On the Relation Between Social Activities and Social-Economic Structures

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Chapter 1

Introduction

Humans are social animals. As far as we can trace, human beings evolved through natural selection mainly because their capacity of living in groups, cooperating and sharing responsibilities [89]. Throughout years of evolution, this social behavior shaped our body, our reasoning, our environments, our economics, and, ultimately, our societies.

The problems we discuss today, whether presented in any major presidential campaign or in the news, such as social inequality, racism, intolerance, economic crisis, etc., are not novelty; in fact, they have been discussed since ancient Greeks [85]. What do they have in common? They can be cause or consequence of the structures and dynamics of our societies.

Chapter 2 reviews the origins of sociology. We briefly show theories that points to individuals as the way to comprehend society and also their duality versions that point to society itself as the agent able to control our behavior. Similarly, we introduce competing ideas regarding the role of economics in society: if society is shaped by its economics or vice-versa. In Section 2.2.3, we discuss more recent theories suggesting something in between those extremes, i.e. there are some dynamic processes or underlying structures ruling how individuals and society interact. In the end of Chapter 2, we highlight important social-economic works to illustrate their methods and their everyday impact on us.

The lack of analysis of social structures (i.e. networks) on the studies presented in Chapter 2 is evident, although Durkheim and Elias pointed to their importance [28, 32]. In Chapter 3, on the other hand, we focus on studies handling with structure; in these works, the importance of networks is a consensus. We present works from sociology and economics which allow us to conceive the benefits of understanding the structure of the complex systems being studied, from pre-digital society to the big data era. The dichotomy, first presented as *individual vs. society*, has shifted to *online vs. offline societies*. The availability of richer datasets and new techniques, such as a whole new field of study (see Network Science in Chapter 4), leverage our knowledge, but impose some constraints. Additional validation of datasets and results are necessary to assure the generalization of online social networks to our daily life.

In Chapter 4, we briefly explain why network science become so popular and multidisciplinary. We introduce basic definitions and common properties used to reveal the knowledge hidden in the networks of complex system.

Chapter 2

Social Economic Studies

In this chapter, we present a brief overview of sociology from its original theories to recent important research. The objective is to understand the basic sociological concepts and motivations in order to engage more critically towards social networks studies.

2.1 Origins

Sociology is the study of societies and the consequence from the interplay between individuals. It aims to develop knowledge about social order, social disorder, and social change. The term *sociology* was first coined by Auguste Comte in 1838, in a book of his series *The Course in Positive Philosophy*, but sociological thoughts and concerns can be traced back to ancient philosopher Plato [85].

2.2 Classical Theories

Despite having lived at least a century ago, classical sociologists are important to sociology and network science as their ideas are still relevant and can motivate new discoveries. There is no specific set of attributes to determine

one as a classical sociologist, but names as Bernard Mandeville (1670-1733), Adam Smith (1723-1790), Auguste Comte (1798-1857), Alexis de Tocqueville (1805-1859), Karl Marx (1818-1883), Émile Durkheim (1858-1917), Max Weber (1864-1920), and Norbert Elias (1897-1990) contributed to set and establish sociology as science [97]. Due to objectivity and space, we do not give detailed description about their contribution. Nonetheless, we do highlight some directly opposite theories such as "individual *versus* society", and "society implying on economy *versus* economy implying on society"; they are considered the main lines of thought and are fundamental to sociology. Thus, understanding them would engage us more efficiently into the socio-economic effects we are pursuing to understand in this work.

2.2.1 Focus on Individual

Some theorists argue society as being not more than a collection of individuals. They believe the only way to understand society is through its individuals. Adam Smith, for instance, described an invisible force holding society together as the result of self-interest social interactions. The *invisible hand*, as he named, is the emergent force from social regulation and social imitation [84]. In other words, egoistic attitudes could lead to mutual benefits.

Max Weber, considered the father of the methodological individualism, said that society could not be anything else than just the individuals that compose it. He defined sociology as the study of *social action* [31]. These actions or behavioral decisions are performed by individuals and can be classified into four ideal types: goal-rational, value-rational, affective, and traditional. Goal-rational social actions are those that can be justified with rational arguments. Once the goal is defined, the individual should behave in such way to achieve it. Value-rational social actions can be perceived similar to goal-rational ones, however, the goal itself cannot be justified in rational terms. For instance, one who decide to live solitary to in a religious seclusion; the sacrifice of such life can only be explained by the value of be-

lieving in rewards after life (it cannot be explained rationally). The affective category is when one acts by impulse, without thinking. Finally, traditional social actions are those we do because it is how society does (e.g. eating with silverware). In modern societies, goal-rational actions are expanding while the other types have been suppressed. These changes are consequence of the slow process of individual *rationalisation* that would, ultimately, reach the *disenchantment* view of the world [96]. That is, a world where scientific knowledge is more valuable than beliefs.

