of an "action research" within the scope of a bachelor's degree called "Professional Licence in Development and Mediation by Sport" (LP DSMS). To do this, in their training courses, students develop professional practices with organized, interventional working groups included in the training unit. Under agreed partnerships between the University and the Institutions, these working groups, or workshops expose students "in a controlled manner" with a public having singular characteristics (social disruption, school leavers, under court order). These working groups are authentic moments of training as they preserve the uncertainty, the randomness of the professional domain and emotionally involve the student. These workshops are "complex training situations" (Clergue, 1997), or "encouraged action spaces" (Durand, 2008) therefore requiring adaptive / development human processes.

It's about being able to adapt professional acts according to potential, to the constraints of the situation and to reasonable and possible objectives. We then talk about moments of expertise and consider the possibilities of simplifying complex situations. More specifically on terminology, we will speak of "Simplexity", a concept introduced by neuroscientist and physiologist Berthoz in 2009. The use of Simplexity does not imply reducing the dimensions of a given situation and thus hiding it's complexity, but rather insists on the importance of prioritizing taking into account situation's current capabilities. The trainer should not over simplify in order to preserve, but "confront and consolidate" and so trigger qualitative changes to professional expertise, to achieve a kind of "elegance in action" (Berthoz, 2009)

"Simplexity is a way of living with the world. It favors elegance over dullness, intelligence over formal logic, subtlety over rigidness, diplomacy over authority. Simplexity is Florentine; it anticipates rather than reacts, suggests laws and interpretive grids, is forbearing. It is adaptative rather than normative or prescriptive, probabilitics rather than deterministic. It takes into account the perceiving body as well as consciousness, and it considers context. Simplexity is intentional." (Berthoz, 2012, p.209)

14.2 Frameworks, object, model

The work of social-sports instructor is conceived as a “situated action”. In this sense, we mobilize the framework of Cognitive Anthropology (Suchman, 1987) We also choose the theoretical and methodological framework of the course-of-action (Theureau, 2004, 2006) because we will look at the work of the student training, engaged in a teaching situation that is "significant for him, i.e. "presentable, relatable and which can be commented by him at any time, under favorable conditions

This self-confrontation, a kind of re-enactment through material traces (for this study, video traces) of the teaching activity gives access to what Theureau calls “pre-reflective consciousness” and testifies of the presence of a “structural coupling”. The dynamical "structural-coupling" according to Durand’s study in 2008 is the assymetric report established between the actor (he calls a system) and his environment. *"This coupling both builds and changes the structure of the system"*, we could say the SSE structure in our study, in a relationship we could characterize as asymmetric.

Moreover, *"this coupling is asymmetrical insofar as it is the system that defines what, in its environment disturbs him, that is to say, in fact, what is relevant and meaningful to him. This "structural coupling" creates a perspective, that of the system* (the SSE), *which changes every moment according to its (his) dynamic and disturbances coming from the environment. “* (Durand, ibidem, p. 107)

This theoretical and methodological framework is based on the assumption of autopoiesis of living systems (Maturana and Varela, 1980).

The course also provides recent discoveries in neurophysiology on the action, perception and decision (including Berthoz, 1997, 2002; Damasio, 2010).

14.2.1 Assumptions

For the moment, two hypotheses have been established in this part of our research project. These two hypotheses need to be supported by a more extensive data research.

> Hypothesis 1: we assume that the hazard and discomfort experienced by the intervener in the case of a local socio-sporting action in complex situations generates emotions, sensations with "magnifying effects" (Ria et al., 2001).

> Hypothesis 2: we assume that these emotions mark changes in quality levels in the process of development / learning of student training (Gal-Petitfaux et al., 2010)

14.2.2 Participants and methods of data collection

Students animate and manage sports workshops with a sensitive public, at 4 sequences per student in the six-month course, each one for a duration of 40 minutes. All the sequences are filmed. Each student then participates in a self-confrontation interview recorded from the video of the day’s session, helped by the trainer, according to Theureau’s method.

Two training assessments are prepared: one at mid-training and the other one at the end of the course. During these assessments prepared in advance with a guide provided, sequences and self-confrontation interviews are discussed from elements that make sense to the student who is able to self-assess his own competency. Audio recordings are made on this occasion for verbatim transcription.

Two classes of students have adjusted this protocol.

In this study, we will mobilize the self-confrontation interviews of two students (Justine and Hélène) and their two individualized training balances conducted on December 21, 2012 and April 17, 2013. At this point of our discussion, some information about the experience of these students could enable us to better appreciate the collected data.

When Justine integrated LP DSMS, she had already completed with difficulty a degree, as a sports intervention educator for standard schools. Due to her lack of confidence and her deep recurring difficulties in the face-to-face teaching, she was a candidate to enter into LP DSMS with the objective of extending her expertise. She is a basketball coach, activity for which she feels legitimate.

Hélène has a degree in STAPS, , we could explain by "Sciences and Technological training course in Sports and Physical Education"; she is a gym coach, activity for which she thinks she is very competent. The qualities she self-claims: methodical, organized, perfectionist. Hélène always appears in interviews and appraisals as very voluntary and engaged in the analysis of her performance and its evolution.

These data, before training, and during training and at different stages of the training process, allows us to mention here a “course of life” (Theureau, 2004).

We have to notice that These two future SSE were particularly comfortable with this kind of qualitive method, even though they have been inclined to speak about discomfort during their teaching time.

14.3 Data

A. Justine - extract from balance training, April 17, 2013, and re-evocation of the 4^{th} workshop in intervention practice.

Justine (J): The trigger that I had, it was with the video analysis (...) really evoking what worked, didn’t work (...) why I was like that (...) it gave me confidence for the following sessions (...)

Trainer (T): "It didn’t destabilize you, it gave you confidence?"...

J: No, no ... The first video session before going there, I was not great, huh ... because I was stressed, I was apprehensive, well like first practice session actually... But I told myself alright... need to take advice...

T: Had you finally started systematically taking into account your positive points?

J: Oh yes, well, yeah right ... I’m very pessimistic about myself ... now I said, I am pleased with myself, I made some progress... I’m out of there... there are positive things... (...) The third year was the total collapse [she is evoking here the previous training]... I said: Am I made for this?

T: Now What?

J: Now, that’s fine. (...) I know what I’m like; it’s not just a matter of pedagogy.

Then, referring to her fourth intervention this year in basketball

J: Yes, I enjoyed myself. (...) In all these years of college, this is the session in which I enjoyed the most (...) it happens late maybe (...) I was with them (...). I felt useful...

B. Hélène - extract from balance training April 17, 2013 and re-evocation of the first workshop on October 24 2012.

Hélène: I’m not the same person in a club and on Wednesday [at workshops intervention]... The stress of there being a public makes a change for me [young minors under mandate of justice] (...) I am less afraid... I manage myself... I do not like being out of my routines

Trainer: why?

H: ... it replays my position, it hurts me... discord, it is like an attack.

T: You are a perfectionist?

H: I'm too demanding with others and myself ... I did not realize ... All of life is like that, it is a facade.

I must go out of gym... be shaken... Being reactive, Adapt, that's the problem I have in my internship ... Even in everyday life, by the way... in my intervention I do it, but it does not please me (...)

I do not remember the positives

14.4 Results and discussions

14.4.1 Justine

Justine freely evokes a "course-of-life" (Theureau, 2004), that is to say the conjunction of several originally separate "course-of-action". At this point of her explanations, Justine speaks about singular moments of her activity during all the training, those of the elements, which became significant and conscious .She re-evokes the difficulties felt; she analyzes a chaotic and painful journey. She evokes, by naming it, the video as the source of a click under stress feelings, like a transition to another type of behavior, or feelings, self-awareness ("I was with them", "I felt useful"), relating to the stage of a dynamic identity.

"Professional identity can be considered as a complex and multidimensional phenomenon incorporating a historic process of building, filled of questions , of losses and re-appropriations, that lead to forms of identity reconstructions which help people building a coherent world, and to give it sense . Feelings of membership, involvement, recognition are parts of a dynamic that integrates strategies and adaptations to the context, to the discipline, to the others, and this in relation with the potential of the actor (many facets related to the diversity of the actor), sometimes questioned by the events"

At this point, we enter in a " logic of subjectivation " the actor is committed to maintain the feeling of being the author of his own life and begins to put at a distance , if necessary , his role or previous positions. His identity is formed (trans- formed) by its tension with the surrounding world, causing it to evolve constantly " *(T. Roux-Perez, 2011, p.146)*

Considering Justine's point of view, here we could be at a tipping point between the feeling of being just a follower student, and the feeling of becoming useful as a professional SSE. Becoming useful, that major aim she mentioned when she joined course. She seems to switch of identity. Before that tipping point clearly identified, she did not consider herself competent, doubted her career choice. This workshop and maintenance, are elements that seem to trigger awareness, a more benevolent self-look. After discomfort, doubt, and pessimism comes pleasure, a more positive self-image, confidence gain, and feeling of being useful.

14.4.2 Hélène

Immediately, Hélène evokes fear of losing face experienced by newcomers. She feels threatened. Thus she re-evokes a workshop that mobilized her in an extreme way emotionally, did not sleep well the night before. She identifies the stress generated by the public as a constraint, which leads her to deviate from her routine as a gymnastics coach. Planner and anticipatory, she veers towards a more open attitude to the environment, even if it remains unpleasant for her. She also reviews that as a perfectionist, she does not focus enough on the positive aspects of her intervention. Hélène transforms her power of action, even if the process is just engaged and needs to be confirmed.

For these two students, interventions workshops, true "authentic learning situations" (Clergue, 1997) are an opportunity to "revelations".

"*Learning is what helps to make sense and the meaning emerges from the interaction of subjects with a world of objects and subjects according to their basic needs and desires. This implies recognition of complexity of things that carries themselves, like a paradox, this doomed to remain unsatisfied need to have control of everything.*" (Clergue, 1997, p.143).

According to the sense of this quotation, these two “SSE” are emotionally involved in the workshops that they re-live with the help of the video sessions. They doubt of their abilities to face the context. But step-by-step, they use precise and personal words to characterize what they do, what they think, what they feel during these experiences of teaching according to their own perception of the environment ("structural coupling"). Because of these workshops, they take advantage of the nature of the situation ("authentic learning situations”) to switch to a new self-knowledge in action, toward a new professional identity, a kind of solution ("revelation") for overcoming the complexity they were afraid of before.

Clergue then cites the thought of Y. Barel "*Is complex at the same time what threaten or destabilize, and what can cope with this situation. Complexity is the problem and the solution of the problem.*" (Amiot et al., 1993).

This increasing knowledge could be a solution to reengage the confidence. To overcome complex professional situations, the SSE’s self-confidence could generate a dynamic that inspires new compliant solutions, far from stereotyped routines. In reality, these routines work as self-benchmarks (when Helene speaks about her job in association) from past experience, but not as solutions adapted to the present which are much more sensitive. These routines could operate as a sort of a sort of barrier when faced with a specific context, and the feeling of discomfort might operate as a emotional alert that suggests to the “SSE” to give up the planned action and to take into account other dimensions of the present context. To a certain extent, we could speak about a kind of emotional invitation in favour of the re-examination of the "structural coupling". We evoke here the sensitive question of discomfort level perceived, which seems to work as an adaptation variable in order to adapt to the teaching context.

Both “SSE” come to training with accrued routines but also questions about their competency. Paradoxically, it is in discomfort and stress, facing the reactions of a public in a state of social or family exclusion that they gain relevance and knowledge of themselves. They clearly identify a tipping point in their training courses, because the training situation keeps all the complexity required for the emergence of random triggers: unpredictable reactions, defiant attitudes, disobedience. These hazards cause emotions that are "*complex and ongoing process of adaptation to the environment. In this respect, the action of teachers is guided by these sensitive signals allowing to perceive things and to act in the classroom*" (Ria and Visioli, 2010, p.14), linked with their capacity to adapt, their sensitivity to context in order to keep in balance a didactic and extremely tenuous contract.

Thus, emotions when training are essential to enable skills development, and can hardly arise outside of authentic learning situations:

"*The relation feeling-knowledge is at the heart of professional development: emo-*

tions are purveyors of knowledge and the relevance given to them depends on sensitive elements conferring a peculiar emotionally marked meaning (e.g. waiting for a pleasant situation or rather unpleasant related to past experiences."(Ria and Visioli, 2010, p.14).

The cases of Hélène and Justine perfectly fit in the hypotheses announced, and are consistent with the results of the research cited. These intervention workshops and associated training tools seem to encourage the development of qualitative adaptation with the involvement of emotions due to the complexity of the environment rebuilt at the University, as part of a professional training.

In this study, the dynamic adaptation process observed in workshops, in other words the "complex training situations" (Clergue, 1997), or the "encouraging action spaces" (Durand, 2008) looks like a described process in the framework of the dynamic systems approach to motor coordination and training, and considering motor skill acquisition as a dynamical process with transition (Haken, 1985).

In our research, we focus on the hazard and discomfort that play a role as contraints - ressources for acquiring gains in development and adaptation and which could be conceived as parameters of control (Nourrit et al., 2003). With this effect "contraints - ressources", the SSE puts aside the stereotyped routines developed in other contexts (basket, gymnastic clubs), as a phase transition. This may be the means of accelerating the development of adaptation to sensitive professional contexts in the initial training course.

Bibliography

Amade-Escot C., 2003, la gestion interactive du contrat didactique en volley-ball: agencement des milieux et régulations du professeur., in Amade-Escot, C. (Ed.), *Didactique de l'éducation physique: Etat des recherches* , 255-278, Paris: Revue EPS.

Amiot M., I. Billiard, L. Brams, 1993, *Système et paradoxe: autour de la pensée d'Yves Barel*, (Vol. 1-1). Paris, France: Ed. du Seuil.

Berthoz A., 1997, *Le sens du mouvement* . Odile Jacob.

Berthoz A., 2003, *La décision* . Odile Jacob.

Berthoz A., 2009, *La simplexité* . Odile Jacob.

Berthoz A., 2012, *Simplexity: simplifying principles for a complex world* . New Haven, CT: Yale University Press.

Clergue G.,1997, *L'apprentissage de la complexité* (Vols. 1-1). Paris: Hermès.

Damasio A. R., 2010, *Self comes to mind: constructing the conscious brain* . New York: Pantheon Books.

Durand M., N. Gal-Petitfaux, 2001, L'enseignement de l'éducation physique comme action située": proposition pour une approche d'antropologie cognitive. *(STAPS*, 55, 79-100.

Durand M., 2008, Un programme de recherche technologique en formation des adultes. *Education & didactique*, *2*(3), 97-121.

Delignières D., 2009, *Complexité et compétences : Un itinéraire théorique en éducation physique.* Revue EPS.

Gal-Petitfaux N., C. Sève, M. Cizeron, D. Adé, 2010, Activité et expérience des acteurs en situation : les apports de l'anthropologie cognitive. *In* M. Musard, G. Carlier & M. Loquet (Eds), *Sciences de l'intervention en EPS et en sport* (pp. 67-85). Paris : Editions Revue EP.S.

Hargreaves A., 2003, *Teaching in the Knowledge Society: Education in the Age of Insecurity*. Teachers College Press.

Haken H., J. S. Kelso, H. Bunz, 1985, A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, *51*(5), 347356.

Le Moigne J.-L., 1999, *La modélisation des systèmes complexes*. Dunod.

Maturana, H. R., & Varela, F. J., 1980, *Autopoiesis and Cognition: The Realization of the Living* . Springer Science & Business Media.

Morin E., J.L. Le Moigne, 1999, *L'intelligence de la complexité* (Vol. 1-1). Paris: L'Harmattan.

Nourrit D., D. Delignières, N. Caillou, T. Deschamps, B. Lauriot, 2003, On Discontinuities in Motor Learning: A Longitudinal Study of Complex Skill Acquisition on a Ski-Simulator. *Journal of Motor Behavior*, 35(2), 151-170.

Perez-Roux T., 2011, *Identité(s) professionnelle(s) des enseignants: les professeurs d'EPS entre appartenance et singularité*. Paris, France: éd. EP&S.

Ria L., J.Saury, C. Sève, M. Durand, 2001, Les dilemmes des enseignants débutants : Etudes lors des premières expériences de classe en Education Physique. *Science et Motricité* , *42* , 47-58.

Ria L., J. Visioli, 2010, L'expertise des enseignants d'EPS. *Science & Motricité* , (71), 3–19.

Suchman L. A., 1987, *Plans and situated actions: the problem of human-machine communication* . Cambridge University Press, New York.

Theureau, J., 2004, *Le cours d'action: méthode élémentaire* (Vols. 1-1). Toulouse, France: Octarès.

Theureau, J., 2006, *Le cours d'action: méthode développée* (Vol. 1–1). Toulouse, France: Octares.

Woods, P., 1990, *Teacher Skills and Strategies* . Taylor & Francis.

Part IV

Interactions between economic agents

Chapter 15

Forecasting Employability in Earth Sciences: The CIPEGE tool

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Abstract

Energy prices and environmental policies influence more than ever employment trends across the world. The purpose of this paper is to develop a strategy to enhance the employability of French graduates in a field that is both a key driver and a significant target of these new trends, namely Earth Sciences. The aim is to provide French universities with a predictive tool to adjust efficiently their skills' supply capacity with the demand forecasts at the European level. This task is treated as a tracking problem from the viewpoint of the control theory. The reference trajectory is obtained via a labour market forecasting model. For the first time, an econometric model and a predictive control strategy are combined. Simulations illustrate the feasibility and potentials of the proposed approach.

15.1 Introduction

In the past two decades, energy consumption, sustainable development and environmental protection have become priorities of energy policies in most countries (Kyoto Protocol, Grenelle environment in France, Carbon plan in the United Kingdom, 20-20-20 targets in the European Union). The transition to renewable energies is leading to many changes in the economy as a whole, in labour markets' structure and dynamics, in societal behavior, and in research and education. Among the study and research disciplines the most affected by these changes is Earth Sciences (ES). ES includes the study of atmosphere, hydrosphere, oceans and biosphere as well as solid Earth. ES can help meet major challenges faced by the society and the environment, such as the management of mineral resources (green mining) with its direct impact on consumption and labor. For instance, rare-earth minerals (REM) are increasingly used for the production of high-tech items such as smart phones, laptops but also in magnets for wind turbines, hybrid-car batteries, etc. After a misleading forecasting of its own consumption needs, the U.S. lost its leading producer position in favour of China and is now constrained to import at a very high price the goods it used to produce domestically. As a consequence of the closure of the mining extractions in the 1990s, the U.S. also decreased its investments in the training of solid ES scientists. While it now faces the need to re-open its REM mining sites to satisfy an increasing demand for high-tech goods, it suffers from a deficit in qualified Earth System scientists. A similar deficit affects Australia and Canada.

With its technical and scientific competences, its historical assets and its first-class actors in the field of ES, France aims at becoming a worldwide leader in the ES training. In 2011, the French Ministry of Higher Education nominated the project VOLTAIRE as a LABEX (Laboratory of excellence). Among the tasks of this project is the construct of an anticipation tool to ensure the employability of Earth System scientists trained in French universities. The CIPEGE center (Centre International de Prospective pour l'Emploi en Géosciences et Environnement - International Center for the Strategic Foresight of Employment in Earth and Environmental Sciences) was created to handle this task. In the sequel, the anticipation tool will be called the CIPEGE tool. This paper presents the innovative forecasting strategy adopted to develop the CIPEGE tool.

The CIPEGE tool builds upon several methods to handle the complexity of the system it aims at predicting. As will be explained in this paper, the system is composed of several elements measured at different levels of units of analysis (individual, institutional, national, international), each with a non-negligeable internal structure. The elements are linked by non-linear interactions. The system is exposed to external factors at different scales and there exists a retroaction of collective behaviors upon individual behaviors. This means that the elements will collectively modify their environment, which in turn will constrain them and modify their possible behavior. Hence, the behavior of the global system can only be predicted by knowing the properties and behavior of each element and the properties of the interactions that link the elements.

Therefore, the CIPEGE tool combines economics (macro- and micro-econometric modeling) and control process strategies (model predictive control). The targeted employability of French ES graduates is estimated using a labour market matching approach, controlling for European macroeconomic trends. The measured and forecasted employability are then derived from a microeconometric multinomial-conditional logit approach. The task of this study is then to ensure that the forecasted employability tracks the reference trajectory of employability for the French graduates in ES. This objective can be viewed as a tracking problem from a control theory perspective. Among the existing advanced control laws, Model Predictive Control (MPC) is a control strategy well-adapted to deal with tracking problems (Alessio and Bemporad 2009, Camacho and Bordons 2007). The success of MPC in several industrial sectors is due to the easy way to formulate the control objective in the time domain and also to the ability to handle constraints (Qin and Badgwell 2003). A wide variety of applications has been reported in the literature but no application in economics exists to our knowledge. MPC is based on the direct use of an explicit model to predict the future behavior of a process. This model plays a crucial role in the MPC strategy. In our case, the econometric model is used to forecast the behavior of the process (the flow of ES graduates in France) over a finite prediction horizon. In the context of this study, the term "prediction" actually refers to an "anticipation" or "forecast".

The main advantage of this strategy lies in the structure of the MPC approach, which enables us to link in a systematic and continuous way all the elements composing the employability of young ES graduates. This structure allows for the definition of different time horizons (at the contrary of classic econometrics) and for the correction of the trajectory continuously thanks to the feedback mechanism of the MPC approach. Another advantage is the fact that this strategy can take into account both estimation errors and modeling errors to correct the reference value at each run. This two-step error correction procedure constitutes a valuable tool towards more robust estimates. Moreover, the MPC approach determines the control inputs exogenously in such a way that it is applied simultaneously to the process and the model. In an econometric model, the effect of the exogenous control input is usually estimated inside the model and is considered as endogenous to the process. For the first time, the control inputs are defined exogenously and policy makers can test an unlimited range of interventions.

The remainder of this paper is organized as follows. Section 2 presents the definition of the employability retained for the CIPEGE tool and the model applied to estimate the employability of reference for French ES graduates. Section 3 deals with the principle of Model Predictive Control and details the control structure used. Section 4 addresses the way of combining the econometric model used to measure the process of employability and the predictive control approach. Then, in section 5, different simulations serve at testing the feasibility of the control strategy. In the last section, we synthesize our preliminary results and draw the perspectives of the proposed approach.

15.2 Employability

Measuring employability of graduates is a controversial issue due to the difficulty to apply a straightforward definition (Gazier 1998, McQuaid and Lindsay 2005, Arjona Perez et al. 2010). Employability is a complex and multi-faceted concept. Therefore, either because of a lack of compatibility between dimensions or a lack of data, a holistic measure of employability has so far been recognized to be impossible. Employability measures are instead reduced to the most pertinent dimensions for the study at hand.

15.2.1 Definitions

In McQuaid and Lindsay (2005), the authors highlight the existence of two alternative perspectives in the employability debate. One focuses only on the individual's characteristics and skills, referring to the individual's potential to obtain a job. The other perspective takes into account external factors (e.g. labor market institutions, socio-economic status) that influence a person's probability of getting into a job, of moving between jobs or of improving his or her job. In De Grip et al. (2004), these factors are called "effectuation conditions", i.e. the conditions under which workers can effectuate their employability. In addition, the literature also considers the aspects of the time lag between leaving education and employment (Boateng et al. 2011), the degree of skills matched between one's educational background and his or her occupation, and the type of contractual arrangement (full-time vs. part-time; permanent vs. temporary) (Arjona Perez et al. 2010).

Employability is about having the capability to gain initial employment, maintain employment and obtain new employment if required (Cedefop 2008). In other words, the employability of a graduate is the predisposition of the graduate to exhibit the attributes that employers consider necessary for the effective functioning of their organization (Harvey et al. 1998). Hence, employability is a combination of capacity and willingness to be and to remain attractive for the labor market, for instance, by anticipating changes in tasks and work environment and reacting on them (De Grip et al. 2004). For a given person, employability depends on the knowledge, skills and attitudes he/she possesses, the way he/she uses those assets and presents them to employers (Hillage and Pollard 1998).