2.2.2 Focus on Society

There were sociologists focusing on the structure; they viewed society as a complex system. Karl Marx suggested society as being defined by individual relations; the individual essence is not in the part, but it is revealed by the network within it. Marx said: "It is not the consciousness of men that determines their being, but, on the contrary, their social being that determines their consciousness." [61, p.11-12]. For Marxists, individuals hold their beliefs regarding their social position as *class consciousness*. Class is not only defined by economical aspects, but also by social-psychological characteristics perceived within a group.

Émile Durkheim had a even more holistic view from society than Marx. He observed a positive correlation between the division of labor and societal progress [30]. He believed traditional societies were bound together by similarities (they shared similar languages, gods, religious beliefs, etc.). In modern societies, in contrast, as the levels of specialization raised from industrial revolution and globalization, society would be bound as a result of differences, i.e. their specializations and interdependence would create organic solidarity, benefiting society as a whole. Thus, *collective consciousness* is the new cement of society [30]. He established sociology as a new science based on the study of *social facts* [29], to understand group formation, group identity, group cohesion, etc. In contrast to Weber's social actions, social facts are inherent to society, they can neither be reduced to individual

facts, nor be used to understand the individual level; they are *sui generis*. Nevertheless, they are coercive to individuals.

2.2.3 In Between Individuals and Society

There are also the *figurational* sociologists. Norbert Elias, in his book *The Civilizing Process* [32], rather than following those dichotomy ideas, he focused on the long chain of interdependence between individuals and society, the long term changes and their dynamics over humankind. He held neither the existence of society without individuals nor individuals completed isolated in society. He opposed static solutions in order to investigate the interaction processes. To Elias, the process of becoming civilized (an ongoing process), individuals learned to adapt their behavior according to their social context. For instance, one often behaves completely different at bars than at work. Note that this adaptation process does not mean to hide ones' real personality, but a truly comprehension about social constraint toward the development of self-constraints.

2.2.4 Economy and Society

There is no consensus among sociologists regarding which force leads to human development, i.e. if economy determines the society or if the other way around. Adam Smith suggested the division of labor would give rise to social stratification [84]. As he exemplified, from economic separation one could find distinct roles in society such as an intellectual professor and an attendant in a hotel. The following generation of these workers would develop their talents in the same social tier, what would keep increasing the stratification. In this sense, despite being equal at birth, differences in economic classes, in custom, and in education would be responsible for the differentiation in character formation and latter social stratification [84, 77]. Yet, Marx is even more radical, he defines the foundation of society to be the productive individual relations (survival, food, etc.). As the division of labor advances

(capitalism), an *alienation* process would be inevitable. During this process, workers decrease the level of interaction, fading their ties, alienating them from the product they are working on, their production process, their fellows, and ultimately, from themselves. Consequently, constant class struggle against social inequality and social stratification. On the other hand, Weber argued exactly the opposite. For him, the economic relations are consequence of the social relations. For instance, the success of capitalism has its roots in the religious doctrine from its earlier entrepreneurs who abdicated from a luxury life making their hard work as the best worship to God.

These plurality of theories allow scientist to explore sociology in many different forms with several complementary approaches.

2.3 Methods

The conflicting theories of Durkheim and Weber can be seen as the two main methodological approaches in sociology, namely: Positivism (quantitative, rational) and Anti-Positivism (qualitative, interpretative). Beyond this classification, there are still different schools of thoughts, *situationism*, for instance, perceives quantitative and qualitative research complementary to each other [72]. Since the former aims to answer precisely questions such as *what*, *where*, *when*, *how often*, and/or *how long*, the later works trying to explain *hows* and *whys* [91].

In addition to the type of targeted question aimed to answer, quantitative and qualitative methods might significantly differ from how they acquire data and about the type of data itself. Quantitative method depends on numbers, statistics, reproducibility to be considered valid. Therefore, quantitative research often use empirical data such as surveys, group experiments, and tracking. In contrast, qualitative works focus on interviews, participant observation, field notes, analysis of documents, among others [60, 67].

A more recent area of Social Network Analysis (SNA) can be conceptually classified as a quantitative approach due to its objectivity and rigors.

Also, it can be described as a framework to social pragmatic studies, providing *exploratory* and *confirmatory* tools [72]. Nevertheless, it is based on Graph Theory and Network Science. The main differences between SNA and the traditional approaches discussed in this chapter are the data acquisition process and the analytical tools. Thus, we have separated chapters for both SNA studies (Chap. 3) and theory (Chap. 4).

2.4 Selected Works in Sociology

In this section we highlight some important works in sociology to illustrate their impact on our daily life and the broader aspects handled by the area.