In the context of the CIPEGE tool, we define employability as the capacity of a French Earth Sciences graduate to be employed at a fulfilling job that enables him/her to make use of the skills acquired during the training, given the evolution of the demand of the relevant sectors of activity at the European level.

15.2.2 Energy prices, environmental policies and employment trends

In a recent report for the European Commission's Employment Directorate General, Cambridge Econometrics (2011) has conducted an in-depth analysis of the employment consequences of the implementation of policies to achieve the key European environmental targets of a 20 percent cut in emissions of greenhouse gases by 2020 (compared to 1990 levels), an increase in the share of renewable energy to 20 percent, and the objective of a 20 percent cut in energy consumption (i.e. the so-called "20-20-20 targets"). The findings from that project suggest that after an initial cost to the European Union (EU), the implementation of the EU 20-20-20 targets will lead to a modest positive outcome for GDP growth and employment over the longer term, increasing by around 1-1.15 percent (in net terms) by 2020.

However, when looking at specific industries, these impacts prove to be much differentiated, with some sectors, such as iron, steel, cement and petroleum, experiencing a decrease in employment; and sectors, such as renewables, construction and transport, experiencing a growth in jobs by 2020. The occupations with potential benefits from a low-carbon transition were identified to be Research and Development, manufacturing and installation or engineering, operation and maintenance, management, administration and sales.

The shift towards a greater reliance upon renewable energies will create a demand for engineering and technical skills related to generating electricity from wind, marine and solar sources. The forecasts of employment from the Energy-Environment-Economy model of Europe (E3ME), developed by Cambridge Econometrics, suggest a greater demand for professional, associate professional, and (to a slightly lesser extent) skilled trade workers. Still, these analyses do not go into detail on the implications for specific areas such as science, technology, engineering and mathematics (for further details on that topic see, for instance, Wilson et al. (2010)).

Further evidence suggests that the shift towards renewable energies may result in an increasing demand for specific types of engineers and technicians who are not only highly qualified and skilled in their general disciplines, such as electronics engineering, but can also apply their skills within a renewable or green policy environment. Hence, there is likely to be an increasing demand for a form of hybrid skill (the general engineering or technical discipline, plus specific knowledge or experience of renewables) (Cambridge Econometrics 2011, p.172).

Moreover, there is also an increasing demand for more renewable-specific skills related to hydrology, hydraulics, aerodynamics, ornithology, environmental impact assessment, etc. Both the hybrid and renewable specific skills need to be deployed in a number of functions, including RnD, design, operations and maintenance. Although the number of workers required to fill these jobs might be relatively small, they are critical to the success of the renewable sector.

The problem that currently arises in Europe is that there will be potentially more and more markets that will display insufficient capacity to fulfill the demand for these new technologies because of a deficiency of human capital capacity. For example, if Europe is not able to establish economically viable wind turbine or solar panel manufacturing capacity prior to the maturity of the technology and its uptake by users, there is a high risk that non-EU producers will take over the market once established. This would clearly have a negative impact on the overall employment potentials within Europe. Another similar example could be given of innovation in the environmental and eco-technology sector.

Among all European Member States, the United Kingdom (UK) is the only one currently investing in upskilling at tertiary level to meet the new "green" occupation needs. The main focus of the UK is on the upskilling of tertiary engineering qualifications in energy, especially in installation and maintenance of low-carbon technologies and customer service skills. Another UK training focus is on tertiary qualifications in commodity trader and broker, with the development of practical skills on the functioning of the carbon market and understanding of trading tools. Other EU Member States are instead focusing on the green upskilling of the workforce at the vocational level (e.g., Denmark, Estonia, France and Germany) (GHK Consulting 2010).

15.2.3 Modeling

Let y_j^F denote the number of employed individuals in France who are graduated in Earth Sciences at degree level j, with $j \in \{3, 5, 8\}$, such that $j = 3$ to a 3-year degree (i.e. Bachelor degree); $j = 5$ to a 5-year degree (i.e. Master degree) and $j = 8$ to an 8-year degree (i.e. Ph.D. degree).

For a given degree level j, the number of ES graduates employed at time t is:

$$y_j^F(t) = S_j^F(t) - un_j^F(t) \tag{15.1}$$

where S_j^F is the stock of ES skills on the French market and un_j^F is the stock of unemployed ES graduates in France.

We model the employment of French ES graduates as a matching function, as suggested by Mortensen and Pissarides (1994), to describe the formation of new relationships ('matches') from unmatched individuals of the appropriate types. In our case, we are interested in the formation of matches, at European level, between the number of unemployed ES j-level graduates and the number of job vacancies in ES domains at j-level. In other terms, we are interested in the European demand for workers with ES skills at each j-level. We assume our matching function to have the following Cobb-Douglas form:

$$m_j^{EU}(t) = M(un_j(t), v_j(t)) = \mu(un_j(t))^a(v_j(t))^b \tag{15.2}$$

where $m_j^{EU}(t)$ is the number of new matches created at current time t on the European market, and μ, a and b are positive constants. While un_j is now the stock of unemployed ES graduates in Europe, $v_j(t)$ is the number of job vacancies in ES field at degree level j. The matching function is increasing, concave, and homogeneous of degree 1. As reviewed by Petrongolo and Pissarides (2001), the Cobb-Douglas form of the matching function can be justified by empirical evidence of constant returns to scale, i.e. $a+b \approx 1$. If the fraction of workers separating from a firm per period of time (due to firing, quits, and so forth) is δ, then the change in employment from one period to the next is calculated by adding the formation of new matches and subtracting the separation of old matches. Combining equations (15.1) and (15.2) yields the following representation of the dynamics of employment over time:

$$y_j^F(t+1) = m_j^{EU}(t) + (1-\delta)y_j^F(t) = \mu(un_j(t))^a(v_j(t))^b + (1-\delta)y_j^F(t) \tag{15.3}$$

The evolution of unemployment is given by

$$\dot{un}_j = \delta(1 - un_j) - m_j^{EU}(un_j, v_j) \tag{15.4}$$

Under the assumption that the matching technology[3] exhibits constant returns, this equation has a unique stable steady solution for every vacancy rate v:

$$un_j = \delta/(\delta + m_j^{EU}(v_j/un_j, 1)) = \delta/(\delta + \lambda(\theta)) \tag{15.5}$$

where $\theta = v_j/un_j$ signals market tightness and $\lambda(\theta) = m_j^{EU}(v_j/un_j, 1)$ represents the unemployment spell hazard. Drawing equation (15.5) in a vacancy-unemployment space generates a Beveridge curve, i.e. a negative relation between vacancies and unemployment that is convex to the origin by the properties of the matching function (for details see Pissarides and Mortensen 1999).

Empirical evidence shows that the job destruction flow, δ, is not constant, especially over business cycle frequencies (Davis et al. 1996). Following Pissarides and Mortensen (1999), we therefore allow future job productivity p to vary according to the relative value (in terms of required competences) x of the product or service. Because $x \in [0, 1]$, px can take more than two values[4].

When an unemployed worker and an employer with a vacancy meet, wage bargaining takes place. The outcome is a wage $w(x)$ that divides the quasi-rents associated with a match between worker and employer, according to the value of x. The value of a filled job is a function of the future job productivity, the bargained wage and the probability of destruction of the job. Job creation takes place if all rents from new vacancy creation are exhausted, i.e. if $v_j = 0$. A job is destroyed only if its idiosyncratic productivity falls below a critical level rs (equilibrium reservation productivity), i.e. if $x < rs$.

15.2.4 Empirical specifications

Except for the matching function, all parameters of the targeted employability are estimated, for the years 1990 to 2011, using the annual Employment Survey microdata collected by INSEE (the French National Institute of Statistics and Economic Studies).

The matching function m_j^{EU} is estimated using an extended version of the E3ME model to forecast skills supply and demand in Europe (Wilson et al. 2010). Thanks to the structure of the E3ME, m_j^{EU} captures the influence of international environmental and economic shocks on the demand for skills in Earth Sciences.

Figure 15.1 shows the linkages between the three modules (Energy, Environment and Economy) of the E3ME. Exogenous factors are shown on the outside edge of the chart as inputs into each component. For the European Union (EU) economy, these factors are economic activity and prices in non-EU world areas and economic policy (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of energy industries). For the environment module, exogenous factors include policies such as reduction in SO_2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the modules are shown explicitly by the arrows that indicate which values are transmitted between components. The economic module is solved as an integrated EU regional model,

[3] A matching technology, like a production technology, is a description of the relation between inputs, search and recruiting activity, and the output of the matching process, the flow rate at which unemployed worker and vacant jobs form new job-worker matches (Pissarides and Mortensen 1999).

[4] According to Pissarides and Mortensen (1999), Mortensen (1994), Cole and Rogerson (1996), the fact of regarding p as a stochastic process characterizing an aggregate shock is consistent with the time series characteristics of job creation and job destruction series reported by Davis et al. (1996).

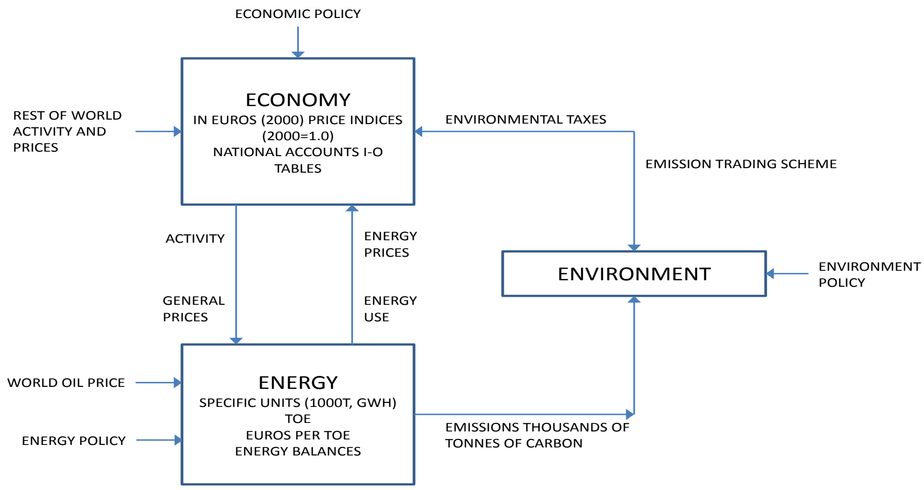

Figure 15.1: The three dimensions of the E3ME: energy, environment and economy (Source: Cambridge Econometrics 2011, p.212)

disaggregated at industry and country level. The labor market is treated with sets of equations for employment demand, labor supply, average earnings and hours worked. The equations for labor demand, wages and hours worked are estimated and solved for 42 economic sectors (industries), defined at the 2-digit level of the European statistical classification of economic activities (NACE). Labor participation rates are disaggregated by gender and five-year age bands, and multiplied by Eurostat population data to obtain labor supply.

Employment is modeled using national accounts data, as a total headcount number for each industry and region. This stock is a function of the evolution of unemployment and job vacancies (depending on industry output, wages, hours worked and technological progress) and of global (worldwide) changes in environmental policies and in energy prices and consumption. The industry output is assumed to have a positive effect on employment, while the effect of higher wages and longer working hours is assumed to be negative. The effects of technical progress are ambiguous, as investment may create or replace labor, depending on the sector of activity.

The E3ME model has been extended to include detailed analyses of the skills' demand and supply, as measured by occupation and qualification. Three levels of qualification were defined, namely low (ISCED 0-2), medium (ISCED 3-4) and high (ISCED 5-6). This extended version computes the stock of labor demand by sector, occupation and educational level.

We run the extended E3ME to generate, for the overall European market, the stock of labor demand at the highest level of qualifications (i.e. ISCED 5-6) by sector and level of occupation. Using the annual INSEE Employment Survey (1990-2011), we identify matrices of sectors and occupations that employ workers with a j-level ES degree in France. We merge the E3ME output with the individual data from INSEE on the basis of these matrices and derive the number of demanded ES workers with

j-level skills, m_j^{EU}. The current employment of ES graduates in France, $y_j^F(t)$, is estimated by Ordinary Least Squares (OLS) regressions, for each level of degree, using the INSEE microdata, controlling for the age, the gender and the sector of activity. The job destruction flow, δ, is also estimated from the INSEE data. The estimated current matching on the European market is then integrated into equation (15.3), alongside the current employment level in France ($(1-\delta)y_j^F(t)$), to estimate the number of employed j-level ES graduates in France in the next period.

15.3 Model Predictive Control (MPC)

This section addresses the principle of MPC and the control structure considered in this study is detailed.

15.3.1 Principle

MPC is a mature control strategy. Initially developed for linear systems in the 1970s, MPC had extensively been studied for nonlinear systems with constraints and successfully been applied in numerous industrial domains (Alessio and Bemporad 2009, Qin and Badgwell 2003). The MPC strategy is based on the receding horizon principle and is formulated as solving on-line a nonlinear optimization problem (Camacho and Bordons 2007). The basic concepts of MPC are the explicit use of a model to predict the process behavior over a finite prediction horizon N_p and the minimization of a cost function with respect to a sequence of N_c controls where N_c is the control horizon. At the current instant t (see Figure 15.2), the process output is measured and the MPC algorithm computes a sequence of N_c control inputs by minimizing the tracking error (difference between the reference trajectory and the predicted model output) over N_p. Only the first element of the obtained optimal control sequence is really applied to the process. At the next sampling time (see Figure 15.3), the finite prediction horizon moves a step forward, the measurements are updated and the whole procedure is repeated.

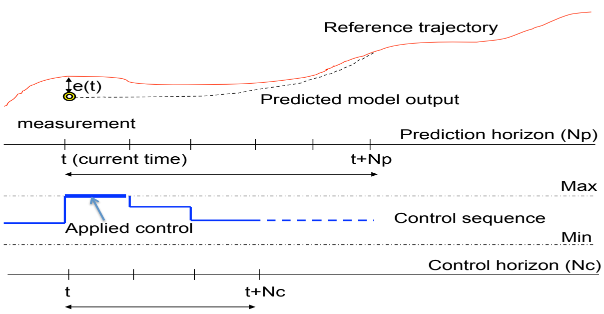

Figure 15.2: Principle of MPC at the current time t

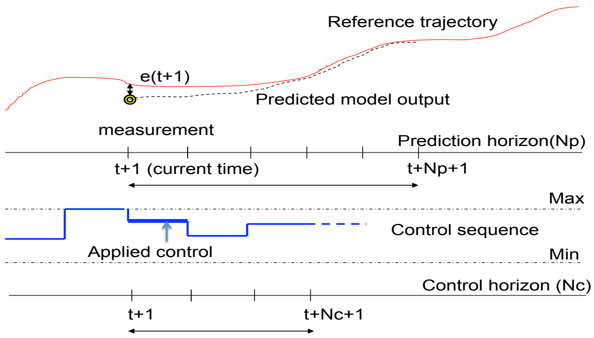

Figure 15.3: Principle of MPC at the current time $t + 1$

15.3.2 Internal Model Control (IMC) structure

Predictions based on data are inevitably subject to disturbances and modeling errors. To gain in robustness, the well-known Internal Model Control (IMC) structure (see Figure 15.4) is considered in this approach.

The process (the physical system) is described by its mathematical model. The control inputs u are simultaneously applied to the process and the model. The difference between the process output y_p and the predicted model output y_m provides an error signal e. This signal embeds disturbances and modeling errors and constitutes the feedback information impacting on the reference trajectory y_{ref}. The feedback information is taken into account in an original way rarely used in economics. Due to the sampled data acquisition, a discrete-time formulation is considered where t is the current time iteration.

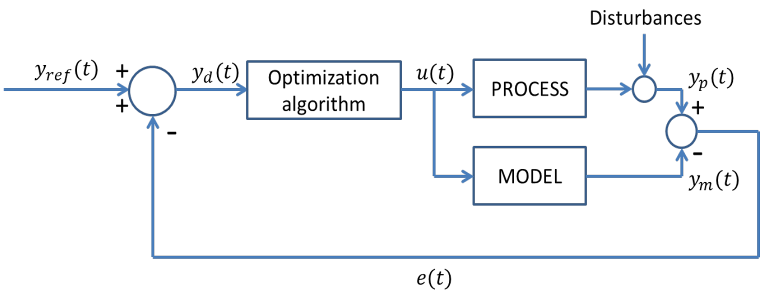

Figure 15.4: Internal model control structure

According to Fig. 4, we can write:

$$\begin{aligned} y_d(t) &= y_{ref}(t) - e(t) \\ y_d(t) &= y_{ref}(t) - (y_p(t) - y_m(t)) \\ y_d(t) - y_m(t) &= y_{ref}(t) - y_p(t). \end{aligned} \tag{15.6}$$

The tracking of the reference trajectory y_{ref} by the process output y_p is equivalent to the tracking of the desired trajectory y_d by the model output y_m.

Remark: the feedback signal e can be filtered to avoid sudden changes due to measurement noises. A low-pass filter suits well in practice.

15.4 Econometric model-based predictive control

This section addresses the way of combining the econometric model and the MPC approach. The common points to all predictive strategies are discussed according to the control objective: the improvement of French students' employability in the field of ES.

15.4.1 The reference trajectory

The reference trajectory corresponds to the expected behavior of the process. In our case, the reference trajectory y_{ref} to be tracked corresponds to the employability of French ES graduates. This reference has been determined off-line by estimating equations (15.1), (15.2) and (15.3) using E3ME outputs and French microdata (INSEE Employment Survey). The following figure (see Figure 15.5) presents the reference trajectory for the employability in France of ES graduates at Master-degree level, i.e. at level $j = 5$, for the period 2003-2025, taking into account labour market shifts at the European level. While the goodness-of-fit of the reference trajectory for the period 2003-2012 could be tested with observed values of the output variable, the trajectory beyond 2012 was drawn as a linear extrapolation of the previous period. In economics, because of the high degree of unpredictability of individual behaviors, fitted values are likely to variate within a 90 percent confidence interval.

The significant drop in employability observed between 2003 and 2007, followed by a significant increase between 2007 and 2012, is mainly due to the changes in the graduation system imposed by the European Bologna Process. In 2004-2005, most European Member States, including France, launched a harmonization process of its tertiary degrees to converge towards a three-level system composed by the Bachelor, the Master and the Doctoral degrees. All intermediary degrees were progressively cancelled from the tertiary systems. In France, this new structure has replaced the previous five-level structure (DEUG-Licence-Maîtrise-DEA/DESS-Doctorat). The former Maîtrise degree corresponds to a Master I level and the former DEA/DESS degree to a Master II. At the time of the implementation of the Bologna Process, French labor markets were more interested in hiring young graduates with a four-year university degree than with a five-year university degree (reflected in the drop in Figure 15.5). With the shift towards the BA-MA-PhD structure, the vacant positions initially aimed at four-year graduates got progressively opened to MA graduates, in addition to the vacant positions traditionally aimed at five-year graduates, which explains the significant increase in MA employability after 2007.

15.4.2 The model of prediction

As we have already mentioned, the model is the keystone of the predictive control approach since it anticipates the behavior of the process in the future and makes possible a successful tracking of the reference trajectory. The more faithful the model is to the

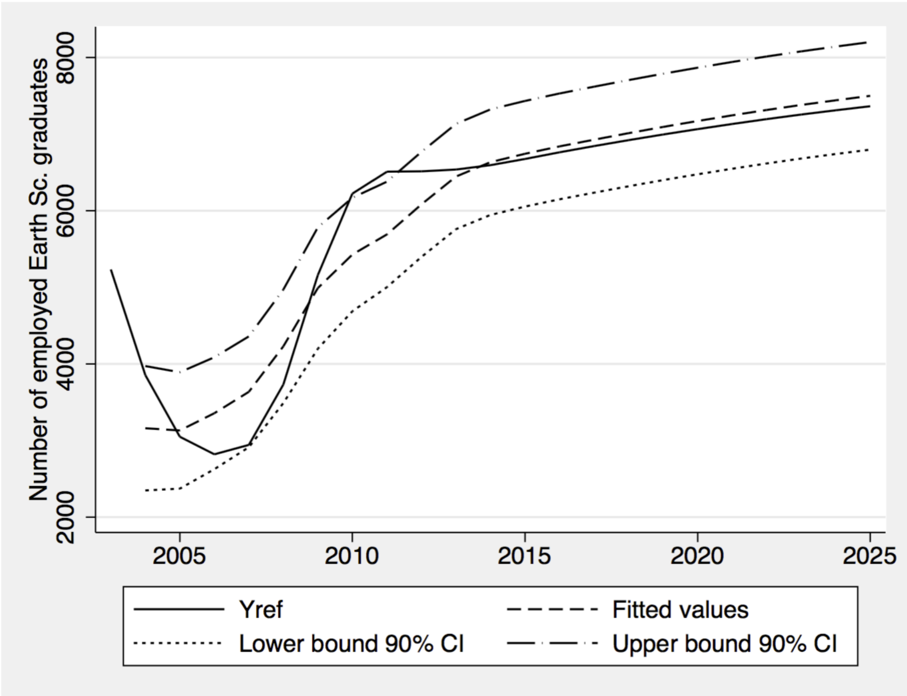

Figure 15.5: Reference trajectory for the employability in ES at master degree level

process, the better the model prediction.

The model, based on an econometric model, is assumed to be dynamically representative of the employability dynamics and to take into account the uncertain dynamics of the human factor thanks to probabilities. The three outputs of the model are the predicted employability at the three different levels $j = 3, 5, 8$ (respectively bachelor degree, master degree, Ph.D degree). For the moment, the more relevant input considered is the number of students enrolled in ES training. It is worth mentioning the specificities of the model. First, employability evolves differently depending on the level. There are therefore three dynamics to be identified, one for each of the three degree levels. Secondly, the control inputs act on the model with a different time lag (delay). For instance, the effect on employability levels of the number of first-year students in ES university programmes at current time t will be measurable in 3 years for Bachelor graduates, in 5 years for Master graduates and in 8 years for Ph.D. graduates. The different delays must be handled in the model in a specific way. Finally, for a given student cohort, probabilities are considered to take into account the enrollment rate in ES, the completion rate, the retention rate, etc. The model of employability is written in discrete-time and can be synthesized by the following non-linear equations:

$$\begin{cases} x(t+1) = f(x(t), u(t-i)), i = 0..7 \\ y_m(t) = h(x(t)). \end{cases} \tag{15.7}$$

The modeled employability y_m estimates the number of students that will complete each degree-level annually by multiplying the number of students enrolled at the beginning of each degree period ($u(t-i)$) and the probability of pursuite of studies in

ES. The probability for a student i to choose to pursue an ES degree is estimated using a multinomial/conditional logit approach (McFadden 1974). At the beginning of each study period, a student can choose between three alternatives: to pursue his/her studies in ES at the upper level, to repeat the same level or to leave ES studies. This approach assumes that an individual chooses his/her training path, among different alternatives, in order to maximize his/her utility.

15.4.3 The cost function

The cost function, also named optimization criterium, is usually a quadratic function of the tracking error. As already mentioned, thanks to the IMC structure (see Figure 15.6), the tracking of the reference trajectory y_{ref} by the process output y_p is equivalent to the tracking of the desired trajectory y_d by the model output y_m. The tracking error is consequently written as:

$$e_{tra}(t) = y_d(t) - y_m(t). \tag{15.8}$$

At each sampling time, the process output is measured and compared to the predicted model output, defining the error signal $e(t) = y_p(t) - y_m(t)$ at the current time. The error $e(k),\ k \in [t+1, t+N_p]$ is assumed to be constant over the prediction horizon and equal to the measurement $e(t)$. This error signal is updated at each measurement. Since the reference y_{ref} is assumed to be known over the whole working horizon, the desired trajectory can be computed:

$$y_d(k) = y_{ref}(k) - e(k),\ k \in [t+1, t+N_p]. \tag{15.9}$$

The cost function can be written in discrete-time as:

$$J(u) = \textstyle\sum_{k=t+1}^{t+N_p} e_{tra}(k)^T Q(k) e_{tra}(k) + \Delta u(k-1)^T R\, \Delta u(k-1) \tag{15.10}$$

where Q and R are symmetric definite positive matrices and $\Delta u(k-1) = u(k-1) - u(k-2)$.