1. The Communist Manifesto, from Marx (1848)

   Marx is one of the most popular sociologist, maybe because of the tragic killing regimes supposedly motivated by his communist ideas, or maybe by his theories. In 1848, Karl Marx and Friedrich Engels wrote a manifesto to the Communist League, an English group of revolutionary workers, *The Communist Manifesto* [62]. In this publication, they stated, among other things, Marx's view of capitalism and the role of classes. For Marx, capitalism divides society in two classes: the bourgeoisie and the proletariat; in other words, the owners of business and production means, and the workers who are dependent on wages in order to live. The natural competition, inherent to capitalism, among the elite class would gradually squeeze workers to lower wages and to longer working hours. The coercive power combined with an increasing surplus of unemployed population would drive to the inevitable final, the revolution. The oppressed would overthrown the bourgeoisie initiating the socialism and extinguishing with classes distinction. Marx presents his work as scientific historical study of society through its economic continuous transformation since the feudalism.

2. Suicide: A Study in Sociology, from Durkheim (1897)

Durkheim used suicide as a study case (i) to show how some personal attitudes could be predictable, and (ii) to discard personal traits, psychological distress, or mental disorder as possible explanations to these behaviors [28]. Different suicide rates were perceived according to social context. By comparing jewish, catholic and protestant communities, he found increasing suicide rates. Statistics also showed that for the pairs – men *versus* women, single *versus* married, non-parents *versus* parents, and soldiers *versus* civilians – the former categories were more likely to commit suicide than the later. As a result, social facts were leading to higher suicide rates and their predictability, instead of personal issues. According to Durkheim, two major forces were responsible for suicides: social integration and social regulation. In the integration continuum he defined *egoistic suicide* as motivated by the lack of social cohesion (e.g. elderly people who lose their sense of belonging) and *altruistic suicide* when individual needs has no importance (e.g. religious suicide bombers); and in the regulation continuum he defined *anomic suicide* as motivated by the lack of social direction (e.g. sexually abused) and *fatalistic suicide* (e.g. slaves). This seminal work in social statistics triggered the importance of social ties and the risks of loss of social integration [16].

3. The Protestant Ethic and the Spirit of Capitalism, from Weber (1930)

   The modern Capitalism began to develop in North-Western Europe, mainly in Protestant countries such as England and The Netherlands. In *The Protestant Ethic and the Spirit of Capitalism* [96], Weber traces Protestant ethics to Reformation and points to its background beliefs as one of the key components to the success of capitalism in West Modern Society. While Catholics are guided through an idea of sharing which sometimes perceive accumulation of goods as bad thing, Protestants (specially Calvinists) are mainly motivated by hard work and simple life; self-confidence and pursuit of success were the key motivation for workers. At the top, the surplus would be invested into the

system, instead of being spent on luxuries, developing even more this structure. This natural process at that time forged the spirit of capitalism that could be followed latter on even when the secularization process advanced over societies. Weber arguments were not only limited to Protestantism, but also included other religions (Confucianism and Taoism, in China; Hinduism and Buddhism, in India; and Ancient Judaism, in Israel); indeed, this work was the first of a series where he studied the effects of religion to the economy. His idea was fundamentally opposite to Marx theories, since the later holds economic relations as the origin to social organization.

4. Conformity Experiments, from Asch (1950s)

   Solomon Asch performed some experiments back in 1950s in order to evaluate the impact of social influence through group conformity [5, 6, 7]. In the experiments, people had to answer trivial questions about explicit facts, such as state out load in a group the comparison between bars length. His findings, confirmed by also several other replications [81, 56, 15, 52, 4], revealed that from one-third to one-half of participants would answer contrary to the facts. That is, group pressure is a real powerful coercive force in our society.

5. Obedience to Authority Experiments, from Milgram (1960s)

   In the 60's and earlier 70's, Milgram performed a series of experiments to investigate the role of social pressure in our society [64, 66]. For instance, he was looking for explanations about the horror in wars and genocides under excuses of merely following superiors orders. In his experiments, a teacher (the subject matter) should apply increasingly electric shocks in a learner, through a sequence of buttons, every time the learner misses questions asked by the teacher. The sequence was labeled from "Slight Shock" (15 volts) to "Danger: Severe Shock" (375 volts), then to "XXX" (450 volts).

While the shocks were being performed, the learner, an actor[1] following a script who was not being harmed, screamed, begged to stop, adverted about heart problems, among other things, in order to make the teacher stop. A research conductor (also confederate) would simply order the participant (teachers) to continue, saying "please continue...", "the experiment requires that you continue...", "it is absolutely essential that you continue...", "you have no other choice. You must go on...".

When presented to general public, most people answer they would have stopped the shocks as soon as the leaner started to complain. However, after several executions, Milgram found more than 60% of participants reached the highest shock. Finally, he adverted people about the power of social pressure via obedience to authority over personal conscience [4].