Remark: the term $\Delta u(k-1)^T R\, \Delta u(k-1)$ allows to provide a smooth variation of the control variables by penalizing sudden changes.

15.4.4 The solving optimization method

The cost function J is to be minimized with respect to a future sequence of control inputs noted $\widetilde{u}$. The mathematical formulation of MPC is then given by the following optimization problem:

$$\min_{\widetilde{u}}\ J(u). \tag{15.11}$$

The control sequence $\widetilde{u} = \{u(t), u(t+1), ..., u(t+N_c), ..., u(t+N_p-1)\}$ is composed of N_c different controls where N_c is the control horizon ($N_c < N_p$). From $u(t+N_c+1)$ to $u(t+N_p-1)$, the inputs are constant and equal to $u(t+N_c)$. Although the prediction and optimization steps are performed over the prediction horizon, only the value of the input for the current time $u(t)$ is used and applied to the process.

Given its formulation in an optimization problem, MPC is well suited to take into account constraints. In practice, processes are generally subject to constraints on states, inputs or outputs which can easily and explicitly be added to the optimization problem

(15.11). It is the most effective way to satisfy all kinds of constraints. Many constrained optimization routines are available in software libraries to solve constrained optimization problems.

15.5 Simulations

All the presented simulations are performed with Matlab software. The constrained optimization problem is solved by using the Matlab function $fmincon$. This chapter only reports the results of the employability forecast at the level $j = 5$ (i.e Master degree).

15.5.1 Data and modeling

The internal model uses data from a student tracking survey collected by the Students' Life Observatory (OVE), which describes the transition trajectories of Master graduates 3 years after graduation, by degree field; university administrative records of the number of intakes and graduates, per year; and complementary data from the report by Varet (2008).

The data collected are represented in Figure 15.6. The red line represents the measured employability. The blue line in the upper graph is the reference employability and the blue line in the lower graph is the observed number of enrolled students. As explained in section 15.4.1, the reference trajectory is calculated using INSEE and E3ME data. The inputs (i.e. number of students enrolled in ES training) are obtained from the OVE data and the administrative data. Thanks to an identification procedure, we obtained a model of employability that simulates the process with a relative error of only 9.33% (see Figure 15.7). The non-linearity of the trajectory of the measured employability reflects the significant increase in the number of employed ES graduates with a Master degree between 2008 and 2009 caused by the Bologna reform of 2004. As explained in section 15.4.1, that reform harmonized the university degrees across Europe into a three-level structure (Bachelor-Master-PhD), which opened further job perspectives for Master students that tended earlier to suffer the labor competition from four-year graduates.

Over the period 2004-2012, the three main sectors of activities employing ES Master graduates were education, professional services and public administration and defence. While ES graduates used to have a relatively high probability of being employed in the sector of mechanical engineering before 2008; with the crisis, their chances of employment have decreased in that sector. Instead, we observe an increase in the number of employed ES graduates in the service sector, largely correlated to a global inflation in consultancy jobs and fixed-term contracts since 2008 (Cutuli and Guetto 2013, Oliver 2012, O'Connor 2013).

15.5.2 Predictive control

The econometric model-based predictive control described in section 15.4 has been implemented. We consider the econometric model identified below. The simulation was performed under the following conditions: $N_p = 5$, $N_c = 4$, $R = [10; 0.1]$ and $Q(k) = Q(1)^k$ with $Q(1) = 2$. The future tracking errors are more and more weighted in order to give importance to the final objective, i.e. the desired employability at the

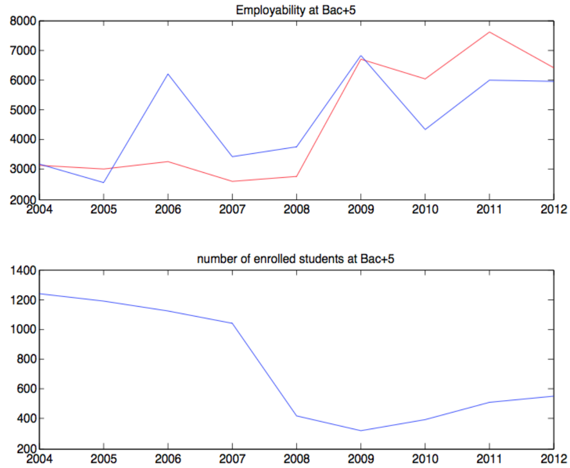

Figure 15.6: Data collected: reference employability (in blue) and measured employability (in red) in ES at master degree level (upper graph); number of enrolled students (lower graph)

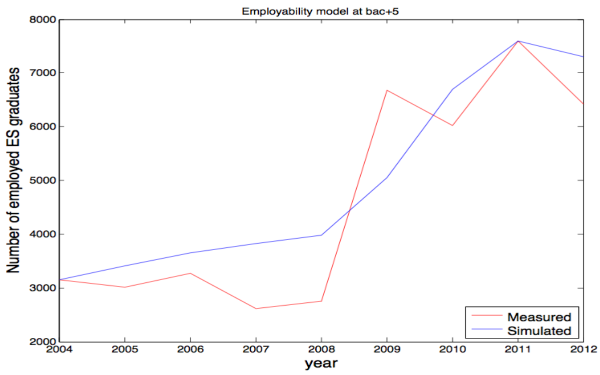

Figure 15.7: Simulated model of the employability in ES at master degree level

end of the prediction horizon, and this, at each sampling time. The reference employability is still obtained applying the model described in section 15.2.3, using INSEE and E3ME data. Several simulations were carried out according to different horizons of control and prediction. The prediction horizon $N_p = 5$ seems to be the best compromise between the tracking accuracy, the intrinsic dynamic (the current control will impact the employability of Master degree graduates in at least five years) and the stability of the controlled system.

From Figure 15.8, we can see that the process output tracks the reference trajectory by remaining within the range of uncertainty. On the other hand, the number of students enrolled seems more relevant and gives a valuable information to policy makers to anticipate universities' future adjustments in human and physical resources. If more students' intakes are needed to reach the desired employability levels, then universities will need to ensure that they have the capacity to welcome and train efficiently this large influx of students.

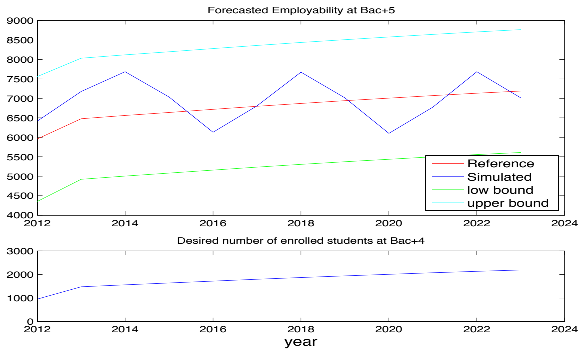

Figure 15.8: Forecasted employability in ES at master degree level: 2012-2023

Overall, these simulations show that the application of such a predictive control strategy to economic issues is feasible and can lead to potentially useful results from a social, educational and economic point of view.

15.6 Conclusions

This paper presented an innovative tool to predict the employability of French graduates in Earth Sciences. Rather than formulating the control objective as a classic computational general equilibrium (CGE) problem, it has been formulated as an optimization problem to take into account the complexity of the system it embeds. For the first time, Model Predictive Control was combined with an econometric model of employability. The MPC enables to take into account disturbances and modeling errors through an internal model control structure, which complements efficiently the error correction model (ECM) implemented in the econometric model used to generate the reference trajectory, at the sectoral and occupational level.

The potential political implications of the CIPEGE tool are four-fold. First, the disaggregated reference trajectory of the CIPEGE tool can inform about the future labor market's demand by sector of activity, by type of occupation and by level of degree. Although the detailed results of the model developed to generate the reference trajectory are not presented in this chapter, here are some examples of the descriptive capacity of the CIPEGE tool. At the horizon 2020, the CIPEGE tool anticipates a drop in the demand for higher education skills in the industry of coal and in the oil and gas sector. In the case of the industry of basic metals, it anticipates instead a smooth increase in the demand for higher education skills. Such a detailed mapping of the skills' demand is strategic for policy makers to anticipate the needs in terms of education provision. The second potential political implication of the CIPEGE tool is the capacity of its reference trajectory to capture the impact of different shocks at the energetic and environmental levels on the demand for skills. Third, combining the econometrics approach and the MPC yields a predictive tool where the control inputs are held exogenous to the optimization process, which makes it possible to test for an unlimited range of possible interventions (e.g., intake rates, specialization modules, international experience). The calculated control inputs can then serve as potential action-tools for policy makers. Finally, because this approach is very flexible, it can easily be adapted to other disciplines (e.g., chemistry, medicine) but also to other countries.

Hence, the statistical capacity (in terms of error control), the economic relevance (in terms of macroeconomic scope and exogeneous nature of the control inputs) and the unlimited potentialities for application expansions of the CIPEGE tool, makes it an attractive and valuable decision tool for universities and policy makers.

As with any approach of predictive control, the model is the cornerstone of the strategy and needs to be clearly identified from consistent data. At this early stage of the project, the statistical robustness of the results obtained from different simulations is very encouraging. However, given the lack of points of observation at hand, any economic and political interpretation of these early results would be irrelevant and adventurous. Additional data will, not only improve the model and the tracking accuracy of the reference employability, but also provide sufficient information to draw pertinent economic conclusions and political recommendations. So far, what comes out from our simulations is the key role that the attractiveness of the ES programs seems to play to ensure sufficient enrollment rates and adequate completion rates. One possible option could be an increase in the investments devoted to the communication of the CIPEGE tool results to the main stakeholders (i.e., Higher Education Ministry, universities, students and industries).

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Bibliography

Alessio A., A. Bemporad, 2009, Nonlinear Model Predictive Control. *Lecture Notes in Control and Information Sciences*, 384.

Arjona Perez E., C. Garrouste K. Kozovska, 2010, Towards a benchmark on the contribution of Education and Training to Employability: a discussion note. *JRC Scientific and Technical Reports*, EUR24147EN.

Boateng S.K. , C. Garrouste, S. Jouhette, 2011, Measuring Transition from School to Work in the EU: Role of the data source". *Conference paper presented at the Conference Catch the Train: Skills, Education and Jobs*, Brussels, June 2011, available at: http://crell.jrc.ec.europa.eu/download/Boeteng1.pdf.

Camacho E., C. Bordons, 2007, Nonlinear Model Predictive Control: An Introductory Review. *Assessment and Future Directions of Nonlinear Model Predictive Control, LNCIS 358*. Berlin: Springer-Verlag Berlin Heidelberg, 1-16.

Cambridge Econometrics, 2011, *Studies on Sustainability Issues: Green Jobs, Trade and Labour*. Cambridge, UK: Cambridge Econometrics.

CEDEFOP, 2008, *Terminology of European Education and Training Policy*. Luxembourg: European Union Publications Office.

Cole H., R. Rogerson, 1996, Can the Mortensen-Pissarides Matching Model Match the Business Cycle Facts? *U. of Minneasota Working Paper*.

Cutuli G., R. Guetto, 2013, Fixed-Term Contracts, Economic Conjuncture, and Training Opportunities: A Comparative Analysis Across European Labour Markets. *European Sociological Review*, 29(3), 616-629.

Davis S.J., J. Haltiwanger, S. Schuh, 1996, *Job Creation and Destruction*. MIT Press, Cambridge, MA.

De Grip A., J. van Loo, J. Sanders, 2004, The Industry Employability Index: Taking Account of Supply and Demand Characteristics. *International Labour Review*, 143(3), 211-233.

Gazier B., 1998, *Employability: Concepts and Policies*. Brussels: European Commission, European Employment Observatory Research Network.

GHK Consulting, 2010, *Skills for green jobs ‚Äì European synthesis report*. Thessaloniki: Cedefeop.

Harvey L., V. Geall, S.Moon, 1998, *Work Experience: Expanding Opportunities for Undergraduates*. Birmingham: Centre for Research into Quality.

Hillage J., E. Pollard, , 1998, Employability: Developing a Framework for Policy Analysis. *Department for Education and Employment (DfEE)*, Research Report no RR85.

McFadden D., 1974 Conditional logit analysis of qualitative choice behavior. In P. Zarembka (ed.), *Frontiers in Econometrics*. New York: Academic Press, 105-142.

McQuaid R., C. Lindsay, 2005, The Concept of Employability. *Urban Studies*, 42(2), 197-219.

Mortensen D.T. , 1994, The Cyclical Behavior of Job and Worker Flows. *Journal of Economic Dynamics and Control*, 18, 1121-1142.

Mortensen D.T., C. Pissarides, 1994, Job creation and job destruction in the theory of unemployment. *Review of Economic Studies*, 61(3), 397-415.

Oliver E.A. , 2012, Living flexibly? How Europe's science researchers manage mobility, fixed-term employment and life outside work. *The International Journal of Human Resource Management*, 23(18), 3856-3871.

O'Connor J.S. , 2013, Non-Standard Employment and European Union Employment Regulation. *Non-Standard Employment in Europe*, vol 46.

Petrongolo B., C. Pissarides, 2001, Looking into the black box: a survey of the matching function. *Journal of Economic Literature*, vol 39(2), pages 390–431.

Pissarides C., D. Mortensen, 1999, New Developments in Models of Search in the Labour Market. *CEPR Discussion Paper*, No. 2053 (January).

Qin S.J., T. A. Badgwell, 2003, A survey of industrial model predictive control technology. *Control Engineering Practice*, vol 11, pages 733–764.

J. Varet, 2008, *Prospective de l'emploi dans le domaine des géosciences à l'horizon 2020*. Orléans: BRGM.

Wilson R.A. *Skills supply and demand in Europe: medium-term forecast up to 2020*. Thessaloniki: Cedefop, 2010.

Chapter 16

Language, interaction, information and the modelization of market interactions

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Abstract

The article's aim is to show how the modelization of market interactions could be greatly improved by taking into account some of the parameters which have proved to be crucial to the understanding of the relation between language and information. Namely their performative, attentional and sequential dimensions. After describing these dimensions and presenting the shortcomings of theoretical assumptions which ignore them, it turns to the modelization of autonomous performative prices under a constraint of scarcity of attention and sequentiality (vs centralized and simultaneous fixation of constative prices under no constraint of attention). It is then shown that such a modelization should start with accounting for the performative capacity of individuals to set their own prices, and thus with the fact that this capacity is primarily constrained by the curve of reaction (IDC) to his/her proposals, and then by the possibility to merge this information with one's own knowledge of the cost and capacity constraints, allowing the formation of a decision curve (OFC) describing all the equally realistic/realizable options among which the price must be chosen. It is then shown that this framework allows to describe in a unitary way price formation and performative prices in extremely variable interactional settings but must be complemented by considering the role and importance of macroeconomic eviction in the upstream determination of IDC, illustrating once again the fact that, ultimately, adopting an interactionally realistic approach only implies to reconsider the ordering of the constraints at stake.

16.1 Introduction

From ethology, the science of animal and human behavior (and a branch of biology) to pragmatics, a science which studies the constraints that govern verbal interactions (and a branch of linguistics) to the sociologies of interactions, half a century of empirical scrutiny and theoretical studies of interactions will be the background of what follows, even if only some aspects of its main outcomes will be considered.

Similarly, from Cournot's first mathematical theory of price formation to general equilibrium and game theory, the study of market interactions within economics also has a long history, with the specificity of not embracing directly an « interactionist » - and hence neither individualistic nor holistic - stance, as is always the case in the above-mentioned disciplines.

Given this double background, our ultimate goal will be to consider and discuss three issues.

The first issue concerns the way the modelization of the complexity of market interactions could be transformed by taking into account some of the parameters which have proved, within interactionist frameworks, to be crucial to a correct understanding of the relation between language, communication and information. We shall in particular discuss the way the performative, attentional and sequential dimension of interactions may prove useful or necessary when it comes to the description of market interactions

The second issue concerns what is arguably the most original aspect of the way interactions have been approached within economic questioning - namely by also questioning the "interactions between interactions" - could the other way round transform the way "individual/local"[2] interactions are to be described, notably by forcing the analyst to clarify the way such interdependencies could be modelized.

Our last issue will be to discuss somehow programmatically the way it could become possible to build models of market interactions which would both fully admit the ultimate autonomy of micro-micro interactions and acknowledge the non-less real interdependency between them.

As for the first objective, we shall first recall the reasons which have led to a profound transformation of the study of language and languages after the late 60s, when linguists started to take seriously into account the enunciative[3] and interactional dimension of language and specifically the fact that there is nothing in languages that was not primarily in an interlocutive and interactive setting and thus that has not been shaped by interactional constraints. We shall then question the heuristic value of what has been learnt in this process and wonder if the discovery of the strongly interactional nature of utterances could prove insightful for the study of market interactions. Specifically, due to the limitation of space here, we shall limit ourselves to the discussion of three of the features and constraints which could arguably be considered as both inherent to all human interactions and important in the study of market interactions, namely their performative, attentional and sequential dimension.

We shall also ask ourselves whether any global or local representation of market interactions may ignore or neglect these dimensions, bearing in mind that when it comes to the role of language in the description of market interactions, it is the case that one must consider:

i. the use of language (including in computerized and algorithmized form) in the very process of market price setting;

ii. the fact that prices themselves are linguistic utterances (and trading utterances);

iii. the use of language (including in mathematical form) in the model itself;

iv. the fact that the interpretation associated to these models is itself language based;

v. the fact that all those layers are actually interdependent, which makes it impossible to make a specific assumption concerning one layer, without making implicit assumptions about other layers.

[2] Interactionist approaches tend to consider individual interactions as the fundamental ground of analytical work.

[3] The concept of *énonciation* describes the fact for something to be said (uttered). It has proven to be the case (see Nemo, 1999) that because of the existence of pragmatic constraints on the fact of saying something, the interpretation of the utterance is deeply altered by its enunciation. It also describes the fact that this dimension of language actually shapes all linguistic realities.

Our answer to this question will be to claim that the relationship between language and what is commonly called information appears to be such that the notion of information just cannot be defined and modelized outside and independently of language interactions. And also claim that this is a chance when it comes to the modelization of market interactions, because it allows and forces to integrate parameters which cannot reasonably be overlooked.

As for clarifying what point iv) concretely means, we may provide a clear-cut example of this interpretational layer in the interpretation of the supply curve in partial equilibrium models, which nowadays is routinely interpreted and taught as the mere aggregation of the suppliers answers to the question "*which quantity would you offer at such or such price* ?", whereas in Marshall's work it was actually obtained by asking a very different question, namely "*what price would be necessary for you to offer such or such quantity* ?". Meanwhile, it must further be noticed that those interpretations would be either inconsistent or contradicting if the interpretation of the question itself was not actually "*which quantity would you offer at such or such price,* ***if you were sure to sell this quantity***?"[4] and "*what price would be necessary for you to offer such or such quantity,* ***if you were sure to sell this quantity?*** ". Otherwise, in both cases, it could be predicted that the only consistent answers to the question would and could only be "*it depends on how much I can sell at this price*". As a consequence; it may be proven to be the case that ***the curves of supply and demand cannot in reality co-exist and be presented together in a single model,*** and that they must be considered as "incompossible", to use a logical terminology. One would indeed have to presuppose[5] that all participants, when they answer both questions will assume that no price will ever be adopted which doesn't allow supply to be met by the corresponding demand. But in that case, it would both be the case that the existence of a market equilibrium would be **a premise** of the model and not **its conclusion**, and that the mere existence of the demand curve would imply that the participants assumption is ill-founded and based on incorrect and poor information.

16.2 Performativity, price modeling and market interactions

Starting with performativity, which concerns what is called the direction of fit between the words and the world and which opposes constative utterances[6] (in which the world precedes the words, which must adjust to it[7]) and performative ones (in which words

[4] The very same presupposition is also present in the interpretation of the Marshallian variant of the question.

[5] At all steps of the construction of the partial equilibrium model, the same assumption is made, for instance when it comes to quantify the expected income of an individual supplier, the parameter used (i.e. a "price x quantity" multiplication) makes sense only if it is assumed that the quantity at stake will be sold, otherwise the information provided by the demand curve can only be described as illusory or irrational.

[6] The distinction between constative and performative utterances in pragmatics is a legacy of John Austin book "*how to do things with words*" (1962). It opposes utterances which simply describe something which exist prior to the utterance itself, and utterances with a potential to create the reality which they are talking about. A single sentence such as « the session is opened » may thus be used as a constative utterance, for instance when uttered by a journalist who is just reporting the fact that the session is open, and as a performative utterance when uttered by the chairman. Who is, literally, opening the séance by declaring that it is open.

[7] Constative utterances are thus either true or false depending on whether what is said is consistent with a preexisting world.

come first and it is the world which has adjust to them[8]), it may be recalled (Nemo, 1995) that while there is no doubt whatsoever that in reality:

- prices are utterances;
- prices are performative utterances and not constative ones, which strictly forbids to consider them as true or false in the logical sense of the term;
- prices do not describe a pre-existing and non interactional object that could be called "value" or anything that could be measured;
- a price is actually something "to take or leave", and thus is a reality only insofar as it is accepted by someone;
- prices are therefore not entities which could be concerned or associated with the logical principle of non-contradiction;

the main models used to account for price formation routinely take for granted the opposite assumptions, namely :

- the idea that prices are propositions (in the logical sense of the term);
- the idea that market prices are not only propositions but true propositions;
- the idea that market prices form a system (which can be modelized as a system of equations) in which they have to satisfy the logical principle of non-contradiction, with the extraordinary outcome of allowing to name "general equilibrium" what is actually nothing else that the logical principle of non-contradiction, and to call "price-taking" what is nothing else that the negation of performativity.

This negation of performativity has moreover been extensively axiomatized over time by a set of assumptions and prohibitions which make it to some degree unthinkable.

The most radical form of eradication of the performative dimensions of prices appears to be the possibly involuntary consequence of the formulation of the question which has shaped all price theory, namely Cournot's foundational questioning of the effect of the number of suppliers on the fixation of price, and the way it was answered, namely by considering successively a market with one supplier (monopoly), with full performative capacity to set the price, a market with two or a small number suppliers (duopoly or oligopoly), with a relative capacity to influence the price etc. and finally the so-called perfectly competitive market with plenty of small suppliers unable to have any influence on price-fixation which are considered as price-takers and are thus devoid of any performative price-setting capacity.

It appears however (Nemo, 1994, 1995) that Cournot's questioning and line of reasoning, is flawed by the fact of being based on the tacit (and uncontrolled) presupposition that the number of suppliers in a market may be considered constant, when it cannot. Given that this presupposition requires in order to be acceptable nothing less than to assume the price level to be completely unable to affect or modify the number of suppliers present on the market. It turns out that because the opposite is true in a true (Darwinian) market, the number of suppliers which are able to stay in the market

[8] Performative utterances are thus said (Austin, How to do things with words? 1962) to be either *happy* or *unhappy* depending on whether what is said becomes a reality following being said, or not. While constative utterances have as mentioned truth-conditional values and are true or false, performative utterances are described in terms of *conditions of felicity* and are said to be either *felicitous*/(happy) or *unfelicitous*/(unhappy).

decrease steadily with price level, such traditionally unthinkable realities as a perfectly competitive monopoly may occur, in which at a (low) price, only one supplier will be present on the market, while at higher prices more suppliers would be present. It also turns out that performativity is essential for the description of such truly competitive markets, and that performativity cannot be reduced to the desire to fix high prices but must actually be considered actually as a mean (and weapon) to exclude competitors from the market. Cournot's approach and all its legacy in mainstream economics may thus be characterized as leading to ignore what is possibly the core nature of market competitiveness: the capacity to remain in a market when prices are going down. As a consequence, "price-taking" models (and so-called perfect competition) are associated with a non-Darwinian notion of competition which actually excludes any competition of any kind between competitors.