6. Social Inequality Studies

There are many types of inequalities within a society. The most ones commonly studied are economic [83, 45], education [63], racial [53, 90], and gender inequalities [43, 80]. Among all of them, a key principle: the uneven distribution of "assets" to individuals in the society. In other words, the public goods, the wealth, or the rights, are not divided through merit, but based on other social aspects such as class, gender, or race. A series of studies have been done regarding economic inequalities, analyzing data from late 1970s to beginning of XXI century, for US [48], for Britain [14], and for Canada [17]. They examined the key measures of economic inequality: wages, hours worked, income, consumption, and wealth. In all of them, inequality steadily increased over this period. In Canada, however, government policy in compressing inequality (tax and transfer system) converted the huge gap in wages and earnings into a mild (but still significant) inequality in disposable income. Canadian wealth inequality presents quite stable

[1] Usually referred as *confederate* in psychological experiments.

results since 1999.

Sometimes the line separating economic, education and race inequalities is blur; all of them coexist as cause and consequence contributing to the increasing gap of knowledge and, therefore, opportunities. A study demonstrated that traditional and current segregation systematically promotes unequal access to education [23]. In addition, the current public funding system is not design to extinguish this problem, and in fact, such system propagates inequalities in labor market, income, and districts [78]. Other times, inequality is explicit raised from race/ethnic issues. In 2004, Bertrand and Mullainathan demonstrated significant differences in number of callbacks when comparing identical resumes of sound like names from African-American and White-American [12].

Chapter 3

Social Networks Studies

Since the beginning of sociology, its classical theorists were doubtful about the role of societies' structure for their own development, specially for modern societies. Either with Durkheim's static ideas (*funcionalism*) or with Elias' dynamic process investigations (*figuration process*) the necessity of a broader comprehension of the social network was evident. However, none of the studies presented in Chapter 2 explored those structures (networks). Since their blindness about social structure, sociologists used *social facts* as emergent properties from networks to better understand society.

In this chapter, we navigate through the evolution of social networks studies using some well cited works, focusing on those related to sociology and economics. As we already mentioned, there were beliefs about the role of the structure to social networks but they were not directed tackled in the earlier studies in the field. As the sociology theories matured, new technologies have been developed, new types of data have become available, and we observed an increasingly multidisciplinary interest over "structures" of society.

If we could draw a timeline under these studies, in the leftmost side, we would have sociologists revealing some interesting network aspects about our pre-digital society (yet lacking statistical rigor). In the rightmost side, a digital world full of online social networks – the big data era. In between, several threads developing the field, such as:

- an increasing understanding of social structure and its impact in our daily lives;
- plenty of theories and methods coming from mathematics, physics, and statistics, giving birth to a new science – the Network Science (see Chapter 4);
- a shifting in the object of study from real individuals to their representation at online social networks;
- a constant concern about how representative these online proxies are to our real society, as well as how trustful are the results derived from them.

3.1 Sociology

One of the first social network studies to become famous was the small-world experiment of Stanley Milgram [65]. Indeed, he was not the first researcher to investigate the increasingly connectivity in the world, but Milgram is more remembered than his precursors such as Karinthy, Kochen, or Pool [8]. Milgram carried out an experiment in order to check how far from each other people are in the world. He selected a person in Massachusetts as the target and, then, several random sources in Nebraska. The sources had to mail a package to the target following simple instructions: one should only mail people who he/she knew at first name basis, i.e. if one did not know the target, one should have sent the package to a friend he/she thought was more likely to know the target. The package contained a list to keep track of names it has passed through. He found people were apart, on average, by 6 connections; it was the origin for the well-known expression "six degrees of separation". Despite being social psychologist, in his experiment Milgram explicit investigated the structure of the network. However, his work has some critical issues regarding its statistics, for instance, Milgram only considered in his calculations letters that reached their destination. Nevertheless, his

claim about a small world was later on statistically confirmed in different research [24, 95, 54, 26]. The small-world phenomena still motivates many fields from epidemics to communications [98, 76, 93].

Another interesting aspect revealed by exploring society and its structure is *social contagion*. Christakis and Fowler performed a series of studies to understand how social behavior could be propagated. They used a dataset collected over a 30-year period from Framingham Heart Study, throughout periodically questionnaires and body measurements. First, they analyzed at what extend obesity could be infectious through social network [20]. From the network formed by friends, spouses, parents and relatives, they constructed observable networks and random networks with similar properties in order to apply longitudinal statistical models to check levels of spreading. They found one has 45%, 20%, and 10% more chance of became obese if he/she is connected to an obese person by 1, 2, or 3 degrees of separation (among all types of relationship), respectively. Geographical distance appeared to have no influence in this contagious, but sex and friendship direction do impact. For instance, if one (ego) names a friend (alter) that become obese, his/her chances of becoming obese too increases 57%; if they are mutual friends, one's risk increases by 171%; finally, a friendship originated from alter to ego does not influence on ego's risk of becoming obese.

In 2008, Christakis and Fowler did a similar study addressing smoking cessation behavior. The results were similar, pointing to be influential until three degrees of separation. Further network analysis showed that as the total number of nonsmokers drastically increased, the smokers were pushed to the periphery of the network. Although the number of smokers has reduced in the population, the size of their clusters remained almost stable. Consequently, smoking cession behavior spreads as local initiatives rather then slowing individual changes [21].

In the last study over social-psychological behaviors of this series, Christakis and Fowler tackled spreading of happiness. Similarly to what they found about obesity and smoking behaviors, happiness also spreads over so-

cial networks, i.e. it is a contagious phenomenon. As in the previous studies, happiness also disseminates up to three degrees of separation. Moreover, not only people surrounded by happy people are more likely to become happier in the future, but also those who are more central[1] in the network. In contrast to previous studies, happiness is more sensible to time and geographical distance [40].

Later, Dodds et al. developed the *hedonometer*, an online non-invasive tool to measure temporal patterns of happiness by word analysis, using Twitter as content provider [25]. Note at this time, it is not the spreading mechanism that is being investigated, but different insights to measure feeling in a population. In theory, this new source of data (online social networks) can provide richer and less expensive datasets to be used to formulate new sociology theories or re-validate the current ones. However, in addition to traditional concerns about theories generalization, external validity, among others [58, 74], the use of online social networks as proxy for our modern society demands further investigations to assure at what extend they are alike.

Once in the digital world, one can easily claim distance is no longer a problem to form or maintain relationships. Then, the expected number of virtual friends would be much greater than in the "real life"[2]. Or in network terms, the online social network is denser than the offline social networks. Thus, these differences could compromise the application of traditional sociological theories using these data, or could lead to the development of new theories, exclusively, for online societies. Some work have been done in order to reduce these uncertainty, specially using Twitter data.

Huberman et al. observe the increasing usage of social media (such as Facebook, Twitter, LinkedIn) as proxy for real social networks by market, academia, and governments [51]. Meanwhile, they warn about the differences

[1] Central in contrast to peripheral nodes when visualizing a network. Centrality is also measure by metrics such as *closeness* and *betweenness* (see Section 4.2.2).

[2] We will not discuss the philosophical questions regarding which life (online or offline) is in fact the real one.

between declared networks (e.g. followers and followees) and real interaction networks. The dense social network, therefore, hides a sparse interaction-friend network (those who has directed a post to at least twice). This findings raises the importance of deep reasoning of the network models in order to achieve realistic results.

Dunbar's number theory states that the number of social ties, i.e. stable interpersonal relationships is biologically constrained by the size of neocortex. Dunbar found the limit for humans to be between 100-200 [27]. Gonçalves et al. created a network through Twitter's conversations to check whether this constraint holds after digital era [44]. They found out the cognitive limitation still plays a role in our relations. Moreover, two basic concepts could explain it: time constraint and prioritization among ties.

Takhteyev et al. [87] investigated the importance of geographic distance, country boundaries, language, and frequency of flights on ties formation. They analyzed how could them be used as tie predictor and if distance still plays role in social ties formation, since a previous study [19] claimed the Internet to diminish the impact of distance. Using Twitter data and the number of direct flights between pairs of airports, their findings revealed that distance do impact on society ties formation. Moreover, they showed the number of flights between micro regions as the best tie predictor when compared with distance, country or language.

Stephens and Poorthuis presents another way to understand geography and information flow in Twitter by integrating physical and social distances [86]. They found Twitter social neighborhoods to be replications of offline social patterns. In addition, closer communities are more dense and effective in spreading information.

Beyond the capacity of being proxy to real life social network, online networks can be segmented by their purpose. For example, some of them are used for friendship, others for professional networking, while others for marketplace, and so on. Since Twitter is being one of the most used online community not just as content provider, but even as quality indicator [88], it

is natural to question its purpose. Kwak et al. investigated several aspects of Twitter network such as: basic topology properties, ranking users, trending topics behavior, impact of retweets. Among other things, they found that more than 85% of trending topics are news headlines or media related [55]. Although this media role intuitively suggests top propagators to be celebrities or showbiz accounts (i.e. those with greater number of followers), this was not observed in retweet analysis. They evidenced the emergence of collective intelligence where ordinary people dictates what is spread over the network.

In addition, Wang et al. investigated how easily people in different social networks could be traced [92]. They revealed people tend to use similar names and keep same friends over multiple applications such as Facebook, Twitter, and Foursquare. This approach could overcome some data limitation due to specificity, however, they adverted security and leakage issues due to cross self-identification or even by friends reverse lookup.

3.2 Economics

We can also use some works to show how the usage of social networks helped us to improve our knowledge in economics. At first, traditional social networks (individuals as nodes) were used to capture information flows and revealing how these would impact economic behavior. Later on, innovative modeling brought up new abstraction to economic-social network, where actors were products, capabilities, countries, etc. (no longer individuals), leveraging the impact of results. There were also a shifting to online social networks, using their sentimental analysis to infer economical consequences. More recently, big data is being used to estimate social-economic indicators [13]. At last, experimental social networks is being used to suggest alternatives approaches against inequality.