A second way of ignoring performativity and pragmatics all together concerns the status of the information/declaration provided by market participants, about which it is either simply assumed that interactants will never lie when asked to provide information about their market intentions, even if lying would in fact be arguably profitable, or simply assumed that they will be forced to "stick to their words", without considering that it is not possible to name *information* what is in fact a performative *commitment* (and thus nothing less than a verbal contract).

An even more problematic aspect of General Equilibrium theory is to actually prohibit any two individuals (or groups)[9] to reach any direct performative agreement outside of a general equilibrium. This prohibition being the consequence of the model incapacity to recognize any autonomy and self sufficiency to local interactions

A major issue and challenge in the modelization of market interactions is thus to fully admit and integrate the performative dimension of prices as an indisputable and important reality, without being led to consider local interactions as independent one of another, since they are not.

16.3 Attentional constraints on interaction

Together with ethologists, psychologists and pragmatists, we may first admit that any human interaction requires attention from the people involved, and that attention at an individual level is a scarce resource which is limited both quantitatively and qualitatively, humans being unable to pay attention to many things at the same time, let alone to everything.

We may further admit to be true that all humans need attention from other humans, and that this need to get and receive attention from others, and to have their existence and value recognized, is a reality which is at the heart of the human condition[10] (Todorov, 1995) to the point of contradicting and countering selfishness[11].

Once combined, it follows firstly from these two sets of assumptions that since all human life involves an allocation of scarce attentional time, not only between production, consumption and trade, but also between economic activity and non-economic activity, any postulation of unlimited attention and overestimation of the (attentional) capacity to process information in a given time should be banned in the modelization

[9] For a postulation of the opposite, see the "islands" of Edmund. Phelps (1969, 1970)

[10] And is as mentioned by Todorov, virtually insatiable.

[11] More precisely, it can be shown that many if not most of the behaviors associated with so-called selfishness may be proven to ultimately be aimed at social recognition and competition for recognition. The same could be proven also and to the same extent for altruistic behavior.

of interactions. They also imply that it is not possible to describe human behavior in purely individualistic terms, let alone to equate rationality with the maximization of individual interest, once acknowledged the fact that the satisfaction something represents for someone will be ultimately dependent (and this to a large extent) on its attentional value at a collective/social level in human interactions. So that as long as individuals are sensitive to the way they and their choices are considered, choices cannot be solipsistic.

Miles away from such an attentional understanding of the nature of information and interactional information, it is important to realize that what has been called "perfect information" in economic theory may (and in fact must) be considered as an "absolute informational chaos" once attentional constraints are taken into account. Because of the limited ability of individual information processing due to the limited character of attention[12]. Because of the fact that being bombarded with irrelevant information will automatically lead to the non-treatment of the information in question, and by interaction suspension. And finally because information circulation cannot but be limited to *relevant* information and be dependent on the pragmatic constraints on relevance.

As importantly, it may be said that any modelization of interactions which postulates for a population of n individuals that everyone is related to everyone, and that everyone is aware of everything, does not describe nor a possible world nor an ideal world, but on the contrary an impossible world and an absolute chaos. "Islands", if they are to be modelized at all, should not be conceived as imperfect fragment or a larger reality but as reasonable aggregates in the first place.

Firstly, because it implies that because the mere existence of any offer - be it to sell/supply or to buy/demand - requires an allocation of attention by a hearer, struggling for such attention is no less important in economy, to use an euphemism, than it is in other areas;

Secondly and most importantly, because the organization of mercantile exchanges in markets, trade fairs, shows, etc. is already based on this logic of visibility and minimization of attentional costs.

And finally because efficient communication and information requires attentional coordination, which, when it concerns large groups of individuals, may emerge only in collectively organized forms.

This implies thus for each interactant to constantly adjust to his interlocutors and select the relevant interlocutors. And also that it is not possible to consider interaction and information as separated issues, the existence and maintenance of interaction being dependent on attention and relevance and the mere existence of information presupposing interaction.[13]

It also means that capacities to win the battle for attention and relevance, such as empathy and mind-reading, are crucial properties of individuals. As are crucial the capacity to know, to guess, to influence and to manipulate the attention of others and through doing this their choices. With the result that choices, ultimately, form an attentional system, whose interactional and social nature cannot be ignored or minimized: people for instance do not only buy goods for what they are, but to a considerable

[12] The idea associated with so-called perfect information being that everyone should be informed of everything is in this respect both quantitatively impossible in purely cognitive terms and irrational since most of this information will be devoid of any interest for the receptors. Scarcity of attentional resources imposes rational information to always be goal-oriented, which makes knowledge about goals themselves a crucial form of information.

[13] In a certain sense, one cannot separate information from its interactional attentional dimension more than it would be possible to separate genetic code from its DNA materiality. Extra-interactional information simply does not exist.

extent through the way these goods are seen and valued by others. And in such a context, postulating only psychologically solipsistic agents with the sole capacity of maximizing solipsistic wellness appears thus arguably as disputable as ignoring the interdependency of markets.

Attentional constraints thus are a parameter which cannot be ignored in the description of market interactions, be it when they are considered as a whole, because they quantitatively limit the global flow of information, or at the level of each individual, because they considerably constrain his/her economic and non-economic behavior.

16.4 Sequentiality and market interactions

Another fundamental characteristics of any interaction from a social or language-oriented perspective, is sequentiality, i.e. not only the fact that everybody's actions are also reactions to previous actions - and also reactions to reactions, etc. - but also the fact that they are ordered chronologically and that such scheduling is indeed crucial to the analysis of market interactions and its outcome.

Considering the apparently trivial fact that a mercantile interaction can begin with either an offer or a demand, both of which may be associated with a price or not, and that this first step either leads to an effective exchange or doesn't, not mentioning possible bargaining process in between, it is worth wondering whether this sequentiality may be completely ignored in the analysis of what is going on - for instance by trying to model the meeting of supply and demand as a non-sequential event in which two "forces" would meet exactly as simultaneous physical forces (Mirowski, 1989) - or whether we should instead take seriously the time gap between supply and demand (or vice versa) into account.

Given that there are numerous reasons to adopt the least view, we shall only be able here to spell out some of them.

What has to be remembered first is the fact that for an individual with no possible knowledge of all current interactions, *the concrete form taken by the reactions to their offers or demands is the primary and more reliable source of information available, and that this reaction is to a large extent a function of what in pragmatics is called common ground, in other words any form of shared knowledge about previous market exchanges.*

An illustration of the first aspect of the question is that if the performative nature of prices implies to accept the idea that exchanges moves (offers or demands) have to be ratified, it is both the case that the sequential nature of ratification allows it to convey a crucial information, and that *describing verbal exchanges that do not result in a commercial exchange is at least as important for the description of market economic interactions that describing those who do*.

An illustration of the second aspect of this question is that - while the gap between offer and demand and vice-versa is typically associated with both considering previous and alternative offers, so that for instance the more important the transaction the bigger the time gap between a proposal and its acceptance will typically take - information is time and time is money and this in both temporal direction[14];

[14] To give but one ordinary example, one may consider this excerpt from a *New-York Times* article entitled "*In a Seller's Market, Every Minute Counts*" (Higgins, 2013) **:** *The rules of engagement for buying an apartment in the city have changed. Negotiation, brokers say, is no longer part of the equation. Forget about taking time to mull over your decision. Serious buyers need to be prepared to pounce.*

As for the markets whose appearance is one of absolute simultaneity (and thus should be considered as counter-examples to the importance of sequentiality), it can be shown that computerized markets for example, far from making a case for the possibility to theoretically ignore sequentiality, are on the contrary the clearest proof ot the opposite, with huge profits relying on the capacity to have a quicker reaction than other interactants, to the point of replacing humans in the decision process by algorithms, to gain edges in sequential competition.

As for the interlocutive and linguistic aspects of economic interactions, it must be emphasized that the actual diversity of the communicative form they may take (e.g. ad, poster, price tag, price-list, catalog, price quotation, individual bargaining, auction, "criée", auctioneer, organized market, computerized market, etc.) is embedded in the organization of sequentiality, typically by institutionalizing a time frame to regulate individual interventions. All of which need not be considered as irrelevant or negligible when it comes to accounting for price formation or for the parameterization of interactions.

Firstly, because of the fact that these communicative forms do not only co-exist and compete one with another, but are actually quite often deeply dependent one with another. So that the idea for instance that market theory should consider such or such interactional and linguistic form of market exchanges - for instance those which rules the wheat market in Chicago - as in any sense prototypical or ideal-typical of a market, is empirically falsified by the fact that a market such as the wheat market is only the emerged part of an interactional iceberg in which market interactions take the most varied linguistic forms. Similarly, because the very idea of a prototypical or ideal-typical market is associated with the idea that some markets would be a better incarnation/exemplar of markets in general than others, it must be abandoned. Economics may study the competition between the various interactional forms of market interactions, but it cannot axiomatize such or such institutionalized form as the best or standard form of the market, for markets have existed for thousand of years under the most varied form, and, more importantly, are strongly and structurally dependent one from another: the Chicago wheat market cannot be opposed to retail trade for instance, whose linguistic/informational and interactional organization is radically different, because the two interactional frames are in fact elements of a single continuum.

Secondly because this diversity should not be considered as an obstacle to the description of market interactions in a unified way, since it is both possible, once taken into account our three parameters, to consider them contrastively and to spell out invariants.

Thirdly because there is nothing odd with the constant coexistence of new and old forms and patterns of interaction - ranging from the most technologically advanced ones such as algorithmized markets or politically motivated ones to immemorial forms such as face to face bargaining - being in constant creation and institutionalization.

Finally, as mentioned earlier, it is also the case that because among other things individual interactions have their own time frame[15], they are forcefully related to a memory of previous interactions (and of their outcomes) which is called common ground

[15] Which to some degree may become institutionalized in collectively accepted forms. The term *market* itself originally describes a traditional form of collective coordination and in that sense, instead of presupposing the existence of a market, or instead of presupposing the existence of thousands of markets, it is important to understand that what is labeled *market* is nothing else than a form of collective organization of economic interactions shaped by the scarcity of attentional constraints and the necessity to enhance all participants visibility and accessibility. In a certain sense, such or such market was initially little else than a meeting.

and which is for instance compulsory to be able to answer such basic questions as "which quantity would you buy at price P ?". Pretending to ignore this reality, for example by affecting to ignore that the information provided by the demand curve - and which serves in the model as a premise to a representation of exchanges which claims to describe interdependency in terms of absolute simultaneity - simply cannot be obtained[16] without a knowledge of *previous* prices[17], is not an option but a fraud. Meanwhile taking on this reality, and acknowledging the fact that it is inherent to the informational reality whose modelization is at stake, could allow to understand that individuals may only position themselves in relation with a system of reference (and by assuming in their answers that this system of reference is shared by their interlocutors) and that whatever they say can only be interpreted in relation to this assumption; information is complex by nature and embedded in common ground. Whisking away the premises of the premises of a model is not a scientific option, nor is the modelization of these informational premises possible by simply relying on the intuitive interpretation of question/answers pairs of ordinary people without explicating its content..

16.5 Interactional autonomy and interdependencies in the modelization of market exchanges

So far we have shown that when dealing with interactions, it is not possible to merely "postulate" and presuppose their existence without taking into account the constraints and parameters which define them and allows them to exist. We have also shown that because any modelization is build on a linguistic frame[18], it inevitably has its blind spots that can literally render "unthinkable" many realities whose existence is beyond doubt[19]. It is thus time now both to introduce a more positive perspective and to show that widening our understanding of what interactions are, and notably acknowledging both the strongly interactional and interlocutive nature of interactions and its linguistic dimension, may be done without renouncing to the modelization of the interdependencies between interactions, which is arguably the most interesting contribution of economics to their analysis.

Decades after the most explicit discussion (Kaldor, 1972) of the contradiction between Equilibrium theory's claim to be a model of a decentralized market and its formal reality as an extremely centralized market in which interdependencies are strongly and, as far as information is concerned, counter-factually overstated, we are still looking for

[16] Without the existence of this common ground, the only answers one could receive to a question such as "which quantity would you buy for price p ?" would be questions such as "what can you buy for price p ?", etc.

[17] It is worth noting that one cannot ask someone to forget this knowledge in his/her answers, with the consequence that no common-ground free information can ever be produced.

[18] The formal dimension of models doesn't alter this reality, both because each of their elements has its own linguistic interpretation and because models are framed by the issue they try to address, Meanwhile because this issue is a question, it is forcefully linguistically and dependent on non explicit assumptions (presuppositions). As we could see with Cournot's assumption that the number of supplier in a market may be considered constant and independent on price-level. And as can also be illustrated by the partial equilibrium interpretations of the supply curve which were described above. It is indeed undisputable, both that formalization cannot dissolve presuppositional issues (first identified by Frege himself) and that scientific utterances, because they are answers to questions, inherit most of their semantic frames from the linguistic framing of the questions.

[19] In that sense, it must be understood that models cannot be considered as mere simplifications or idealizations of reality, for they are indeed semantic filters which determine what is worth considering or not, and in that sense may actually be "wrong" when they ignore dimensions of reality which cannot be overlooked.

a model that would be able to combine relative autonomy and relative interdependence, and we know from experience that attempting to approach this issue by trying to introduce some autonomy in equilibrium interdependence - as was repeatedly attempted in the last 45 years by somehow trying to disaggregate general equilibrium, and to avoid a Walrasian "commissaire-priseur"[20] are due to fail if an interaction-based conception of interdependency is not spelled out.

When it comes to the co-existence of interactional autonomy and interdependence between interactions, it is indeed important to realize that the modelization of interdependency should not require neither a centralized market nor so-called perfect information (and its pre-condition, the absolute interdependency of all interactions one with another), But once acknowledged the facts i) that attention is scarce and thus that the number of interactions is forcefully and strongly limited[21]; ii) that selling or buying is a decision and that as a performative act they must therefore be considered as axiomatically free and unpredictable; iii) information is accessible only through interactions and thus limited and enhanced by individual capacity to enter interactions, it is possible to completely reconsider the way we see and understand market interdependencies and market information, and to realize that in interactions, *autonomy and interdependency come as the two sides of a single coin,* interdependency being "embedded" in autonomy and vice-versa[22].

To provide a concrete illustration of this reality, one may consider for instance the modelization of demand in an attentionally constrained market ultimately defined by performative autonomy. Departing from the idea that aggregated demands would meet aggregated supplies producing an equilibrium market price which the individual interactants would have to accept as a fatality they cannot escape, we may consider that at the level of the individual interactant, demand[23] is basically nothing but the name of either the reaction which an interactant encounters when he/she proposes something, or his/her reaction to a proposition which another interactant has made.And consequently that describing economic encounters and understanding economic interdependencies impose:

- to consider the individual offer/demand exchange as the primary form and pre-condition of economic decisions in a merchant society;

- to describe a decentralized and non-institutionalized market as ultimately based on a set of "individual demand curves" (IDCs from now on[24], representing all the credible responses to his/her offers that an individual may observe or expect,

[20] In mainstream market theory, the fixation of a market price is described as a process involving a commissioner whose role is to gather information for the determination of the equilibrium price. The term used is French *"commissaire-priseur"* in which *priseur* means litteraly "pric-er" (which would translate as "price-maker" in English).

[21] Even admitting a twitter-like connection between all interactants, in other words even assuming the possibility for an information to be shared by all, it follows from the scarcity of attention that only a limited number of topics (and information) could be widely shared, and that perfect attention on one subject would forcefully mean imperfect or no attention to others. Modelizing the allocation of attention is thus a pre-condition of any modelization of exchanges.

[22] Among other things, because performative prices are autonomous decisions which are interactionally constrained.

[23] A point which must be clarified is that equality between demand and supply may both be said to be an analytic truth as a consequence of the fact that all effective exchange is simultaneously an offer and a demand, and to be problematic if at a given price not all demand or supply is satisfied.

[24] IDCs thus are distinct here from what is called an individual demand curve in neoclassical theory, the individual being the supplier/offerer and the IDC resulting from the aggregation of each demander demand to him/her.

a curve of reaction) forming a set of coexisting but not aggregated[25] demand curves.

Further admitting that theses curves have a temporal dimension, which is variable, and that they are the main and often only source of information available to the initiator of the interaction, we may define "perfect information" at interactant level as the exact knowledge of the form of theses curves and "imperfect information" at interactant level as ignorance or uncertainty of the form of these curves.

Being aware of the fact that the outcomes of the trading process is determined equally by the individual demand curve and the "offerer"[26]constraints and reactions to this curve, it is important to understand that the reactions which an individual demand curve synthesizes are in fact reactions ***not only to a specific offer but to all existing alternatives to that offer***.

It follows from this that no matter how autonomous an interaction later is when it comes to economic decisions and actual exchanges, it must be understood that the very form of a demand curve is ***the trace of its current state of relatedness between the on-going interactions and all other interactions***, and that consequently "islands" are not truly "islands" because autonomy does not mean independence.

It follows from this that there is no such thing as a purely local interaction, once understood that each interaction is indeed connected to the global interactional web through the form of the IDC demand curve. It also follows that because each autonomous decision potentially affects the later form of possibly all other demand curves, be it marginally, we may further realize that the detailed/interactional form of the demand curves allows the offerer to gain direct information and also to make interpretational inferences, providing him/her in both cases to a precise mapping of the current situation. This being a consequence of the difference between "aggregative demand" - which provides only access to the global quantity which is demanded at such or such price - and « interactional/detailed demand » which also provides a more precise information about "who want what at what price" as we shall see now.

16.5.1 Interactional complexity of IDCs

The fact that what has been labeled here "individual demand curve" is simultaneously deeply interactional is clearly its most interesting feature. It must be indeed stressed out that the IDC is individual only from the perspective of an individual offerer F_1: it aggregates in fact a set of reactions for each distinct individual D_1, D_1, etc which are in interaction[27] with F_1. and which we shall label DDCs (demander demand curve) to avoid any confusion. Since these DDCs are interpersonal reaction functions, it must further be stressed out as mentioned that the IDC provides F_1 with much more precise information than the purely quantitative figure that classical demand curves used to provide. For each price, S_1 will indeed know which quantity (s)he could sell if (s)he

[25] In a decentralized market, and in a situation of strictly balanced competition, it may be assumed that individual IDCs for a commodity are, *at each price*, obtained by the *division* of the quantity which is demanded *globally* by the number of suppliers *which are present at that price*.

[26] « Offerer » here could not be replaced by « supplier » because this last word presupposes an exchange which is not certain at that stage and may never occur. Far from any false symmetry between the two sides of the market, it must be stressed out that the ultimate decision always belong to the offerer, who even tough he/she may be cornered and left with little choice, is the only one with the performative power of making the transfer true, or to transfer this power to his/her interlocutor(s).

[27] It must be stressed out indeed that each IDC aggregates a variable number of interactors, and a variable set of interactors, due to the attentional constraint which strictly forbid all offerers to be in interaction with everyone.

wanted to, but (s)he will also know individually each interlocutor's price sensitivity so that the information which is available is both much more precise and much more relevant than the aggregated information postulated in classical price theory.

As for this last point, it must be remarked that the problem of knowing which degree of sincerity can be attributed to each DDC is not a parameter which the model has to decide for, for it can vary. But what can be said about it is that there are some interactional rules about it and they are interestingly asymmetrical: A basic fact about a DDC is that saying something as "I would buy such quantity if it was offered at such price" is an utterance with a commissive value. This means, in other words, that it constitutes a commitment from the individual demander, and should be considered as a pre-contract[28]. Not only because commitment to the truth of what is said is a general commitment in human conversation (e.g. Grice's Maxim of quality), but because it concerns the credibility and the reputation of the individual demander involved whose credibility is a social and interactional capital whose value must not be underestimated.

It does not however follow from this that what is said may be considered as a reliable and undisputable premise when it comes to exchange modelization, because the commissivity of the utterance is in fact strongly asymmetrical; the necessity for the demander involved to stick to his/her word in order to preserve its reputation being restricted to the necessity not to demand *less* than stated previously but does not forbid him/her to demand *more* than previously stated. One may indeed pretend for instance than (s)he is not interested by something at such a price, and it may simply be false, the reality being that (s)he would still be interested at that price, as the future may later prove. Which is consistent with the fact that bluffing may be an essential and normal part of what will then be called a bargaining or negotiation process, for instance by pretending that one does not want something at a certain price or that selling under a certain price would be unconceivable. To this extent, DDCs may have a manipulatory dimension which must not be ignored or outlawed. But the above-mentioned constraint of sticking to one's word does not apply to changes which are conceived as favorable to the other participant. So that finally accepting something which was initially refused will rather be considered as a defeat than in terms of lack of reliability. Commitment thus will be restricted to forbidding any back-tracking that would be disadvantageous to the receiver of the "comitmental" utterance. Another important dimension of DDCs is that what an individual demander will answer may prove to be, to some extent, dependent on the hypotheses (s)he will make about the global IDC of the supplier. So that on the one hand, it may often be the case that what will be answered will be based on self-conscious beliefs transforming it into a kind of bet that one may perfectly loose[29].

16.5.2 From IDC as a reaction curve to OFC as a decision curve

But once acknowledged all this background, the main issue will be to know how and to which extent an IDC will determine or influence what ultimately will take place in the exchange. Modeling this issue starts with the necessity to predict which reaction the individual offerer will have to his/her IDC but supposes then to admit that this reaction

[28] If the utterance is addressed to a single offerer. If addressed to various offerers, it becomes a call for a price proposal but remains a commitment, not to someone in particular but to anyone who will react to it.

[29] In that sense, it is the case on the one hand that equilibrium between expressed demand and supply may perfectly coexist with unsatisfied (because unexpressed) demand and effective disequilibrium, and also the case that because bets are speculations, the idea that expressed demand should always be satisfied is not rational.

will be a two-step reaction in which the ordering of constraints will be the opposite of the ordering which is postulated by the centralized approach to price fixation.

The information provided by his/her IDC allows each individual offerer to know for each price the quantity that (s)he *could* sell at that price. But since this quantity is not most of the time the quantity that (s)he want or can provide at that price, and since *(s)he knows* which quantity (s)he could sell at each price if the corresponding demand existed, ***our performative offerer is informationally in a position to merge information about demand and information about constraints on supply into a unique decision curve*** in which each price is associated with a quantity (which measure the aggregative felicity of a price, i.e. the number of times the performative utterance will become true). As for the modelization of price fixation, the fact that each performative interactant is in terms of information perfectly able to adjust demand and supply at all prices *before* having to choose between them is a feature which radically transform the way price-fixation can be approached and modelized and implies the construction of what we propose to call an offerer felicity-curve (OFC from now on) from the IDC base, prior to the price fixation itself which comes as the last step and is described in terms of making a choice between equally possible prices, all of whom being so to say "equilibrium"[30] prices.

A felicity curve may be defined as constrained by the adjustment/alignment of possible supply on the one hand and IDC on the other hand, and as aimed at providing a realistic representation of the options in terms of exchange which are available to the offerer involved. It may further be defined by an alignment rule which states that it consists:

> for each price, in the quantity that may be exchanged will be either the quantity which is demanded, if it is superior or equal to what can be supplied, or in the maximal quantity which may be supplied, if it is inferior to what is demanded [31]

and this for all prices for which this quantity is not null.[32]

In the arguably standard situation in which potential demand decrease with prices and potential supply increase with prices, there will further be a price which may be called an inflection price and may be characterized as threshold between the supply constrained part of the felicity curve associated with lower prices and the demand constrained part of the OFC associated with higher prices, but this price of inflection will play no specific role in what ultimately will determine the final setting of the offerer's price, which will be a matter of choosing between all the *realistic* options represented by the felicity curve. For its role is only to provide a complete set of "price/quantity" pairs which all can be felicitous, even though not all prices will later prove to be equally advantageous for the offerer.

It follows from this that the freedom of the offerer to fix a price is limited to the felicity curve, so that (s)he is not a price-taker but a felicity-curve taker. An individual cannot define what is possible, but (s)he may define what takes place.

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[30] The use of *equilibrium* here is similar to its use in game theory, where it is interpreted as "possible" and not as "necessary" (see Cadiot & Nemo, 1997), due to the fact that no assumption is made that there would be only one equilibrium price, and to the more positive observation that nothing could prohibit this price to become true if ever for any reason, it was chosen.

[31] In classical terms, it means that the felicity curve represent the association of a price with the shorter side of the market. But plays a completely different role, being a decision curve.

[32] This implies that the felicity curve starts at the minimal price for which something could be sold and ends at the maximal price at which something can be sold, thus representing at the level of the individual the possibilities of exchange (and hence his/her "market").

16.5.3 From decision-curve OFC to price fixation

The final step of the process, and of its modelization, concerns the choice which our offerer will make between all the equally realistic options which are available to him/her and which are synthesized in the OFC. In this respect, considering this process to be driven by maximization and optimality is a first approximation, which should not mask the fact that what exactly an optimal price stand for might prove to be quite variable, not least because of the variabilility of IDCs in the first place, the variability and dynamics of production capacities, and this of the OFC and also because maximization is strongly time-framed.

It is important nevertheless to stress out that such an optimality model of decentralized performative deeply question the relevance of transforming the constraints of adjusting supply with demand into a price-setting mechanism, for it assumes that maximization takes place first (being a central assumption for the modelization of supply) and *then* that the adjustment of supply and demand will decide of the price, whose role is thus forcefully to ensure this adjustment. Whereas in an economy in which individual performative price fixation is the rule, adjustment between supply and offer will (only) be a key constraint for the determination through OFC of the exchange options, with maximization taking place only in the comparison between these options.

It must also be stressed out that the ultimate right to fix one's own price cannot be denied to an offerer under any circumstances or assumptions, for two complementary reasons, both of which cannot be ignored in any attempt to model price fixation. The first is that the term *price-taker* is actually used to denote a *market-price taker* and associated with a cournotian line of reasoning according to which when offerers become too small they loose all capacity to influence the *market*-price, notably to set it at a higher price than this market-price. Where in reality and axiomatically any individual will always keep the right to propose any price for what he has to offer and in particular to propose a lower price than any existing market-price. So that not model can ever make the opposite claim, let alone transform price-taking into an axiom and overlook the complex assumptions which are implicitly associated with it.

Proving it is easy, for it is possible to describe within our three-step model of performative pricing (IDC, OFC, price selection) the kind of situations which allegedly are associated with price-taking. A first feature of such a situation would require that in the IDC demand would be inexistent for any price higher than the price offered by the market (or competitors). Another feature would then be that for lower prices[33], it would require them to be less interesting than the price offered by competitors. So that ultimately, it may be shown on the one hand that "price-taking" could occur in many circumstances unrelated to cournotian assumptions, and more importantly that the interpretation associated with price-taking (namely that the offerer has literally no option but to adopt the "market" price) is ill-founded, since such price-taking may only take place[34] in a situation in which adopting the "market" price is the best option,

[33] The same would be the case for higher prices if demand was not inexistent.

[34] Another situation in which something similar to price-taking could be observed is what might be called "mimetic pricing", i.e. a situation in which an offerer will choose as its price the same price than his competitors. The rationality of such a strategy could be explained by admitting the simultaneous existence of an MDC (a mimetic demand curve), i.e. of a set of answers to the question "which quantity would you buy to me if everybody's price was p ?" (versus "Which quantity would you buy to me if my price was p" for the IDC) and of a favorable comparison of the MDC's outcome with the IDC's outcome. In any case, it must be stressed out that mimetic pricing is unrelated with cournotian price-taking notably because the copied price is a performative one and because, typically, mimetic pricing consists in not proposing a higher price than the copied one and implies that the "market" price-maker will be the proposer of the lower price, whoever

and thus remains a *choice* and something quite distinct from the cournotian powerless price-taker whose modelization requires performative autonomous pricing.

The same could be said about the idea that price fixation should be a clearing process, leaving no demand unsatisfied and no supply in stock at the fixed price, where in reality it is not part of anyone's responsibility to set his/her own price to allow for the satisfaction of all demand at a given price, nor acceptable to assume that anyone should be especially concerned about clearance per se and the inflection price in particular.[35] Wondering what could happen in an IDC/OFC model if clearance was to become an exchange issue, for instance if there was frustration or competition among demanders for an available supply and not only transfer of the unsatisfied demand to someone or to something else, may nevertheless be interesting. In such a case, one issue would indeed be to know to who the available supply would be attributed and is solution widely variable: first arrived first served, priority to regular customer, contacting only a subset of interactants to avoid frustrating the others, temporal queuing, delayed delivery, ordering or reservation, redirecting demand to someone else, subcontracting, etc. All of which may take place without any necessity to change the price itself, unless the situation lead to a modification of certain DDCs and hence of the IDC and OFC. As; for instance, if unsatisfied demanders try to avoid being excluded from exchange by accepting higher prices than stated previously, especially if their non-sincere DDC failed, thus changing their DDC (and hence the IDC, the OFC) or finally if they propose to pay a higher price than others to obtain priority, thus creating a dual price system. But once again, because an important dimension of any interaction is that the interactional settings cannot be unilaterally changed[36], and because the choice of a price is made with perfect knowledge of the OFC, adopting a higher price in case of shortage is ruled out by the fact that the shortage was perfectly known before price fixation, and cannot thus be considered as a possible driver of price change. It may thus be said that price per se is not the adjustment parameter, contrary to IDCs, which may adjust to the situation associated with a chosen price. With the consequence that the DDC/IDC/OFC/Optimality sequence in itself as a model of price fixation will not be affected by such variations, which are the simple result of the fact that DDCs are to some extent revisable.

In any case, what we hope to have shown is that performativity and its modelization is not a problem but a solution.

16.5.4 Web adjustment to price decisions

Admitting that the capacity for an individual to fix a price is neither absolute nor inexistent, for being absolute within the OFC and inexistent outside of it, what remains to be described is the way the choice of a price within an OFC may affect other interactions and thus what we propose to call the exchange web.

The most immediate consequence of the fact that a price/quantity pair is chosen is to clarify which commitments will have to be fulfilled and which commitments and provisions are dissolved by this choice,

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he might be.

[35] Under specific but standard assumptions about the shape of the IDC, cost and maximization, it could be shown that the quantity sold at this inflection price being greater than at lower prices, the choice of a price lower than the inflection price could thus be excluded, excluding hence the existence of unsatisfied demand. Higher prices than the inflection price remain possible and cannot be excluded.

[36] Which means in other words that the rule of the game cannot be changed during the game without recrimination.

A second consequence is that this clarification will leave many with no other options than to turn to another offerer or product, thus leading to a modification of some at least of their DDCs.

A last but crucial consequence is that since all exchange imposes a transfer of what we shall call “validation rights” - in other words of the power for the offerer to become a demander and to produce his/her own DDCs - it is also the case that in a closed economy they will keep on being transferred indefinitely.

As a whole, it is thus the case that each individual exchange will modify the premises of at least some of subsequent exchanges, through a pattern of propagation which deserve to be modelized and whose minimal form is an exchange web and the maximal form an exchange system.

16.5.5 From exchange web to exchange system

So far we have assumed that the performative power to make a price true was dependent and constrained ultimately by a set of DDCs measuring the acceptability of a set of price for a set of demanders with validation rights. And shown that any exchange implied a transfer of such validation rights.

What we shall try to explain now in the short space available here will be that to fully understand the performativity of price, it is also necessary to question the often circular pattern of propagation of the validation rights themselves.

The most basic example of interdependencies between DDCs is division of labor with a single standard of consumption, in other words people consuming A and B but producing A or B. What is important for us in such a case is that the propagation of validation rights is forcefully circular, the buying of A by producers of B being the condition for the buying of B by A producers, leading to a situation in which, if hoarding is excluded, whatever is spent by A producers will later on become their income and vice-versa for producers of B. So that in performative terms, the performativity of a price will ultimately be self perpetuating and based on a performativity cycle, allowing for the clarification of the relationship between the micro-economics of performativity and its macro-economic dimension.

With no possibility to address this last issue in any detail, it must be stressed out that an important dimension of performativity appears to emerge from constraints which are invisible in a strictly individual perspective but which are crucial to the understanding of the overall relationships between performative prices.

A major constraint in that respect, which has been central to the explanation of profits, i.e. to the explanation of the capacity of offerers to receive more validation rights than they have initially transferred, the difference being called a profit, is based on a complex chain of transfer of validation rights whose paradoxical starting point is the impossibility for some validation rights to be used for all what is produced, resulting in the concentration of these validation rights on a part P of what is produced, which in turns allow the offerers of P to choose price-quantity pairs whose total value is superior to what they have spent (and thus transferred), leaving them with a difference that they can use to buy non-P products, with the ultimate constraint of a closure of the system by validation of its starting point, which thus appears to be self-perpetuating. The description of what takes place by reversing this sequence is also possible, as is apparent in the claim attributed to Kalecki by Kaldor (1956, p. 96) according to which “capitalists earn what they spent, workers spend what they earn” and in Keynes’s coining of the term Widow's cruse[37], and as can be illustrated by introducing in our A+B economy, a new production C, C being for instance a 50 meters long luxury yacht (or the building of a bridge whose exploitation/use will start only years later[38]) in a situation where the producers of A+B cannot afford buying the luxury yacht. What happens then is that any transfer of validation rights in the production of C will only be usable to buy A or B, forcing through a rise of price the producers of A and B to share the quantities of A and B with the producers of C and allowing the value of these quantities to rise. What is worth understanding in any case is that such eviction effects will translate directly into the existence of additional DDCs associated with the production of C[39], which will contribute to modify the IDC and the OFC of A and B[40] in the direction of increased demand at all prices and an elevation of the point of inflection.

The conclusion of all this is that behind the IDCs and OFCs, important forces are in action which might not be visible as such but which form a crucial background to account for the performative power of fixing the price at a certain level.

When it comes to the modelization of the performative dimension of prices and market interactions, what can be generalized from the Kalecki/Kaldor/Keynes[41] macroeconomic principles is that given that the performativity of prices is directly constrained by effective validation by validation rights detainers and that the role of validation rights is to provide access to what is produced (or sold), it can be shown that whatever affects and restricts access to what is produced will similarly affect and restrict the power of validation rights to provide such an access. Which means ultimately that the role of validation rights in the price fixation process that we have described in the previous section is itself further embedded on eviction mechanisms and practices, A reality which can be illustrated by the fact that in the 18$^{\text{th}}$ century (see Thompson, 1971), the population was well and violently aware of the fact that the power of wages to buy cereals was governed not only by climatic hazards and objective rarity but by the concrete capacity of suppliers to hide cereals or export them away from those who had produced them. At a local level, this reality was indeed undisputable and shows that saying that prices reflect rarity, saying that prices are performative, and saying that eviction is crucial to both are not contradictory claims, once acknowledged the fact that rarity may prove to a large extent to be artificial and that prices are not mere constative utterances describing rareness as a preexisting reality, but performative utterances whose conditions of felicity to some extent are eviction mechanisms and practices and the capacity to create alone the rarity which they could seem to describe. The temporary conclusion of all this being that the study and modelization of the performativity of prices could well allow to associate in a single model of price fixation, the modelization of micro-micro-economic interactions, and the modelization of macro-economic interdependencies, shedding considerable light on the macroeconomic dimension of

[37] John Maynard Keynes (1930, p. 139) argued that profits forcefully emerged with increases in investment and increases in consumption out of profits, stating that "*however much of their profits entrepreneurs spend on consumption, the increment of wealth belonging to entrepreneurs remains the same as before. Thus profits, as a source of capital increment for entrepreneurs, are a widow's cruse which remains undepleted however much of them may be devoted to riotous living*".

[38] Access eviction is a polymorphous phenomenon, which can be the result among other things of: i) the production of something which will never be sold (and financed through taxation for instance); ii) the production of something which will take years to be amortized; iii) he production of luxury goods; iv) he mere reservation of a part of ordinary production; v) the power to create money.

[39] Notably wages.

[40] We may assume here that if all producers of A (and B) were in a situation of perfect competition, the IDC of each of them would be identical.

[41] For more recent modelization of circuit transfers, see Schmitt (1966, 1996)

micro-economic interactions, and vice-versa.

16.6 Conclusions

Our starting point was that because attention is scarce, because interactions consequently are limited, because information can only emerge in interactions and has to be relevant, and because prices are performative utterances which can become realities only insofar as they are accepted, any model of market interactions which assumes or axiomatizes the opposite claims cannot but fail to be a model of market interactions, for it will overlook their inherent complexity and will have to postulate, under the name of perfect information, an informational chaos.

What we have then started to demonstrate is that accepting all this parameters as realities, far from turning the modelization of market interactions into an impossible task, provide a reference frame in which its complexity and variability can be expressed. Notably by admitting that price theory should start with accounting for the performative capacity of individual to set their own prices, and with describing the fact that such a capacity is primarily constrained by the curve of reaction (IDC) of the other interactants, and then by the merging of this curve with one's own knowledge of the cost and capacity constraints to form a decision curve (OFC) which serves as the informational basis for individual price fixation. Thus showing that modelization of autonomous agents may comes at no price need in terms of capacity to account for interdependencies.

We have finally shown that performativity of prices may also reflect or create eviction mechanisms, and more generally that its study and modelization cannot ultimately be separated from the study of validation rights, both in terms of the capacity for the transfer of validation rights, which is inherent to any exchange, to form circuits and thus to become the condition of their own existence, and in terms of the performative nature of the validation rights themselves, notably of money itself.

Ultimately however, what is worth considering is not only that the modelization of autonomous performative prices under a constraint of scarcity of attention and sequentiality is possible and insightful, but that the difference between this modelization and models which postulate the centralized and simultaneous fixation of constative prices under no constraint of attention nor relevance can be shown to be reducible to the way the same fundamental constraints are distinctly ordered, with macroeconomic constraints being upstream of microeconomic ones in the second model and considered as negligible (or "overlookable") in the first one, and with the maximization constraint being a downstream constraint in the second model and an intermediate one (i.e. a premise) in the first one. In this respect, we hope to have shown that making realistic hypothesis about the nature and complexity of interactions could be the only way to understand and modelize the way they interfere.

Bibliography

Austin JL. 1962, *How to do things with Words: The William James Lectures delivered at Harvard University in 1955*, Oxford: Ed. Urmson.

Cadiot P., F. Nemo 1997, Propriétés extrinsèques en sémantique lexicale, *Journal of French Language Studies*, 7, 1-19.

Cournot AA.1838. *Recherches sur les principes mathématiques de la théorie des richesses*, Hachette, Paris.

De Vroey M. 1999a, Equilibrium and disequilibrium in economic theory. A confrontation of the classical, Marshallian and Walras–Hicksian conceptions, *Economics and Philosophy* , 15, 161-185.

De Vroey M. 1999b, The Marshallian market and the Walrasian economy.Two incompatible bedfellows, *The Scottish Journal of Political Economy*, 46, 319-338.

Friedman M. 1949. The Marshallian demand curve, *The Journal of Political Economy* , 57(6), 463-495.

Higgins M. 2013. In a Seller's Market, Every Minute Counts, *New-York Times. May 31*

Ingrao B., I. Giorgio 1990 *The Invisible Hand. Economic Equilibrium and the History of Science*, MIT, Cambridge (Mass).

Kaldor N.,1956, Alternatives Theories of Distribution, *The Review of Economic Studies*, 23, 94-100.

Kalecki N. 1954,The determinants of profits". In *Selected Essays on the Dynamics of the Capitalist Economy. 1933-1970*, Cambridge University Press, Cambridge, 78-92.

Marshall A.,1961, *Principles of Economics*, Ninth (Variorum) Edition, Volumes I and II. Text. London: Macmillan and Co.

Mirowski P. 1989, *More Heat Than Light: Economics as Social Physics, Physics as Nature's Economics*, Cambridge University Press, Cambridge.

Nemo F. 1994, Énoncés marchands - Où il est montré que les prix ne sont pas ce que l'on croit, *Revue du MAUSS*, 3, 182-193.

Nemo F. 1995, Une alternative à la loi de l'offre et de la demande, *Revue du MAUSS*, 6, 166-176.

Nemo F. 1999, The Pragmatics of Signs, The Semantics of Relevance, and The Semantic/Pragmatic Interface, in :*The Semantics-Pragmatics Interface from Different points of View* , CRiSPI Series, Amsterdam, Elsevier Science, 343-417.

Schmitt B., 1966, *A New Paradigm for the Determination of Money Prices* , Presses Universitaires de France, Paris.

Schmitt B., 1996, A New Paradigm for the Determination of Money Prices in G. Deleplace and E. J. Nell (eds), *Money in Motion*, Macmillan and St. Martin's Press.

Todorov,T. 1995, *La vie commune : essai d'anthropologie générale*. Paris: Seuil. Translated in 2001. *Life in Common: An Essay in General Anthropology* University of Nebraska Press.

Tomasello M. 2008, *Origins of Human Communication*, MIT Press, Cambridge (Mass).

Chapter 17

Kinetic collisionnal models and interacting agents in complex socio-economic systems

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Abstract

In this paper, we present a simplified model of micro-economy that describes the evolution of the wealth distribution in a population. The trades between economical agents consist of binary exchanges and stochastic speculation. We explain that the mathematical analysis using kinetic models allows to prove that, for large wealth, the probability distribution function behaves as a power law as observed by Pareto.

Keywords. Econophysics, Boltzmann equation, wealth distributions, Pareto distribution.

17.1 Introduction

The emergence of collective phenomena and self-organization in systems composed of huge number of agents receives an increasing interest from various research communities in economy, sociology, biology, ecology, robotics. This has been illustrated by several lectures during the ISC conference in June 2013 in Orléans, in particular plenary ones by H. Beresticky "Propagation in inhomogeneous media : from epidemics to contagion of the ideas", K. Fischer "Complex processes in human-robot interaction", S. Galam "Interacting with a few random liars can jeopardize the democratic balance of a public debate", E. Goles "Regulatory and segregation networks" and A. Kirman "Ants and Non-Optimal Self Organization: Lessons for Macroeconomics". Let us mention the recent and complete book by L. Pareschi and G. Toscani that describes in details the mathematical tools and the numerical methods that can be used like multi-agent or Monte Carlo methods Pareschi and Toscani (2013).

These so called multiagent systems can be studied using methods which originate in statistical physics. The first attempts made in this direction date back twenty years ago, when the term econophysics was introduced to describe an interdisciplinary research field Bouchaud and Mézard (2000), Mantegna and Stanley (2000) which aims to solve problems in economics by means of well-established physical methods. The main idea is that the description of emerging phenomena could be obtained by assuming that the collective behaviours of a group composed of a sufficiently large number of individuals could be treated using the laws of statistical mechanics as happens in a physical system composed of many interacting particles. Let us mention that statistical physics study has been also used recently for sociological models, like for example, model of opinion formation Boudin and Salvarani (2009), Boudin et al. (2012) for which the asymptotics is called the "quasi-invariant opinion" limit. Let us refer to the recent book by Galam (2012) for an interesting and personal presentation of the use of physical originated approaches for sociological issues, that starts more than thirty years ago.

These methods permit to build complex systems composed of autonomous agents who, as a result of their mutual interactions, exhibit a well-defined collective behaviour. The mathematical analysis of the collisional kinetic theory has been a very active field within the last twenty years. Let us refer to the complete survey written by Villani (2002).

In this article, we will briefly present an example of such a methodology applied to a simplified model of interacting economical agents introduced in Cordier et al. (2005). It starts from microscopic models of simple market economies that describe the interaction between couple of individuals and the goal is to extract from this microscopic model information about the averaged wealth distribution.

The study of wealth distributions has a long history going back to the Italian sociologist and economist Vilfredo Pareto which studied the distribution of income among people of different western countries and found an inverse power law Pareto (1897). More precisely if $f(w)$ is the probability density function of agents with wealth w we have

$$F(w) = \int_w^\infty f(w_*)\, dw_* \sim w^{-\mu},$$

this equation means that the part, $F(w)$ of the population with an income w_* larger than w decays, for large value of w, like some power of w. Pareto mistakenly believed that such power laws behavior of the apply to the whole distribution with an universal exponent μ approximatively equal to 1.5. Later, Mandelbrot (1960) proposed a weak Pareto law that applies only to high incomes.

The starting point of the present modelling is to describe the so-called microscopic model i.e. the process of trading between a couple of agents. Then, we describe the evolution of the associated probability distribution function (pdf) which is described by a Boltzmann type collision operator. In other word, the exchange of money during a trade is represented in the model like the change of momentum during a collision between particle. Then, the idea is to perform an asymptotic analysis in the limit of large number of small exchanges. This leads to a partial differential equations (PDE) for which we are able to find the large time behavior and to describe the stationary or equilibrium solutions. This equilibrium state can be computed explicitly and is of Pareto type, namely it is characterized by a power-law tail for the richest individuals.

This asymptotic limit hereafter called “continuous trading limit” has been inspired from the one used in the context of kinetic theory for granular flows, where the limit procedure is known as “quasi-elastic” asymptotics Toscani (2000). It is also connected to the so called “grazing collision” limit that permits to pass from the Boltzmann equation for Coulombian particle to Fokker-Planck-Landau equations (see Villani 2002).

17.2 A kinetic model of money asset exchanges

We consider now a very simple model of an open market economy involving both assets exchanges between individuals and speculative trading, following Cordier et al. (2005). In this non-stationary economy the total wealth is not conserved due to a stochastic dynamics which describes the spontaneous growth or decrease of wealth due to investments e.g. in the stock market. It is important to note that this mechanism corresponds to the effects of an open market economy where the investments cause the total economy to growth (more precisely the rich would get richer and the poor would get poorer). The exchanges dynamic between individuals redistributes the wealth among people.

Thus, from a microscopic view point, the binary interaction is described by the following rules

$$\begin{aligned} w' &= (1-\gamma)w + \gamma w_* + \eta w \\ w'_* &= (1-\gamma)w_* + \gamma w + \eta_* w_* \end{aligned} \tag{17.1}$$

where (w, w_*) denote the (positive) money of two arbitrary individuals before the trade and (w', w'_*) the money after the trade. In (17.2) we will not allow agents to have debts, and thus the interaction takes place only if $w' \geq 0$ and $w'_* \geq 0$. In (17.2) the transaction coefficient $\gamma \in [0, 1]$ is a given constant, while η and η_* are random variables with the same distribution (for example normal) with variance σ^2 and zero mean.

Let us describe the three terms in the right hand side. The first term is related to the marginal saving propensity of the agents, the second corresponds to the money transaction, and the last contains the effects of an open economy describing the market returns. Note that since debts are not allowed, the total amount of money in the system is increasing.

This binary interaction model is related to previous work (Bouchaud and Mézard 2000, Levy et al. 2000). In a closed economical system it is assumed that the total amount of money is conserved ($\eta, \eta_* \equiv 0$). This conservation law is reminiscent of analogous conservations which take place in kinetic theory. In such a situation, the stationary state is a Dirac measure centered in the average wealth. Thus all agents will end up in the market with exactly the same amount of money.

The kinetic model associated with this simple market economies describes the evolution of the statistical distribution of money by means of these *microscopic* interactions among agents or individuals which perform exchange of money. Each trade can indeed be interpreted as an interaction where a fraction of the money changes hands. We will assume that this wealth after the interaction is non negative, which corresponds to impose that no debts are allowed. This rule emphasizes the difference between economic interactions, where not all outcomes are permitted, and the classical interactions between molecules.