The use of social networks in economy can be traced back to Granovetter and his work about the strength of weak ties [46]. He suggested the analysis of social ties as a way to link micro and macro levels of sociological theory,

i.e. from these ties one might understand how individual actions are shaped by social structure and vice-versa. He defined ties' strength according to frequency of interaction. Throughout a series of experiments in the labor market, he reveals the importance of weak ties to information diffusion and to promote local cohesion. For instance, one is much more likely to know about a job offer through a weak tie rather than a strong one.

The traditional discussion about the role of economy into society, headed by Marx and Weber (see section 2.2.4), evolved to a segmentation into economics – Formalists *versus* Substantivists [75]; the former stands for rational actions and proposes an economy based on utilitarianism, while the later holds economy as a result of social relations and their provisions. Granovetter proposes neither is possible to understand economics without the social structure nor just considering the social relations [47], reinforcing Weber's theories. Then, he proposes a balance between these two schools of thoughts.

Burt proposed a similar concept to the weak ties from Granovetter [46]. He claimed the existence of structural holes in social networks, i.e. gaps between cohesive groups, leading to opportunities to gain social capital [18]. Whoever is able to fill these gaps would take advantages from his/her position and would provide valuable non-overlapping information to groups (brokerage). Furthermore, he showed that entrepreneurs are more likely to have good ideas; those evaluated as valuable and accepted within society.

Hidalgo et al. explored a new way to study economy using social networks. They studied the relatedness between products to show the development of nations [50] and constructed a network of products based on their similarities – the product space. Products are said similar if they require similar amount of labor, types of infrastructure, sanitary laws, climate, among others (input perspective). For instance, if a country already exports apples, given that pears are very similar to apples, this country is expected to easily starting export pears because the inputs requirements for that second product are already present. However, if this country want to export computers, all the capabilities from the apple market are useless. The intuitive idea behind the

proposed model is that it is much easier for countries to grow developing new products similar to the ones they already export (output perspective). Then, a proximity measure between products can be calculated through the minimal conditional probability of a country exporting a good given that it exports another. We can see in Figure 3.1 (the product space) there is a core of more-sophisticated and more-connected products while a periphery o less-sophisticated and less-connected products. They showed through longitudinal experiments how countries could explore the product space developing themselves and revealed that even allowing countries to navigate non-realistic-long distances, some countries could not reach the core of the product space. Therefore, suggesting a possible explanation for the constant existence of rich and poor countries.

Motivated by Adam Smith's ideas, where the wealth would be the result of specialization (division of labor), Hidalgo and Hausmann presented the concept of building blocks of economic complexity [49]. They compared the economy complexity of countries to Lego buckets diversity, where a Lego piece is a capability. Products would require a set o capabilities in order to be develop and countries could only develop products for which they posses all the required capabilities. In addition, capabilities could not be compared just quantitatively, for instance, some of them were quite ubiquitous among countries while others, less-common, were used to build more sophisticated products. They proposed the method of reflections in order to measure and understand the structure of the bipartite network of countries and their exported products [49]. In other words, their measures were a proxy to understand countries capabilities (complexity) by depicting diversification (countries) and ubiquity (products). Moreover, this complexity correlates with GDP and "errors" in the correlation are predictive of future growth.

Gilbert and Karahalios, on the other hand, explored online social networks and the possibility of sentiment measurement to investigate the correlation between anxiety and worry to stock market variations [42]. They used social media data from LiveJournal to built the Anxiety Index and the S&P

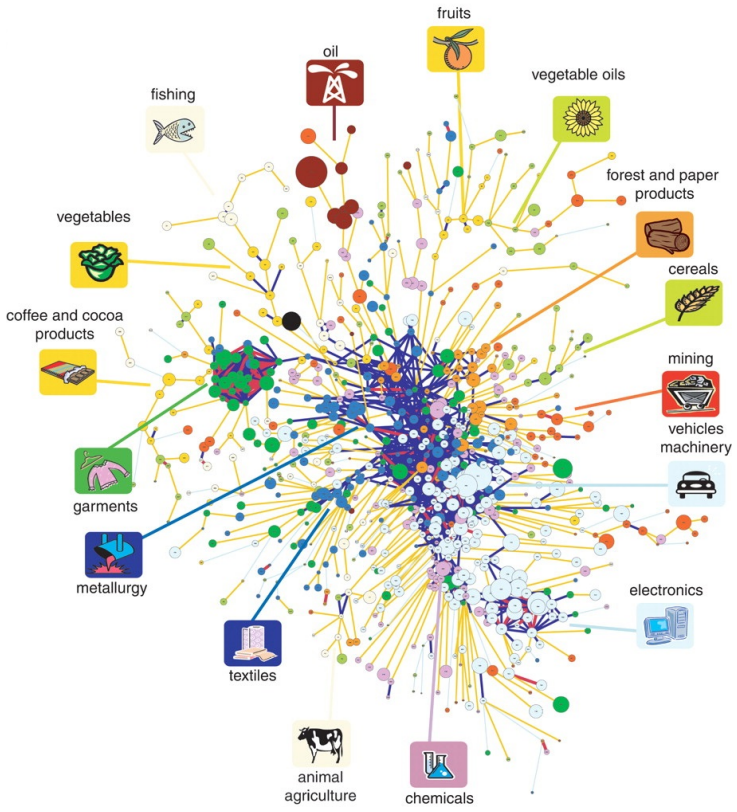

Figure 3.1: Network representation of the product space. Links are color code with their proximity value. The size of nodes are proportional to world trade, and their colors are chosen according to the classification introduced by Leamer [57](extracted from paper [50]).

Index as the stock market indicator. They found that the feelings presented in economical unrelated data from social media do help to point the fluctuation directions of market. In fact, anxiety and worry negatively correlates with S&P 500 closing prices.

Blumenstock et al. used new sources of data to provide demographic and economic profiling [13]. They used mobile phone data from Rwanda to predict poverty and wealth, by combining the cell phone data with real census data, and a phone survey. The survey with mobile data were used to create a predictive model of wealth. However, instead of using directed

variables, they combined them in order to get a wealth index. Since the correlations between the predicted index and the survey questions were very strong, they estimate the whole dataset for wealth with the benefit of using the mobile location information. This approach generated new information that, previously could only be retrieved in a much more aggregated view.

Finally, Nishi et al. developed a virtual social-economic game to understand the emergence of inequality. In their experiments they varied initial levels of inequality to individuals and the visibility of wealth to their neighbors [71]. They found that when wealth is visible, inequality is stimulated; and there is reduction of cooperation, interconnectedness, and wealth within population. The initial inequality setup has barely any impact on society capacity of wealth redistribution, but the visibility has been shown as the enemy. Despite being results from laboratory experiments, these findings could help to understand the true origins of inequality, as well as to provide means to diminish it all around the world.

Chapter 4

Network Science

4.1 Why Networks?

Networks (or graphs[1]) have been studied for a while. The graph theory can be traced back 1735 by the earlier works of Euler about the Königsberg's bridges [39, 3], but by the end of 20th century new discoveries lead to the birth of a new field – The Network Science.

Until the end of 90s, most real world network applications were modeled based on the probabilistic random graph theory of Erdös and Rényi [79, 33, 34, 35, 36, 37, 38]. The lack of data (maps) and the complexity of large real systems (networks) induced researchers to treat them as random networks. When real world networks began to become available, their analysis did not match to what was the expected for random models. For instance, Watts and Strogatz evidenced the lack of clusters in random networks and showed simple mechanisms to find "small-world" networks in between regular and random graphs [95]. Moreover, Barabasi et al. discovered an intriguing property that would change the area [9]; the degree distribution of many real world networks fits to a *power law* instead of a *gaussian* distribution (expected for random networks). The consequences of such paradigm changes have direct impact

[1]Sometimes the term *graph* is more used in mathematical contexts while *network* is applied for real world representations.

on network's properties, from its resilience, to its capacity to spread diseases, or to its robustness to random attacks [10, 2]. In addition, this property has been observed in networks in a myriad of domains, from protein-interaction to the WWW [1]. The universality of such property throughout networks of different fields made the *scale-free* networks the focus point of this new multidisciplinary field.

In almost two decades, with an increasing community, researchers have been showing the importance of the structure of complex systems, i.e. their networks, as a powerful tool in order to understand, to predict, and even to control such systems.

4.2 Basic Definitions

4.2.1 Representing Networks

Networks or graphs can be seen as abstraction to how things are connected. They are represented by a collection of *nodes*, *actors* or *vertices* and a set of *links*, *ties* or *edges* connecting them, respectively. The nomenclature can vary according to area such as computer scientists prefer nodes while sociologists prefer actors.

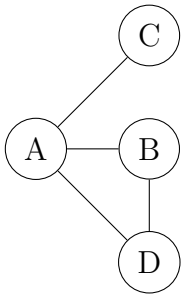

Figure 4.1: A simple network.