Let $f(w, t)$ denote the distribution of money $w \in I\!R_+$ at time $t \geq 0$. By standard methods of kinetic theory (Villani 2002), the time evolution of f is driven by the following integro-differential equation of Boltzmann type,

$$\frac{\partial f(w)}{\partial t} = \int \left(\beta_{('w,'w_*)\to(w,w_*)} J f('w)(f('w_*) - \beta_{(w,w_*)\to(w',w'_*)} f(w) f(w_*)\right) dw_*\, d\eta\, d\eta_* \tag{17.2}$$

where $('w,' w_*)$ are the pre-trading money that generates the couple (w, w_*) after the interaction. In (17.2) J is jacobian of the transformation of (w, w_*) into (w', w'_*), which is a usual technical term and the kernel β is related to the details of the binary interaction and represents the probability to change from pre-trading state to the actual one. As usual in kinetic theory, we note $f(w)$ instead of $f(w, t)$ to simplify the notations. Let us refer to Cordier et al. (2005), Pareschi and Toscani (2013) for a more detailed presentation.

We shall restrict here to a transition rate of the form

$$\beta_{(w,w_*)\to(w',w'_*)} = \mu(\eta)\mu(\eta_*)\Psi(w' \geq 0)\Psi(w'_* \geq 0),$$

where $\Psi(A)$ is the indicator function of the set A, and $\mu(\cdot)$ is a symmetric probability density with zero mean and variance σ^2. The rate function $\beta_{(w',w'_*)\to(w,w_*)}$ characterizes the effects of the open economy through the distribution of the random variables η and η_* and takes into account the hypothesis that no-debts are allowed. We refer to Cordier et al. (2005) for a detailed interpretation of the chosen form for β. The above equation can be included in a more general settings where the trade rule has a more complex structure including, for example, risk, taxes and subsidies (Pareschi and Toscani 2013).

We remark that, for general probability density $\mu(\cdot)$, the rate function β depends on the wealth variables (w, w_*) through the indicator functions Ψ. This is analogous to what happens in the classical Boltzmann equation Villani (2002), where the rate function depends on the relative velocity. A simplified situation occurs when the random variables take values on the set $(-(1-\gamma), 1-\gamma)$. In this case in fact, both $w' \geq 0$ and $w'_* \geq 0$, and the kernel β does not depend on the wealth variables (w, w_*). In this case the kinetic equation (17.2) is the corresponding of the classical Boltzmann equation for Maxwell molecules, which presents several mathematical simplifications. In all cases however, methods borrowed from kinetic theory of rarefied gas can be used to study the evolution of the function f.

17.3 The continuous trading limit

As explained in the introduction, we are interested in the repartition of wealth due to a large number of such interactions or, equivalentlty, the large time behaviour of the equation i.e. the associated stationary states.

It is proven in Cordier et al. (2005) that the kinetic model (17.2) is well posed. However, it is not possible to explicitly describe the equilibrium or stationnary solution of this equation. As is usual in kinetic theory and explained in the introduction, particular asymptotics of the equation result in simplified models (generally of Fokker-Planck type), for which it is possible to find steady states.

We will consider the situation in which most of the trades corresponds to a very small exchange of money ($\gamma \to 0$), rescaling the time scale accordingly ($\tau = \gamma t$) such that both $\gamma \to 0$ and $\sigma \to 0$ in such a way that $\sigma^2/\gamma \to \lambda$.

As proved in Cordier et al. (2005), the scaled density $g(v, \tau) = f(v, t)$ obeys a Fokker-Planck model derived from the Boltzmann equation, introducing a Taylor expansion in the weak formulation, ϕ being a test function with bounded moments

$$\frac{d}{d\tau}\int_0^\infty g\phi\, dw = \\ \frac{1}{\gamma}\int_{I\!R^2}\int_{I\!R^2_+} \mu(\eta)\mu(\eta_*)g(w)g(w_*)(\phi(w') - \phi(w))dw_* dw d\eta\, d\eta_*. \quad (17.3)$$

This derivation is similar to the quasi-elastic limit of granular gases of Toscani (2000) and is of major relevance for the study of the asymptotic equilibrium states of the kinetic model. The right-hand side is nothing but the weak form of the Fokker-Planck equation

$$\frac{\partial g}{\partial \tau} = \frac{\lambda}{2}\frac{\partial^2}{\partial w^2}\left(w^2 g\right) + \frac{\partial}{\partial w}\left((w-m)g\right). \quad (17.4)$$

The limit Fokker-Planck equation can be rewritten as

$$\frac{\partial g}{\partial \tau} = \frac{\partial}{\partial w}[(w-m) + \frac{\lambda}{2}w)g + \frac{\lambda}{2}w\frac{\partial}{\partial w}(wg)]. \quad (17.5)$$

The stationary state of the Fokker-Planck equation can be directly computed and, by assuming for simplicity

$$m = \int_{\mathbb{R}_+} f(w,t)\, dw = 1,$$

it can be written as

$$g_\infty(w) = \frac{(\mu-1)^\mu}{\Gamma(\mu)} \frac{\exp\left(-\frac{\mu-1}{w}\right)}{w^{1+\mu}} \tag{17.6}$$

where $\mu = 1 + \frac{2}{\lambda} > 1$. Therefore the stationary distribution exhibits a Pareto power law tail for large w's as observed by Pareto (1897) on real economical data as an "universal" behavior" . Thus, the proposed model agrees with this observed repartition of weath for richest individuals.

17.4 Conclusions

Note that the numerical simulations of a Boltzmann equation (17.2) to compute its steady state are usually based on Monte Carlo methods as explained in Pareschi and Toscani (2013). Note that such Monte Carlo methods rely on the underlying microscopic process (17.2). Some numerical test are presented in Cordier et al. (2005) that illustrated numerically the "continuous trading asymptotics".

This simple market economy model, based on binary exchanges of money and speculative trading becomes at suitably large times, in presence of a large number of trades in which agents exchange a small amount of money, a linear Fokker-Planck type equation, which admits a stationary steady state with Pareto tails. The analogy between the trade rule (17.2) and a one-dimensional molecular dissipative collision suggests in a natural way the continuous trading asymptotic which is well-understood in kinetic theory as quasi-elastic asymptotic (Toscani 2000). Furthermore, the formation of overpopulated energy tails for large times in the kinetic model is in accord with the analogous result valid for the Boltzmann equation for a dissipative granular Maxwellian gas.

Let us mention another model where interactions between individuals is replaced by exchange through a financial market where a finite number of assets are available (Cordier et al. 2009). In this case, the similar asymptotic approachs yields to a log-normal distribution behovior for large wealth.

This short note presents a very particular case of complex system - a population of agents that interacts by trades - that is given to illustrate how the mathematical framework of collisionnal kinetic theory (see Villani 2002) can be useful to understand and predict the formation of equilibria. We refer to Pareschi and Toscani (2013) for a recent book on related topics with numerous other applications.

Bibliography

Bouchaud J.P., M. Mézard, 2000, Wealth condensation in a simple model of economy, *Physica A*, 282, 536-545.

Boudin L., A. Mercier, F. Salvarani, 2012, Conciliatory and contradictory dynamics in opinion formation, *Phys. A*, 391, 5672-5684.

Boudin L., F. Salvarani, 2009, A kinetic approach to the study of opinion formation, *M2AN Math. Model. Numer. Anal.* 43(3), 507-522.

Cordier S., L. Pareschi, C. Piatecki, 2009, Mesoscopic modelling of financial markets, *Journal Statistical Physics*,134(1), 161-184.

Cordier S., L. Pareschi, G. Toscani, 2005, On a Kinetic Model for a Simple Market Economy, *Journal of Statistical Physics*, Vol. 120, N 1-2, p.253 - 277.

Galam S., 2012, *Sociophysics : A Physicist's Modeling of Psycho-political Phenomena*, Series: Understanding Complex Systems, XXIII.

Levy H., M. Levy, S. Solomon, 2000,*Microscopic simulations of financial markets*, Academic Press, New York.

Mandelbrot B., 1960, The Pareto-Lévy law and the distribution of income, *International Economic Review* ,**1**, 79-106.

Mantegna R.N., H.E. Stanley, 2000, *An introduction to econophysics*, Cambridge University Press, Cambridge.

Pareschi L., G. Toscani G., 2013, *Interacting Multiagent Systems: Kinetic equations and Monte Carlo methods*, Oxford press.

Pareto V., 1897, *Cours d'Economie Politique*, Lausanne and Paris.

Toscani G., 2000, One-dimensional kinetic models of granular flows, *RAIRO Modél Math. Anal. Numér.* 34, 1277-1292.

Villani C., 2002, *A review of mathematical topics in collisional kinetic theory*, in Handbook of Mathematical Fluid Dynamics, S. Friedlander and D. Serre, Eds, Elsevier Science.

Chapter 18

Study choices in an evolutionary game

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Abstract

Since Becker's (1964) contribution, the accumulation of human capital has been developed only within the framework of individual choices based upon wage expectations. For over forty years, this approach showed itself fruitful. However, with the rarefaction of jobs during periods of crisis, it seems light to explain most of the decisions regarding human capital accumulation. Indeed, because nobody can be sure to obtain an employment which will yield a positive return to education, the decision to acquire further education can only be apprehended as a strategic decision taken in a situation of imperfect information. This individual decision will depend on the answer to the following simple question: *With the level of studies which I intend to acquire, will I have bigger chances to obtain a job than my classmates who stopped their studies at a lower level?* It's the reason why we model studies' length as a two strategies evolutionary game to show under which condition the population of players splits in two class of strategies in equilibrium.
Keywords: Labor Economics, Evolutionary Game Theory, Strategic Interactions

18.1 Introduction

In economics, many topics should be considered from the complexity point of view.

First of all, while it took approximately four hundred years to establish a utility theory from the early works by Edme Mariotte[2] — see Mariotte (1717) —, thirty years were sufficient to make the building vacillate on its basis.

Among other sciences, Behavioral Psychology and Neurosciences question the very existence of a utility function derived from preferences and used to construct practical decisions. The assumption that human behavior can generate rational decisions[3] has been denied by new experimental evidences from the recent access to the brain through magnetic resonance imaging (MRI) and molecular biology. Thanks to the MRI, it is now proven that decisions can not be taken without reference to emotions and that we are sensitive to chemical substances which alter profoundly our behavior and decisions — see Damásio (1994), Lehrer (2009).

[2]Mariotte is the second name to appear in the appendix of Jevons (1871) dedicated to mathematico-economic books, memoir, and other published writings.

[3]This assumption originated from the great greek philosophers (essentially Aristote), followed by Daniel Bernoulli, Emmanuel Kant (for the moral point of view), Jeremy Bentham, Stanley Jevons and Von Neumann, among many others

At the same time, with the emergence of a new type of society where information is huge and plethoric, we have begun to understand that the brain is, in some aspect, a wired electrical network with limited transmission speed[4] and limited capacity to treat information[5]. Furthermore, since Poincaré, but more effectively since Edward Lorenz, we know that linearity, through which we believe to understand the most essential structure of our universe, is misleading and that a very small departure from it can produce some processes that are truly indistinguishable from randomness — Poincaré (1890), Lorenz (1964) and also Devaney (2003).

At last, we begin to understand that strategic interactions, which are mainly described in the setting of standard game theory may not bee understood from rationality itself.

Nevertheless, despite all these new evidences, many analysts are globally satisfied with their inherited instrument and are not yet ready to change paradigm. For instance, the core of the modelling of economic markets has not been fundamentally changed in thirty years.

For instance, let us have a look at labor economics. Since the development of the *Human Capital Theory* — Schultz (1961), Becker (1964) —, economists have concentrated their attention essentially on the main advantage that the education confers to individuals: an increase in their income.

The mechanics highlighted under this original human capital theory allowed, in a standard neo-classic framework, to propose an alternative explanation to the theory of *compensatory differences,* that was first advanced by Adam Smith and in which individuals were considered as indistinguishable.

Two research areas have caught the attention and the energy of economists. On the one hand, following Mincer's works — see Mincer (1974) —, an effort has been made to estimate empirically education returns through some earning functions. That approach enables to estimate a return curve for each educational level and to make international comparisons. On the other hand, more recently, human capital has been introduced in models of endogenous growth.

Following Lucas (1988), macroeconomists have favored the stock of human capital over technology to explain growth, and the differences of rates in its accumulation to explain the persistence of international differences in growth rates. In particular, because of the externalities generated by its human capital, for a given qualification's level, a worker is more productive in a country already strongly endowed with human capital. Therefore, he is better paid. This mechanism could explain the strong migratory pressures of the South towards the North.

Without questioning the legitimacy of the Beckerian individualistic approach of human capital accumulation, it seems, nevertheless, important to reinterpret the contemporary logics of its accumulation in the context of jobs competition. In the Beckerian

[4]Here, we can plead for the limited capacity channel in Shannon-Hartley theorem on the maximum rate at which information can be transmitted over a communication channel of a specified bandwidth in the presence of noise — see Pierce (1980). But we can also plead for the problem of the acquisition of the expert performance as in Ericsson et al. (1993) or Shim et al. (2005).

[5] According to Marois & Ivanoff (2005), despite the impressive complexity and processing power of the human brain, it is severely capacity limited. There are many way to approach this fact but an interesting one is linked to the magical number seven± 2 — see Miller (1956) — which has been recently replaced by the number 4 — see Parker (2012). The problem is to know how many element can be hired in the human memory. We must underline that the working memory is one of the central concepts of the current cognitive psychology. As the place of holding the information necessary for ongoing treatment, the limits of working memory constrain a large part of our thinking activity and the evolution of these boundaries with age plays a vital role in the intellectual development — see Barrouillet & Camos (2008).

logic, the rise of the level of education appears as a real solution against unemployment, from the individual point of view, because the level of education is positively correlated with the speed of transition towards employment. This transition advantage is also assumed by the *filter theory* developed by Arrow (1973) and the signal theory developed by Spence (1974).

Other things being equal, considering a homogeneous population, this transition advantage given by education is expected to motivate all individuals to apply for further education and training. Hence, the ultimate consequence of this dynamic process is the deletion of the number of non-graduates.

In practice, we observe a conflicting logic which substitutes itself to the Beckerian individualistic approach as soon as such a situation is reached or, at least, as soon as a critical threshold of graduates is exceeded. Indeed, the diploma competitive advantage tends to disappear with an increase in the number of its graduates. Outside a conflicting approach of the human capital accumulation, we can only predict a desertion of the educational sphere: education does not generate any more a return on investment which can be evaluated in comparison to an investment in stocks.

However, from the empirical point of view, it is rare to observe parents preferring to donate the cost of their education to their children in the form of a financial endowment because its seems to them higher and less risky than that of the studies that their children undertake. Indeed, in spite of its depreciation, human capital can become the entry key to active life. So, on the contrary to the predictions of the Beckerian model, the model of the conflicting logic seems to predict a wild race towards the accumulation, the non-accumulation appearing as an almost insuperable handicap.

However, if a model which rests on a conflicting logic ends in an extreme distribution — either every player graduates or nobody graduates —, it must be rejected as empirically not relevant because, as far as one can observe, in populations where the individual characteristics are distinguished with difficulty, the coexistence of the two logics of accumulation of human capital — *i.e.*: the maximalist logic of the acquisition of the highest diploma and the minimalist logic of the acquisition of the lowest diploma.

This paper proposes to examine the evolution of the graduate population within the framework of the theory of evolutionary games. For every generation, for a given unemployment rate, the percentage of graduates is predetermined by their expected remuneration relative to the previous generation. The graduates, in a context where the diploma gives essentially a priority access to jobs, are all the stronger as there are few qualified people. Consequently and *a priori*, we should expect that the global educational level does not stop to grow excluding the possibility of a mixed balance, that is a balance of population in which coexists both categories of agents. However, when the trained population is numerous, the high training costs decrease the relative advantage conferred by the studies and can incite to disinvest in education.

The problem hereby underlined is a real problem that all developed countries seem to encounter. For instance, in France, for the year 2000, it has been revealed that one third of the youth undergo a downgrading. Even if the apex of the phenomena has been observed between 1986 and 1995 for the graduates at the Baccalauréat (High School exit examination) level, and between 2001 and 2004, at the BAC+2 level (two-year post-secondary or tertiary level degree), due to the overall decrease in employment, even the higher-level graduates got heavily impacted. The chances for a newly graduate to get a position as an executive fell from 85% to 70%. Only 26% of the youth have a perfectly matched job according to their formation, in level and in speciality. At the same time, we still observe that the higher the level of the diploma, the higher the smoother the transition towards the first job — see Mazari & Recotillet (2013).

In the first section, we consider the static evolutionary game and its dynamics when the matching of the young job-seekers is realized pairwise. The second section considers explicitly the effect of the unemployment growth on the population dynamics. The third section studies the formation of the long-term balances when irrational mutations appear. The fourth and last section is devoted to the commandability of the education system[6].

18.2 Pair matching dynamics

Here we study more particularly a game in which the players have two strategies:

① undertake short studies — strategy (**S**)[7];

② undertake long studies — strategy (**L**);

At first, we are interested in two players that compete for a job, both of them assigning to it a common present value V. The agent having adopted the **L** strategy will be given priority access to the job compared to the agent having adopted the **S** strategy. This preference for the most qualified refers to the human capital theory — under its shape filter or under its shape signal. Because our focus is on the advantage conferred by education, we suppose that the level of the remuneration V is independent from the educational level.

Labor markets are segmented and it is notable that the multiplication of the graduates at every level of study entailed a toughening of the dualism — for a definition of the dualism, we can consult[8], for example, Taubman & Wachter (1986). Young people that are excluded from markets, which access conditions correspond exactly to their diplomas, are thus brought to look for an outlet on a market for which they are overqualified. This downgrading search creates an additional bottleneck for their companions who had acquired the diploma required to enter on the secondary market.

We can unwind this reasoning up to the markets which require no specific training and which are, in turn, assailed by young graduates. This logic leads to a more or less important eviction of the non-graduates of the labor market[9]. Naturally, later in their active life, some individuals will manage to return to their desired market, but they will certainly represent an exception to the rule of the strict dualism. So, on an isolated market, we can expect to observe applications emanating from young graduates possessing the minimum level of required diplomas — see Figure 18.1.

A rather reliable indicator of these observations would be established by the ratio between the level of education of the candidates at public service job competitions and

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[6]See the survey published by the CÉREQ at http://www.cereq.fr/gsenew/concours2008/cereq/G98ind/premierepage.htm.

[7]On the sociological motivation of the short studies and its evolution in time see — Jaoul-Grammare & Nakhili (2010).

[8]Nevertheless, one can follow Piore (1978). According this theory, the labor market is divided in two sector : a *primary* which give right to better paying, promotion, more stables opportunities and a *secondary* which contains the poor paying unsecure and otherwise unattractive jobs.

[9]It is not in our objective to explain why the non-qualified market can not be itself balanced, while we describe a balancing process by downgrading rejection of populations towards the least qualified jobs, and while the existence of an involuntary unemployment is a necessary condition for the justification of the model.

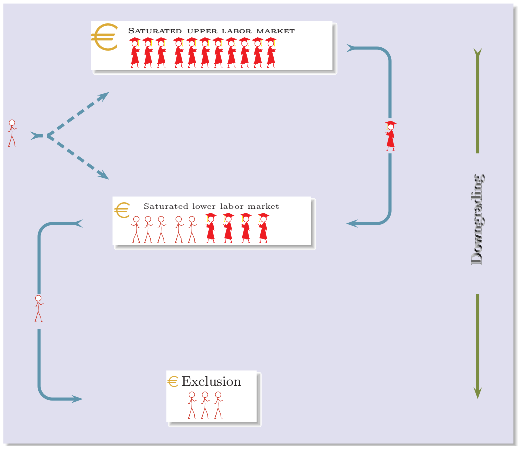

Figure 18.1: The graduates' downgrading process

the education level required by the examination[10]. We observe that a large share of the candidates have a must higher level of education and qualification than required by the examination. As a consequence, these overqualified candidates systematically evict the least endowed without benefiting of a more generous salary scale. On the other hand, on the analytical point of view, we can imagine that the status of the labor market is such that companies are in a position to monopolize a rent or to make sure of the honesty of their employees. This point was developed in particular by Shapiro & Stiglitz (1984). Returning to the model, let us assume that initially all players were used to short studies. As, *ex ante*, none of the players is able of determining the stemming from the overcoming conflict, by adopting Laplace's insufficient reason principle, it is possible to suppose that they anticipate to each have a 1/2 probability to monopolize the desired job. The couple of payoffs in a conflict between two individuals having adopted the short strategy is thus: $(0.5V, 0.5V)$.

Let us suppose that after a punctual mutation[11], a fraction $1-\epsilon$ of the population decides to opt for a new strategy consisting of a cycle of longer studies. These players can be perceived as predators by all those players who have decided not to change strategy. Indeed, we suppose that it is of common knowledge that, if a long player is accidentally mated to a short player, the first one will obtain the employment and will be paid[12] V, while the second will have to pursue its job search. However, we suppose that, compared to strategy **S** (short studies), the long studies yield a fixed additional cost C. The couple of payoffs bound to such a confrontation is then: $(V-C, 0)$.

Obviously, a mutant can be mated with an other mutant. As previously, in this case, they will obtain the couple of remuneration $(0,5(V-C); 0,5(V-C))$. Presented under normal form, the bi-matrix of the payoffs, associated with this game, can then

[10]It's not a red herring to say that in the French public function examination, a huge part of the candidates are overqualified — see Kopel (2005). Obviously, this is not a French exception phenomenon — see Green & Zhu (2010). So, in a first approximation, we can postulate that V is independent from the education level.

[11]The term of mutation, borrowed from the biologist vocabulary, is here excessive. We can imagine that this phenomenon comes upstream from a human capital investment behavior or, more simply from the invasion of the labor market for the non-qualified by individuals stemming from a qualified labor market which has reached saturation, hypothesis which is defended in the body of the text.

[12]We use V because all the monetary values here must be understood as present values since the decision of the studies length is made for the complete life cycle of the players.

been spell as in Figure 18.2.

	S	**L**
S	$\left(\frac{V}{2}, \frac{V}{2}\right)$	$(0, V - C)$
L	$(V - C, 0)$	$\left(\frac{V-C}{2}, \frac{V-C}{2}\right)$

Figure 18.2: Payoff matrix for the game

In what follows, we will postulate that $0 \leq C \leq V \leq 2C$. This hypothesis is as fundamental as natural. First of all, we imagine badly a negative cost. Then, because a cost lower than the present value of the income of the promised job is a necessary and sufficient condition to ensure that some individuals will wish to bear it. And finally, one has to impose that $V \geq 2C$. Indeed, let us suppose the opposite: $V > 2C$. In this case, $(V - C)/C$ which is the *ex post* rate of return of longer studies is lower than the unit. Now, if the return was greater than 100%, there would be no student to not undertake longer studies.

18.2.1 The game as a perfect information game in normal form

Assume first, that each player knows his opponent, that is to say the other player who will apply to the same position as him. In pure strategies, under the hypothesis $V < 2\ C$, there are two Nash-equilibria in this game[13]: $\texttt{PSNE}_1 = (\mathbf{S}, \mathbf{S})$ and $\texttt{PSNE}_2 = (\mathbf{L}, \mathbf{L})$. Both equilibria are symmetric — *i.e.*: both players must choose the same strategy —, which in itself is not so astonishing since the players are indistinguishable. To those pure strategy equilibria, one must add a mixed strategy equilibria. One finally has :

$$\texttt{MSNE}_1 = (0, 0), \quad \texttt{MSNE}_2 = \left(\frac{V - C}{C}, \frac{V - C}{C}\right) \quad \text{et} \quad \texttt{MSNE}_3 = (1, 1)$$

Figure 18.3 gives the three equilibria as intersections of the players' reaction correspondences[14].

In front of the embarrassment induced by the multiplicity of the Nash equilibria, game theorists have developed a number of procedures aiming at extracting a single equilibrium, which will most probably be played by the player[15]. The first seducing approach consists in postulating that the players are going to notice that one of the two pure equilibria is socially more favorable than the other one, in the sense that the

[14] In Figure 18.3, the line player chose a mixed strategy $(p, 1 - p)$ and the column player a strategy $(q, 1 - q)$. Normally, since players must solve two linear programs to find the mixed equilibrium, we would be obliged to use an algorithm of the Lemke-Howson type to find numerically this equilibrium, or any more modern approach, but in the case of two strategies one can easily find the analytical solution — see, for instance, Nisan et al. (2007).

[15] In a finite game, every pure strategy Nash equilibrium is also a mixed strategy Nash equilibrium.

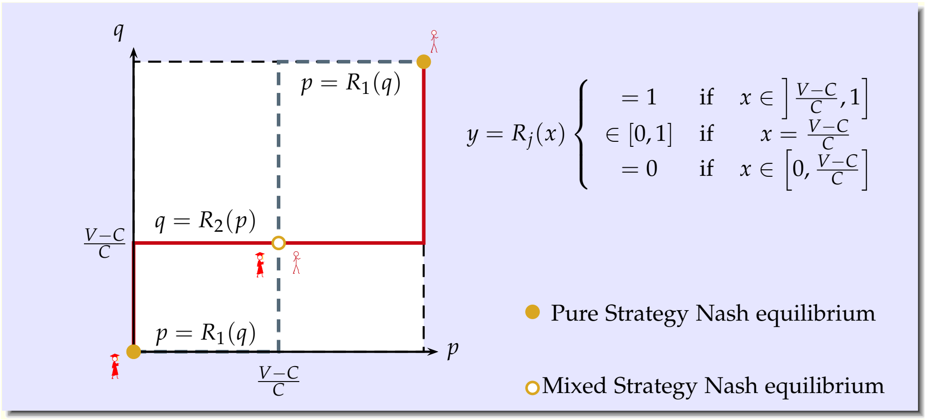

Figure 18.3: The Svastika for Nash equilibria

expected payoff is higher there — here, it is about the (**S**, **S**) which gives a payoff equal to $V/2$ which is greater to the payoff of $(V - C)/2$ associated to thee second pure strategies equilibrium. (**S**, **S**) is called the Pareto-dominant equilibrium.

A standard approach of the selection of the multiple equilibria was proposed by Harsanyi & Selten (1992). This approach to equilibrium selection is known as the *risk dominance*. This approach of equilibrium selection presents the interest of a double interpretation. A player can realize an experiment in which he tries to guess the strategy adopted by the opponent with whom he will be mated — this is a game theory interpretation. He can also, *ex ante*, try to conceive the characteristics of the distribution of the players between both strategies as members of the population to which they belong — this is a sociological interpretation.

Let us begin by replacing us in a frame where only pure strategies could be elected and let us endorse the clothes of one for the two matched players. If he thinks that his opponent will choose the **S** strategy with probability q and the **L** strategy with probability $1 - q$, his expected utility is :

$$\mathbb{E}U_1(s) = \begin{cases} (1-q)\left(\frac{V}{2}\right) & \text{if} \quad s = \mathbf{L} \\ q\left(\frac{V}{2}\right) + \left(\frac{V-C}{2}\right) & \text{if} \quad s = \mathbf{S} \end{cases}$$

The player will prefer to adopt the **S** strategy — the **L** strategy — over the **L** strategy — the **S** strategy —, if :

$$\mathbb{E}U(\mathbf{S}) < (>)\ \mathbb{E}U(\mathbf{L})$$

Writing $\overline{q}$, the q value which makes the player indifferent between both strategies, we find that :

$$\overline{q} = \frac{C}{V + C}$$

Now, the player's choice depends of his mental scheme which drives him to postulate a q specific value. However it's clear that if $1 - \overline{q} \geq q$ — or, more simply, if $\overline{q} \geq 1/2$ —, which is the present case since $C \leq V$, the opponent will take a greater risk in postulating that the player will choose the **S** strategy over the **L** one. As this is a symmetric game, what is valuable for one player is also valuable for the other. So one will say with Harsanyi and Selten that the (**L**, **L**) equilibrium *risk dominate* the (**S**, **S**) equilibrium if $\overline{q} > 1-\overline{q}$, which means that there is a greater likelihood that both players coordinate on the (**L**, **L**) equilibrium than on the (**S**, **S**) one. In this game, according to the *risk dominance concept*, the players should be incited to adopt a coordination over long studies.

18.2.2 The static evolutionary game

The application of traditional game theory to the duration of education raises two problems:

① On the one hand, we cannot consider two isolated players, because the game is played by a very large number of players simultaneously.

② On the other hand, the players have to make decisions without knowing which type of player they will later be mated with — an **S** player or an **L** player. Now, the *ex ante* yield of a strategy depends on the percentage of players which endorse it in the population. In particular, even if there are **S** players in the population, a player can be interested in being an **L** player because the probability to be mated to an **S** player is low and because, by choosing to be an **L** player, he does not have to support the additional cost of the extra time of studies.

We begin by studying the pure strategies game. Let us note[16] ϵ, the percentage of players who use the **S** strategy. In such a way, the expected payoff of a **S** player in a mixed population is :

$$\mathbb{E}U(\mathbf{S}|\mathbf{L}) = \epsilon U(\mathbf{S},\mathbf{S}) + (1-\epsilon)U(\mathbf{S},\mathbf{L}) = \epsilon\left(\frac{V}{2}\right)$$

where $U(\mathbf{X},\mathbf{Y})$ is the utility of a **X** player matched with a **L** player. In the same way, one can write :

$$\begin{aligned}\mathbb{E}U(\mathbf{L}|\mathbf{L}) &= \epsilon U(\mathbf{L},\mathbf{S}) + (1-\epsilon)U(\mathbf{L},\mathbf{L})\\ &= \epsilon(V-C) + \ (1-\epsilon)\left(\frac{V-C}{2}\right) = \left(\frac{1+\epsilon}{2}\right)(V-C)\end{aligned}$$

In the evolutionary game terminology, a strategy **X** is *evolutionary stable* if :

$$U(\mathbf{X},\mathbf{Y}) > U(\mathbf{Y},\mathbf{Y})$$

for every other **Y** strategy. This means that **X** offers a better fit[17] to the game than every other **Y**. Maynard-Smith (1974) has shown that **X** is evolutionary stable[18] if the two following conditions are satisfied :

① *A Strict Nash Equilibrium Condition* : $U(\mathbf{X},\mathbf{X}) > U(\mathbf{Y},\mathbf{X})$.

② *A stability Condition* : if $U(\mathbf{X},\mathbf{X}) = U(\mathbf{X},\mathbf{Y})$ then $U(\mathbf{X},\mathbf{Y}) > U(\mathbf{Y},\mathbf{Y})$.

[16] We must distinguish here p — q —, which are variables relating to personal choice of ϵ that is the percentage in the population of people using the **C** strategy.

[17] In the sense of greater expected utility.

[18] One speaks of an *Evolutionary Stable Strategy* — ESS.

It is obvious that the pure strategies Nash equilibria are *ESS*, which here was predictable as far as the game is symmetric. Consequently, by neglecting the fact that they are immersed in a larger population than that of both matched players, and as far as they manage to coordinate on an equilibrium — for example the risk dominating equilibrium —, the players protect themselves against the invasion of mutant players, who would have adopted the other strategy. Now, in the same way as in the traditional interpretation, what happens if one allows mixed strategies? If one redefines the utilities in terms of mixed strategies, that is:

$$\mathbb{E}U(\boldsymbol{p}|\boldsymbol{q}) = \epsilon \left(\boldsymbol{p}^\top \boldsymbol{U}\boldsymbol{p}\right) + \ (1-\epsilon) \left(\boldsymbol{p}^\top \boldsymbol{U}\boldsymbol{q}\right)$$

where $\boldsymbol{p} = [p, 1-p]^\top$ is the mixed strategy of the first player, $\boldsymbol{q} = [q, 1-q]^\top$ the mixed strategy of the second one and $\boldsymbol{U}$ is defined as earlier. Evaluating in the same way $\mathbb{E}U(\boldsymbol{q}|\boldsymbol{p})$, we can define an *Evolutionary Stable Mixed Strategy — ESMS —* in the same way as for the *ESS*. In that case the Maynard-Smith theorem gives that $\boldsymbol{p}$ is and *ESMS* if two conditions are verified:

① *A Nash Equilibrium Condition* : $\boldsymbol{p}^\top \boldsymbol{U}\boldsymbol{p} > \boldsymbol{q}^\top \boldsymbol{U}\boldsymbol{p}$.

② *A stability Condition* : if $\boldsymbol{p}^\top \boldsymbol{U}\boldsymbol{p} = \boldsymbol{q}^\top \boldsymbol{U}\boldsymbol{p}$ then $\boldsymbol{p}^\top \boldsymbol{U}\boldsymbol{q} > \boldsymbol{q}^\top \boldsymbol{U}\boldsymbol{q}$.

Now, for exactly the same reason as in the pure strategy case, the three Nash equilibria are *ESMS*.

18.2.3 Population dynamics

The direct *ESS*[19] or *ESMS* approach are clearly insufficient. Indeed, unlike the classic theory of antagonistic games, evolutionary game theory does not postulate any form of rationality from the players. Generally, it considers that they inherit their behavior. On the labor market, and in an unstable environment, the only way of making a decision more or less justified, is, from one period to the next, when the information is available, to observe the relative fit of a strategy with regard to an other one. Therefore, on a macroscopic plan, one shall notice an increasing evolution on behalf of the population which adopts the strategy **C** if that strategy gives, on average, a satisfactory payoff in the matching with the upper strategy **L**.

If students can observe that the **C** strategy can offer a greater utility than the average utility associated with a population divided out of $\epsilon(t)$ percent of their own type and $1-\epsilon(t)$ percent of the other, then in all likelihood, $\epsilon(t)$ is going to rise. This leads to a Malthusian population dynamics of the **C** players called *replication dynamics*. This dynamics is describe by the following differential equation[20] :

$$\begin{aligned}\frac{\dot{\epsilon}(t)}{\epsilon(t)} &= \mathbb{E}U(\mathbf{C}) - [\epsilon\mathbb{E}U(\mathbf{C}) + (1-\epsilon(t))\mathbb{E}U(\mathbf{L})] \\ &= \frac{C}{2}(1-\epsilon(t))(\epsilon(t)-\overline{\epsilon})\end{aligned}$$

[19]It is important to distinguish both because the first one is clearly less debated than the second. Numerous economists refuse to consider mixed strategies.

[20]Only a small bunch of studies was interested in the justification of the recourse to the replication dynamics in the economic environment. Nevertheless, we can quote Weibull (1995), who shows how the dynamics of replication can appear as approximation for imitation behavior.

with $0 < \bar{\epsilon} = (V - C)/C < 1$. This dynamics[21] to translate the idea according to which the **C** players' population growth rate is proportional to their relative payoff in a mixed population. Now, the average payoff in a mixed population is defined by the sum of the product between payoffs and probabilities of the realization of a specific matching. This replication dynamics may be also written as :

$$\dot{\epsilon}(t) = \epsilon(t)[1 - \epsilon(t)][\mathbb{E}U(\mathbf{C}) - \mathbb{E}U(\mathbf{L})]$$

which gives also the following interpretation : the increase of the **C** players population is proportionate to the expected utility differential gap between both strategies, conditioned by the emergence of a mixed matching[22].

Define the $h(\epsilon(t))$ function as :

$$h(\epsilon(t)) = \frac{C}{2}\epsilon(t)(1 - \epsilon(t))(\epsilon(t) - \bar{\epsilon})$$

which leads to rewrite the replication dynamics as :

$$\dot{\epsilon}(t) = h(\epsilon(t))$$

The $h(t)$ function possesses three fixed points: $\epsilon_0 = 0$, which is the case for the degenerated population composed exclusively of **L** players; $\epsilon_1 = \bar{\epsilon}$, which corresponds to a mixed population; and $\epsilon_2 = 1$, which is the case for the degenerated population composed exclusively of **C** players. These three fixed points are the three *SMES* . As the derivative of $h(\epsilon)$ is $h_\epsilon(\epsilon) = (C/2)[-3\epsilon^2 + 2(1 + \bar{\epsilon})\epsilon - \bar{\epsilon}]$, it is very easy to show that ϵ_0 and ϵ_1 are locally stable equilibria[23] when ϵ_2 is locally unstable, the **C** strategy is completely evinced in favor of the **L** strategy. From a formal point of view, we can develop a symmetric argumentation[24]. So there are two attraction manifolds for the locally stable equilibria — see Figure 18.4:

① a first attraction manifold $\mathcal{B}_0 = [0, \bar{\epsilon}[$ for ϵ_0.

② a second attraction manifold $\mathcal{B}_1 =]\bar{\epsilon}, 1]$ for ϵ_1.

Thus, according to its initial distribution — $\epsilon(0) \in \mathcal{B}_0$, $\epsilon(0) = \epsilon_0$ or $\epsilon(0) = \epsilon_1$ —, the population converges towards the Pareto-dominant equilibrium — (**S**, **S**) —, remains in the internal equilibrium — if by chance it was yet at this equilibrium —, or converges towards the risk dominant equilibrium — (**L**, **L**).

We can propose a simple explanation for this result. For an initial population such as $\epsilon(0) < \bar{\epsilon}$, the players are matched with numerous players who, on average, have made long studies rather than short. The cost of longer studies is more than compensated by the low probability to be mated with an other long studies player. The expected relative advantage of a strategy over another determines its adoption.

Hence, at the final stage of the dynamics, the **S** strategy is completely evinced in favor of the **L** one. From a formal point of view, one can develop a symmetric argumentation[25] for the case where $\epsilon(0) > \bar{\epsilon}$.

[21]To obtain $\mathbb{E}U(\mathbf{C})$ and $\mathbb{E}U(\mathbf{L})$ one needs only to substitute $\epsilon(t)$ to q — *cf supra*.

[22]It would be possible to generalize the dynamics by the use of an increasing function of the right side of the replication dynamics, but this does not change the qualitative behavior of the dynamics.

[23]If we note $x_j(t) = \epsilon(t) - \epsilon_j$, in the neighborhood of ϵ_j, we get $\dot{x}_j(t) = h_\epsilon(\epsilon_j)x_j$.

[24]Since $h(0) = 0$ and $h_\epsilon(0) < 0$, as $\epsilon_2 \in]0, 1[$, $h_\epsilon(\epsilon_2)$ is, by necessity, positive.

[25]When $\epsilon(0) = \bar{\epsilon}$, the population repartition is temporally invariant.

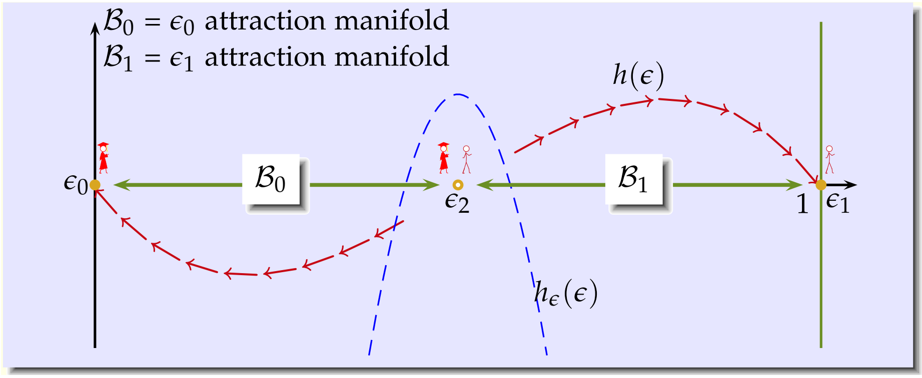

Figure 18.4: THE REPLICATION DYNAMICS

However, this symmetry is only visible. Indeed, if we suppose that, initially, only the short studies existed and that a spontaneous mutation has moved a small percentage of players towards the **L** strategy, it is not very likely, that this percentage makes tip over the initial condition to the attraction manifold of the other *SMES*, i.e. to the long studies attraction manifold.

While the risk dominance argumentation is more convincing than the Pareto-dominance argumentation, in the final equilibrium choice decided by the population of players, it seems that the replication dynamics pleads clearly in favor of the eviction of long studies from the education system. This, unless, it is possible to produce an initial mutation which drives the initial population in the other attraction manifold — *i.e.* : which moves $\epsilon(0)$ over $\bar{\epsilon}$. A classic argument is then to suggest the appearance of behavior determined by a rationality still weakened by the number of agents.

18.2.4 Population dynamics with continuous mutations

As pointed out in Orlean (1995), this dynamics leaves aside an important aspect of the evolutionary logic, namely the constant presence of mutational factors. Indeed, two elements can overlap to explain that the moving decision of a number of players is not directly driven by the relative advantage of a strategy. First of all, there is always a certain percentage of the population which has a very restricted access to information — in the replication dynamics, the access to information is supposed free and without cost for the players. Similarly, a certain percentage of the population is likely to decide to undertake or not to undertake long studies only based on its interest for the studied fields.

Then, the State, for reasons which run from the adequacy of the population to jobs which require an accumulation of human capital always more important for the prolonged, to the young people withdrawal of the labor market in period of underemployment, to make migrate sub-populations having adopted a particular strategy to an other one in a permanent way. So, a second dynamic system is build upon the first one, and this new system does not answer the arguments of the replication dynamics.

This dynamics translates into the fact that, over a lapse of time of length h, a percentage m of the players go from the **L** strategy to the **S** strategy and a percentage l goes from the **S** strategy to the **L** strategy. In $t + h$, the percentage of the population that has adopted the **S** strategy is then determined by the recursive equation:

$$\epsilon(t+h) = \underbrace{[1 - mh\epsilon(t)]}_{\substack{\text{probability not to migrate} \\ \text{for a } \mathbf{C} \text{ player}}} \epsilon(t) + \underbrace{[lh\epsilon(t)]}_{\substack{\text{probability to migrate} \\ \text{for a } \mathbf{L} \text{ player}}} (1 - \epsilon(t))$$

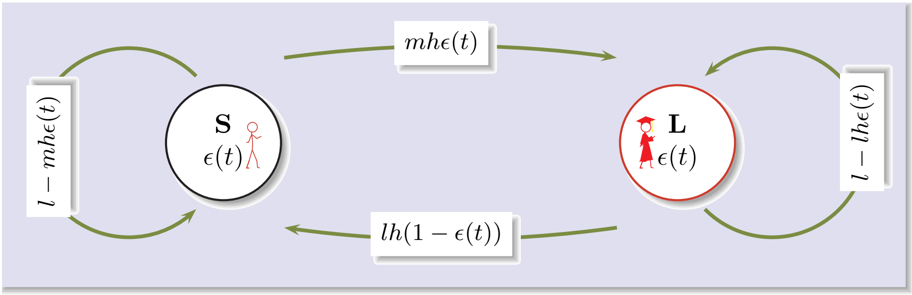

Figure 18.5: The continuous mutations population dynamics

By making h stretch to dt, one finally obtains:

$$\dot{\epsilon}(t) = [l - (m+l)\epsilon(t)]\epsilon(t) = k(\epsilon(t))$$

This dynamics has two fixed points $\epsilon_0 = 0$ and $\epsilon_4 = l/(m+l)$. As $k_\epsilon(\epsilon) = l - 2(m+l)\epsilon$, ϵ_0 is locally unstable, unless $l \equiv 0$, and ϵ_4 is locally stable. $\epsilon_1 = 1$ is no more an equilibrium. It could be under the restriction $m \equiv 0$, in which case $\epsilon_4 = \epsilon_1 = 1$. This has a very simple explanation : if at each period of time some **S** players migrate to become **L** players, it is impossible that the final population-state be fixed in an all **S** players population. This dynamics, which could be called *a rational extreme dynamics*[26], in opposition to the replication dynamics, insists on the central role of an equilibrium where **S** players and **L** players coexist — see Figure 18.6.

Let us consider the general population dynamics corresponding to the juxtaposition of the two types of behavior: *the strategic behavior* and the *pre-determined behavior*. It takes the form :

$$\begin{aligned}
\dot{\epsilon}(t) &= h(\epsilon(t)) + k(\epsilon(t)) \\
&= \left[\frac{C}{2}\epsilon(t)(1-\epsilon(t))(\epsilon(t) - \bar{\epsilon})\right] + ([l - (m+l)\epsilon(t)]\epsilon(t)) \\
&= \epsilon(t)\left(\frac{C}{2}\left[(1+\bar{\epsilon})\epsilon(t) - \bar{\epsilon} + \epsilon^2(t)\right] + [l - (m+l)\epsilon(t)]\right) \\
&= H(\epsilon(t)|m,l) \qquad \texttt{(dm1)}
\end{aligned}$$

Here the mutations remind a *trembling hand process* — see Orlean (1995). They constitute a permanent and autonomous source of variability inside the labor market system.

[26]This type of dynamics is not derived from the rationality of learning as in the evolutionary game and its associated replication dynamics. Nothing forbids the agents to base this type of behavior on another logic, even a logic of maximization.

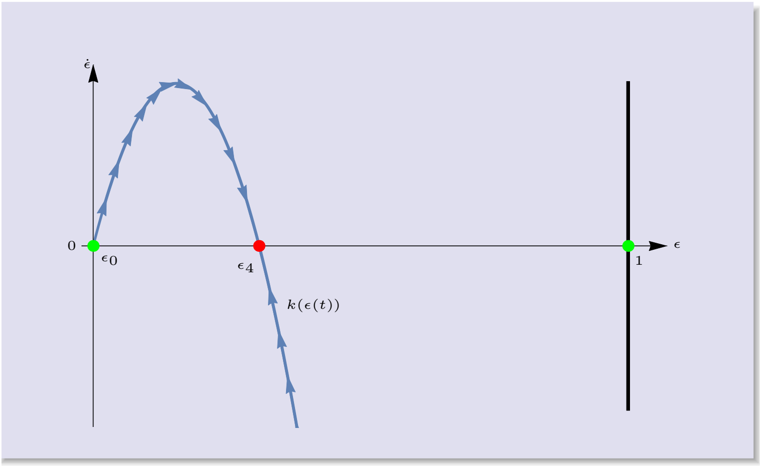

Figure 18.6: The extreme arational dynamics

Then one can also envision a new population dynamics in which, α percent of the population share a *quasi-rational* behavior, when the other $1-\alpha$ has adopted an *irrational* one. In this case, the dynamics becomes:

$$\begin{aligned}\dot\epsilon(t) &= \alpha h(\epsilon(t)) + (1-\alpha)k(\epsilon(t))\\ &= \alpha\left[\frac{C}{2}\epsilon(t)(1-\epsilon(t))(\epsilon(t)-\bar\epsilon)\right] + (1-\alpha)\left([l-(m+l)\epsilon(t))\epsilon(t)\right]\\ &= K(\epsilon(t)|m,l) \qquad (\texttt{dm2})\end{aligned}$$

It is particularly noticeable that both dynamics are not reducible. Indeed, in the dynamics `(drnl)`, the irrational dynamics appears as stacked over the replication dynamics, whereas in the dynamics `(dm2)` they work in parallel. In this case, for one unit value of α, we get back to the replication dynamics and for $\alpha = 0$, we find the irrational dynamics. However, in spite of these differences, the two dynamics approach the same phenomenon in an increased complexity with regard to both elementary dynamics.

In what follows, we will adopt the subsequent strategy: we will pose $\alpha = 1$, $m = l = 0$ from the replicator dynamics, and study the deformations induced on it from small variations of the parameters.

The `(dm1)` dynamics

Let us note that the `(dm1)` dynamics is identical to the replicator dynamics for $m = l = 0$ because: $H(\epsilon(t)|0,0) = h(\epsilon(t))$. As the presence of two new parameters fairly complicates the problem, let us begin by assuming that $l \equiv 0$. In such a way, we start with three equilibria: ϵ_0=0, ϵ_1 and ϵ_2.

First case: $[l \equiv 0]$

In this case, let us leave from the replication dynamics to study the way a tiny variation apply on it. An equilibrium of the `(dm1)` dynamics is characterized by: $H(\epsilon(t)|0,0) = 0$. Let us suppose that the value of m increases from $m = 0$.

The equilibria move in the neighborhood of ϵ_i — $i = 1, 2, 4$ — in agreement with the equation:

$$H_\epsilon(\epsilon(t)|0,0)d\epsilon + H_m(\epsilon(t)|0,0)dm = 0$$
$$\iff \quad \left.\frac{d\epsilon(t)}{dm}\right|_{m=0} = -\frac{H_m(\epsilon_i|0,0)}{H_\epsilon(\epsilon_i|0,0)}$$

Now:

$$\begin{cases} H_m(\epsilon_i|0,0) = -\epsilon_i \\ H_\epsilon(\epsilon_i|0,0) = \left(\frac{C}{2}\right)\left[-3\epsilon_i^2 + \ 2(1-\overline{\epsilon})\epsilon_i - \overline{\epsilon}\right] \end{cases}$$

In consequence of what, a small variation of m induces — the results are shown in the (a)-quadrant of Figure 18.7 —:

① an invariance of ϵ_0 since in that case $H_m(\epsilon_i|0,0) = 0$.

② an increase of $\epsilon_2 = \overline{\epsilon}$ since :

$$\left.\frac{d\epsilon}{dm}\right|_{m=0} = \frac{\overline{\epsilon}}{(C/2)\overline{\epsilon}(1-\overline{\epsilon})} > 0$$

③ a decrease of $\epsilon_2 = 1$, which is driven inside $[0,1]$ since :

$$\left.\frac{d\epsilon}{dm}\right|_{m=0} = \frac{-\overline{\epsilon}}{(C/2)\overline{\epsilon}(1-\overline{\epsilon})} < 0$$

So, a small variation of m in the neighborhood of $m = 0$ when $l = 0$, eliminates the all in **C** equilibrium, in which all the players become **C** players — *i.e.* : eliminates the Pareto-dominant equilibrium. In fact, the disappeared equilibrium swerves inward, which gives now two internal equilibrium, the new one being stable and at the heart of its attraction manifold.

As long as m remains smaller than $\widetilde{m} = (C/2)[(1-\overline{\epsilon})/2]^2$, nothing changes. Then, at $m = \widetilde{m}$, there is a drastic qualitative change[27] because, even if ϵ_0 remains stable, both interior equilibria merge to become a saddle node equilibrium — noted ϵ_5 —, which will be reached from every starting point $\epsilon(0) > \epsilon_5$ but not from a starting point $\epsilon(0) < \epsilon_5$ — see the (b) quadrant in Figure 18.6. Finally, if $m > \widetilde{m}$, ϵ_0 remains an equilibrium. The (d) quadrant in Figure 18.6 — called the *equilibrium bifurcation diagram* — summarizes the qualitative properties of the equilibria.

The main lesson induced by the perturbation of the replicator dynamics, with the exclusive irrational flight from the **S** players to the **L** players, is that, when m rises, the attraction manifold of the all **L** players equilibrium, is the emergence of a mixed stable equilibrium which may vanish with a further increase of m beyond $\widetilde{m}$.

In this scenario, the risk dominant equilibrium tends to win over the Pareto equilibrium. One has :

① 3 equilibria for $m \in [0, \widetilde{m}[$,

[27] $H(\epsilon|m,0)$ has $\epsilon_0 = 0$ and $\epsilon_\pm = (2\,C)^{-1}[C(1+\overline{\epsilon}) \pm \sqrt{\Delta}]$ with $\Delta = C^2\overline{\epsilon}^2 - 2\,C^2\overline{\epsilon} + C^2 - 8Cm$. One can see that, when $m = \widetilde{m}$: $\epsilon_+ = \epsilon_-$.

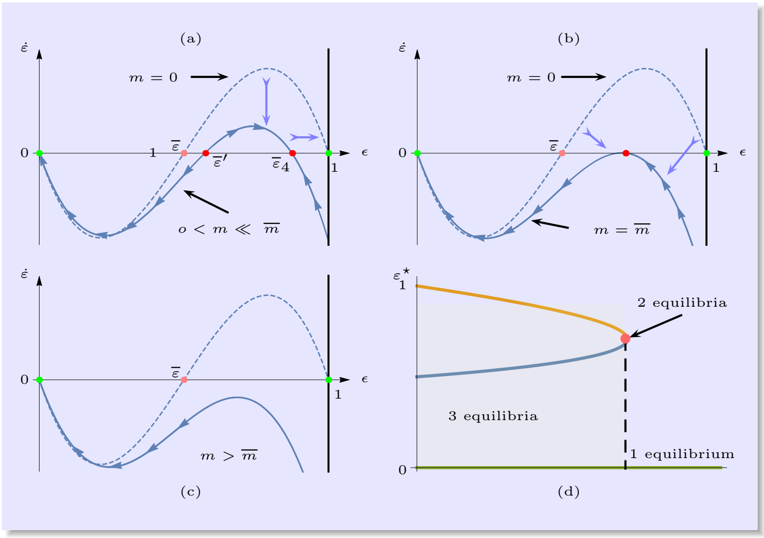

Figure 18.7: The mixed dynamics for $l \equiv 0$

② 2 equilibria for $m = \widetilde{m}$,

③ 1 equilibrium for $m \in]\widetilde{m}, 1]$.

Furthermore, we can observe that it is really the irrational dynamics — a pure mutation dynamics —, which pollutes the replication dynamics because the subset of m value for which one has a stable mixed equilibrium is very small. This tends to confirm that the replication dynamics plays the central role in this scenario.

Second case: $[m \equiv 0]$

Now that the scenarii analysis tools have been set up, we will proceed with a graphic analysis based on Figure 18.7. This time, a small variation of l induces the immediate disappearance of the equilibrium $\epsilon_0 = 0$. In that case, it could not be any more the case of the convergence towards a state where nobody chose to become a **S** player. ϵ_2 remains a stable equilibrium in all the declinations of this situation. At first, two internal balances coexist, the equilibrium ϵ_5 arisen from the shift of the defunct ϵ_0 being stable, while the equilibrium $\overline{\epsilon}'$, born from the $\overline{\epsilon}$ equilibrium remains unstable. But, when l reaches the limit value $\widetilde{l} = (C/2)(\overline{\epsilon}/2)^2$, there is a fork which compacts both internal equilibria in a unique saddle point, which immediately disappears. Only one equilibrium remains. One has :

① 3 equilibria for $l \in [0, \overline{l}[$,

② 2 equilibria for $l = \widetilde{l}$,

③ 1 equilibrium for $l \in]\widetilde{l}, 1]$.

Here again, it is the irrational dynamics which pollutes the replication dynamics because, when m rises, $\overline{\epsilon}$ and its siblings — interior equilibria generated by the m induced sliding of $\overline{\epsilon}$, change only at the margin in their qualitative behavior.

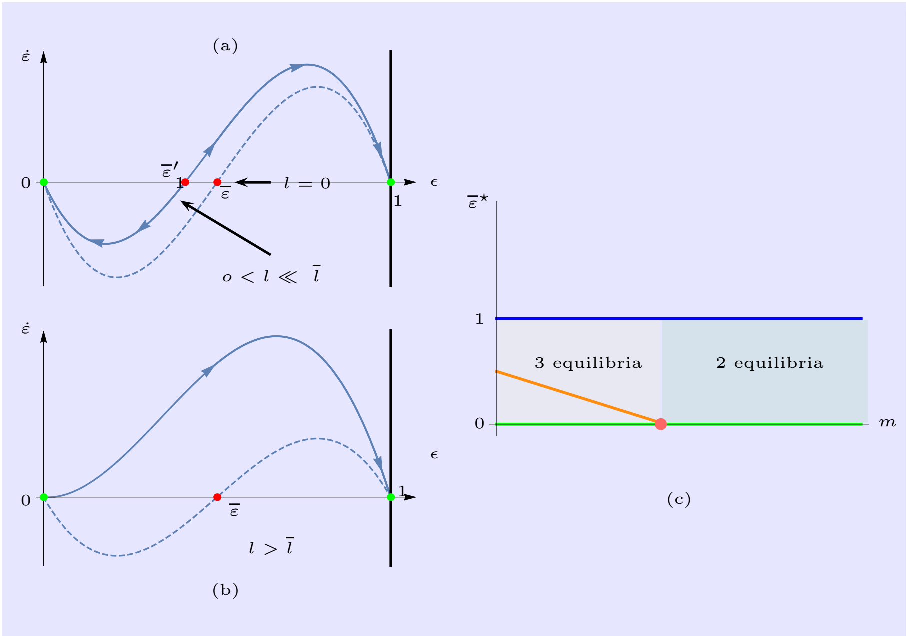

Figure 18.8: The mixed dynamics for $m \equiv 0$

Naturally, the most realistic situation corresponds to $m \neq 0$, $l \neq 0$ and $m \neq l$. However, this situation is particularly complex and a more precise approach could be obtained in posing $l = m$. In fact, one can rely on intuition to assume that the values of m and l are not too much apart from each other. First of all, they are mutation rates and, by nature, they are restrained on $[0, 1]$. Then, if those mutations are irrational, i.e. induced by purely subjective elements without any reference to any strategy from mutants, in all likelihood one can suppose that, in a great population, we will observe very similar percentages of mutant from both populations.

Third case: $[m = l = k]$

$$\dot{\epsilon}(t) = \frac{C}{2}\epsilon(t)(1 - \epsilon(t))(\epsilon(t) - \overline{\epsilon}) + k[1 - 2\epsilon(t)]$$

Once again, let us study the properties of this case from a purely graphical point of view — see Figure 18.8. In contrast with the two polar cases studied above, the focus in this case is concentrated on the internal mixed equilibrium. Indeed, not only the increase in k drives both extreme equilibria to their disappearance but the internal equilibrium nature is modified by the variations of k. For $k < \widetilde{k} = (C/2)(\overline{\epsilon}^2 - \overline{\epsilon} + 1)$, it is unstable, while stable for $k > \widetilde{k}$. In fact, in $\widetilde{k}$ there is a bifurcation of the dynamics and the internal equilibrium is the only equilibrium to remain — see Figure 18.9 for the separation hyperbola as a function of $\overline{\epsilon}$ for C given — one must not forget that $\overline{\epsilon}$ is a function of C and V.

Consequently, as soon as k exceeds $\widetilde{k}$, the replication dynamics is absorbed by the irrational dynamics, which imposes its properties on the replication dynamics equilibrium. As far as a stable mixed equilibrium seems to better correspond to the observed situation of the labor market than any other equilibrium, the model preaches in favor of

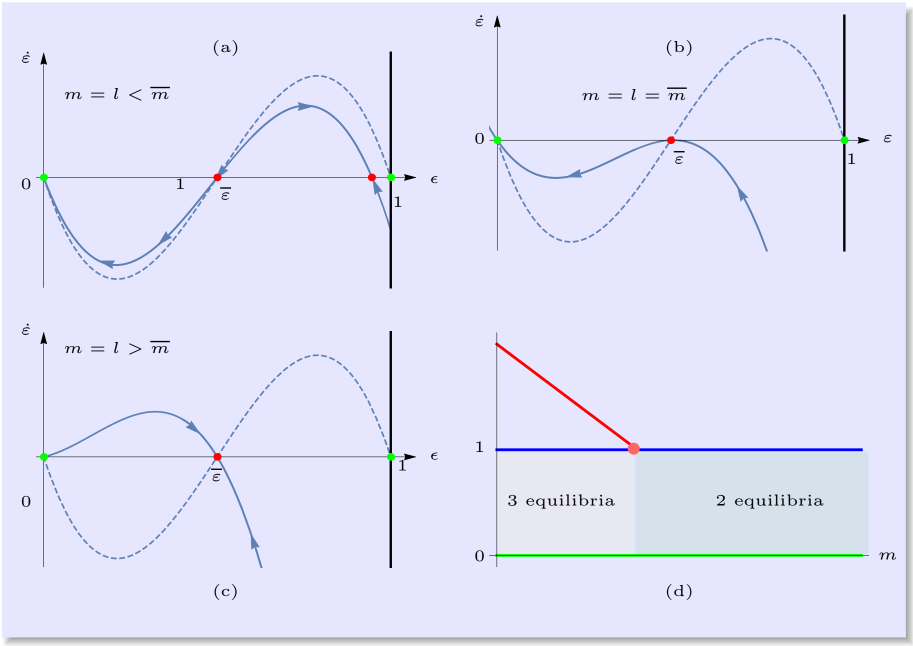

Figure 18.9: The mixed dynamics for $m = l = k$

a significant pollution of the replication dynamics by the irrational dynamics. Contrary to what asserts Orlean (1995), with the increase of k, the attraction manifold of the risk dominant equilibrium — but also the attraction manifold of the Pareto-dominant equilibrium —, if it can rise for a moment, eventually disappears to make way for a unique stable equilibrium.

This conclusion applies to the general model, i.e. to the model for which $m \neq l$. Indeed, by the methodology of the tiny variations in the neighborhood of $m = l = 0$, if the measure or the variation of m is equal to that of l, we find the same result as the one from which we had just moved from. It would therefore be useful to explore in detail the case $m \neq l$.

The `(dm2)` dynamics

We can immediately observe that in the case of this representation of the pollution of the replication dynamics by the irrational dynamics, only one value of $\alpha = 1$ allows to find the Pareto-dominating balances and the dominant risk anew. The general case pleads for internal equilibria, even for a unique stable internal equilibrium when the irrational dynamics dominates the replication dynamics. Some simulations — which are not presented here — prove that the irrational dynamics dominates very quickly the replication dynamics. Consequently, the `(dm2)` dynamics seems to confirm the results obtained during the study of the `(dm1)` dynamics see Figure 18.10.

In fact, this description is only true on the surface, because the dynamics embed a *local emergence phenomenon*. While one should expect that, with the decrease of α, the only observed behavior of the dynamics is the change of sign of its slope leading the internal equilibrium from instability to stability, we can observe for a very peculiar

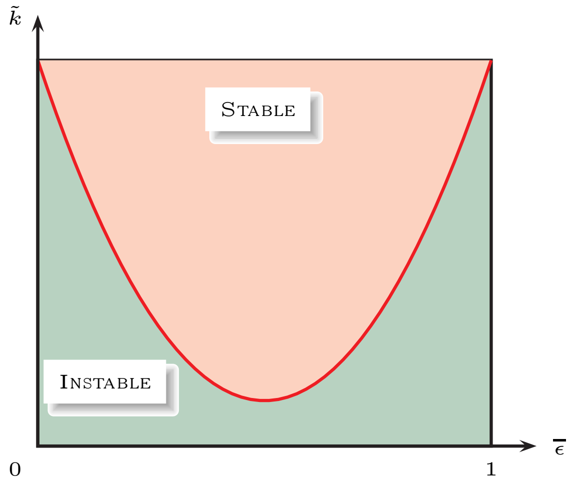

Figure 18.10: The bifurcation frontier for the mixed equilibrium — $l = m$

range of values of α the emergence of an unexpected unstable equilibrium .

Unfortunately, we can not show this emergence other than by specifying the parameter values. We have chosen $\overline{\epsilon} = .5$ and $l = m = 0.1$. For this specific range, a simple simulation shows that for the approximate value of their bounds, we have the emergence of an unstable internal equilibrium on $]0, \overline{\epsilon}[$ when $\alpha \in]0.167667, 0.285667[$ — see Figure 18.12 .

18.3 Conclusions

In this paper, we have tried to explain the persistence of a mixed equilibria composed of **S** players and **L** players. It is no way, at least in the evolutionary game formalism, a trivial affair since one is obliged to pollute the standard evolutionary game by irrational behavior to generate such an equilibrium. We even show that there is an embedded emergence phenomenon inside the mixed model.

Many extensions to this approach are under study: First of all, a differential wage distinguishing job introduce according to their place in the dual hierarchy of the labor market can easily be introduced. Then one can also improve the description of the matching by introducing two distinct effects: agents can run several things at once, in that they can not receive a simple but several jobs and / or not be matched in pairs but by N-tuple. One can also introduce rigid agents who never change their mind according to the length of the study. Finally, the information available on the labor market is necessarily dated and it would be interesting to see what is the impact on the evolutionary dynamics of a delayed reaction.

In all the cases, this approach reveal the complexity of the specific decision whether to undertake studies even in a stationary world.

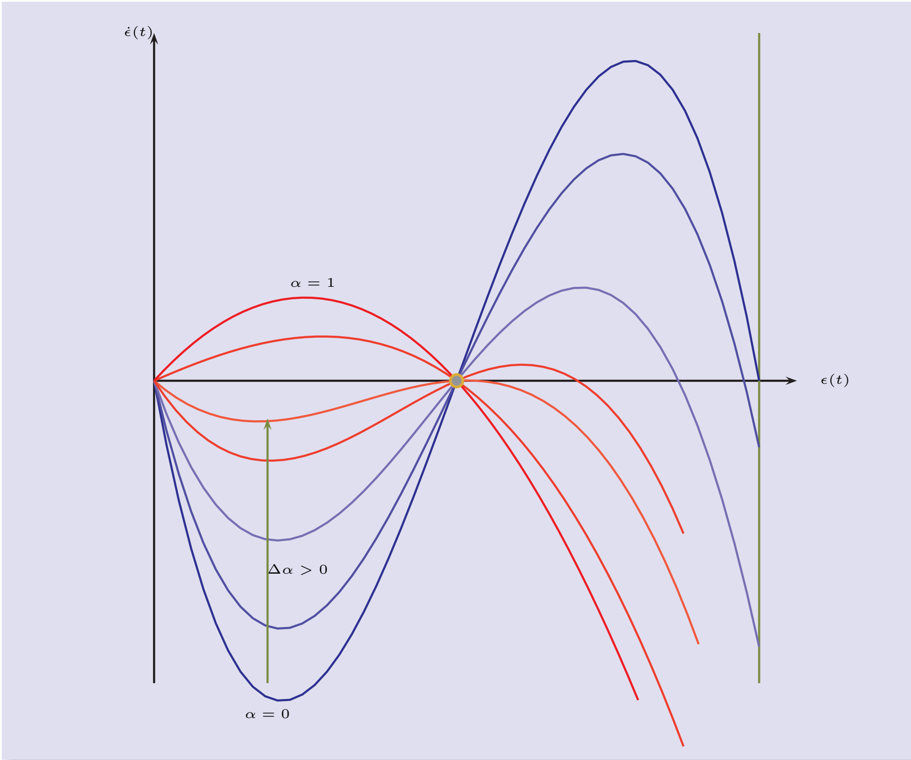

Figure 18.11: the `(dm2)` dynamics

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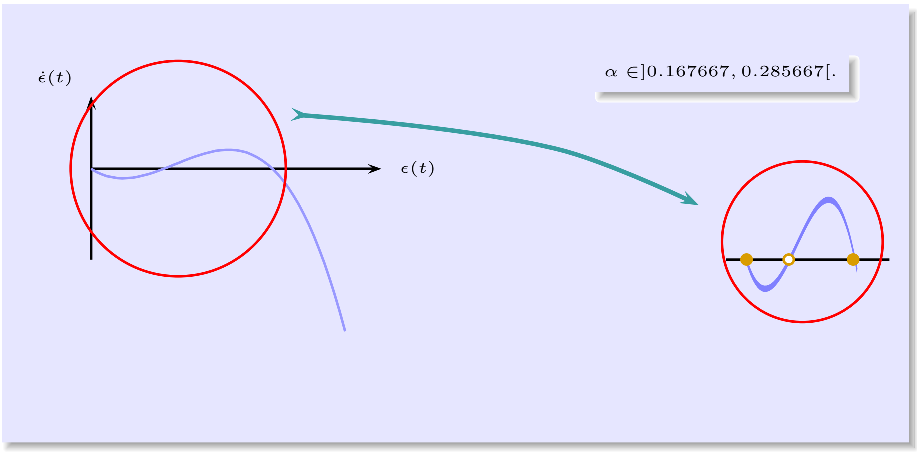

Figure 18.12: Local emergence of an instable equilibrium

Bibliography

Arrow, K. (1973), 'Higher eduction as a filter', *Journal of Public Economics* **2**, 193–216.

Barrouillet, P. & Camos, V. (2008), Le développement de la mémoire de travail, *in* J. Lautrey, ed., 'Psychologie du Développement et de l'éducation', PUF, pp. 51–86.

Becker, G. (1964), *Human Capital*, Columbia University Press.

Damásio, A. (1994), *Descartes' Error: Emotion, Reason, and the Human Brain*, Avon Books.

Devaney, R. (2003), *An Introduction to Chaotic Dynamical Systems*, Westview Press.

Ericsson, K., Krampe, R. & Tesch-Romer, C. (1993), 'The role of deliberate practice in the acquisition of expert performance', *Psychological Review* **100**(3), 363–406.

Green, F. & Zhu, Y. (2010), 'Overqualification, job dissatisfaction, and increasing dispersion in the returns to graduate education', *Oxford Economic Papers* **62**(4), 740–763.

Harsanyi, J. & Selten, R. (1992), *A General Theory of Equilibrium Selection in Games*, The MIT Press.

Jaoul-Grammare, M. & Nakhili, N. (2010), Quels facteurs influencent les poursuites d'études dans l'enseignement supérieur ?, Groupes d'exploitation génération 2004, Net.Doc .68.

Jevons, W. (1871), *The Theory of Political Economy*, Augustus M. Kelley.

Kopel, S. (2005), 'Les surdiplômés de la fonction publique', *Revue Franćaise de Gestion* **3**(156), 17–34.

Lehrer, J. (2009), *How We Decide*, Houghton Mifflin.

Lorenz, E. (1964), 'The problem of deducing the climate from the governing equations', *Tellus* **16**, 1–11.

Lucas, R. (1988), 'On the mecanics of economic development', *Journal of Monetary Economics* **22**, 3–42.

Mariotte, E. (1717), *Essay de Logique Contenant les Principes de Sciences, & la Manière de s'en Servir pour Faire de Bons Raisonnements*, Étienne Michallet.

Marois, R. & Ivanoff, J. (2005), 'Capacity limits of information processing in the brain', *TRENDS in Cognitive Sciences* **9**(6), 296–305.

Maynard-Smith, J. (1974), 'The theory of games and the evolution of animal conflicts', *Journal of Theoretical Biology* **47**, 209–221.

Mazari, Z. & Recotillet, I. (2013), 'Génération 2004 : des débuts de trajectoire durablement marqués par la crise ?', *Bref du Céreq* (311), 4p.

Miller, G. (1956), 'The magical number seven, plus or minus two: Some limits on our capacity for processing information', *Psychological Review* **63**(2), 81–97.

Mincer, J. (1974), Schooling experience and earnings, Technical report, NBER.

Nisan, N., T.Roughgarden, E.Tardos & Vaziran, V. (2007), *Algorithmic Game Theory*, Cambridge University Press.

Orlean, A. (1995), 'De la stabilité évolutionniste à la stabilité stochastique', *Revue Économique* **47**(3), 589–600.

Parker, G. (2012), 'Acta is a four-letter word', *Acta Psychiatrica Scandinavica* **126**(6), 476–478.

Pierce, J. (1980), . *An Introduction to Information Theory: Symbols, Signals & Noise*, Courier DDover Publications.

Piore, M. (1978), 'Dualism in the labor market : A response to uncertainty and flux. the case of France', *Revue Économique* **1**, 26–48.

Poincaré, H. (1890), 'Sur le problème des trois corps et les équations de la dynamique', *Acta Mathematica* **13**(1), A3–A270.

Schultz, T. (1961), 'Investment in human capital', *The American Economic Review* **51**(1), 1–17.

Shapiro, C. & Stiglitz, J. (1984), 'Equilibrium unemployment as a worker discipline device', *American Economic Review* **74**(3), 433–443.

Shim, J., Carlton, L., Chow, J. & use of anticipatory visual cues for highly skilled tennis player, W. C. (2005), 'The use of anticipatory visual cues for highly skilled tennis players', *Journal of Motor Behavior* **37**, 164–175.

Spence, M. (1974), 'Job marker signaling', *Quarterly Journal of Economics* **87**, 353–374.

Taubman, P. & Wachter, M. (1986), Segmented labor markets, *in* O. Ashenfelter & R. Layards, eds, 'Handbook of Labor Economics', Vol. II, Elsevier Science Publisher, chapter 21, pp. 1183–1217.

Weibull, J. (1995), *Evolutionary Game Theory*, The MIT Press.