In Figure 4.1 is shown a network with 4 nodes and *edge list* (A,B), (A,C), (A,D), and (B,D). A more intuitive way to represent networks is using an

adjacency matrix where each element can be defined as

$$A_{ij} = \begin{cases} 1 & \text{if there is a link between nodes } i \text{ and } j, \\ 0 & \text{otherwise.} \end{cases} \tag{4.1}$$

For example, the adjacency matrix of the network in Figure 4.1 is

$$\mathbf{A} = \begin{array}{c} \begin{matrix} A & B & C & D \end{matrix} \\ \begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix} \end{array} \begin{matrix} A \\ B \\ C \\ D \end{matrix} .$$

Note this network is undirected, i.e. its adjacency matrix is symmetric and if we use a link connecting i to j, there must be another one connecting j to i. We also can see there is no *self-loop* since the diagonal has only zeros. The network in Figure 4.1 is unweighted, i.e. its links only inform connectivity, but not *strength* of connection. Weighted networks, on the other hand, can represent the intensity of the connection, they are defined as

$$A_{ij} = \begin{cases} w & \text{if there is a link between nodes } i \text{ and } j, \\ 0 & \text{otherwise.} \end{cases} \tag{4.2}$$

where w can be distance, number of calls, number of co-authored papers, etc.

4.2.2 Networks Properties

Degree

Degree is the number of connections a node has and it is commonly used as a centrality measure [70]. We denote the degree of node i by k_i and, for an

undirected network of n nodes it is calculated as

$$k_i = \sum_{j=1}^{n} A_{ij}. \tag{4.3}$$

As the number of links is doubled in an undirected network, the number of links m is given by

$$m = \frac{1}{2} \sum_{i=1}^{n} k_i. \tag{4.4}$$

The mean degree c of a node in an undirected network is

$$c = \frac{1}{n} \sum_{i=1}^{n} k_i, \tag{4.5}$$

or combining equations 4.4 and 4.5 we get

$$c = \frac{2m}{n}. \tag{4.6}$$

The maximum number of links in a simple network[2] is $\binom{n}{2} = \frac{1}{2}n(n-1)$. The density ρ of a network is the fraction of links that are in fact present:

$$\rho = \frac{m}{\binom{n}{2}} = \frac{2m}{n(n-1)} = \frac{c}{n-1}. \tag{4.7}$$

Degree Distribution

The degree distribution is one of the most important property of a network. It shows how is the frequency of degree in the network. Although it is not enough to reveal the complete structure of a network, it can gives very important information about network behavior and helps in theoretical network modeling [70].

We define p_k to be the fraction of nodes in the network with degree k. In Figure 4.1 we have $n = 4$ nodes, of which, 1 has degree 1, 2 have degree 2,

[2]Simple networks do no have self-edges or multiedges.

and 1 has degree 3. Then, p_k values are

$$p_0 = 0, \quad p_1 = \frac{1}{4}, \quad p_2 = \frac{2}{4}, \quad p_3 = \frac{1}{4}, \quad \text{and} \quad p_{k>3} = 0. \tag{4.8}$$

The degree distribution (p_k) is commonly seen as probability and it is plot as a histogram (see Figure 4.2).

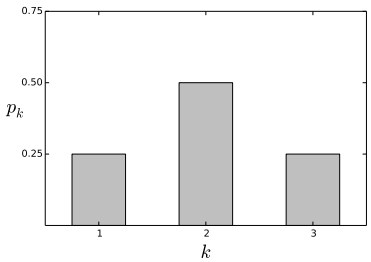

Figure 4.2: The degree distribution of network in Figure 4.1.

Diameter and Shortest Paths Length

A *path* is any sequence of edges connecting any pair of nodes. Path length is the number of edges in this route (distance between source and target nodes). A primary property of a network is its *diameter*. The diameter is the largest *shortest path* between any pair of nodes in the network. The shortest path is also known as *geodesic path*. Many other properties are defined in terms of number of paths, average length of paths, etc.

Clustering Coefficient

The local clustering coefficient C_i of node i is the likelihood of any of its neighbors are also themselves neighbors (it ranges between 0 and 1) [95]. It is the ratio of the number of links between neighbors of node i, denominated E_i, and the total number of possible links between them:

$$C_i = \frac{2E_i}{k_i(k_i - 1)}, \tag{4.9}$$

where k_i is the degree of node i.

The *average clustering coefficient* of a network,$\langle C \rangle$, is given by averaging C_i of all nodes

$$\langle C \rangle = \frac{1}{n} \sum_{i=1}^{n} C_i. \tag{4.10}$$

There is a different metric called *global clustering coefficient* that measures the total number of closed triangles in a network. This metric is often called as the *number of transitive triplets*, proposed back in 1940s [59] [94].

Centralities

Many research in network science use the concept of centrality. Depending on the area, the centrality of a node can mean importance, power, influence, connectivity, among others. Most of these concepts were originally developed for social network (suggestive name for social relations) [94], but they are largely applied to many fields.

- *Degree Centrality* – one of the most simple centrality, and as the name suggests, it is the number of links of a node. Conceptually, as more connections one posses, more potential to be influential he/she has.

- *Closeness Centrality* – measures the overall proximity to other nodes in a network [11, 82]. Someone closer to everybody else would receive new information quickly and this could lead to advantage. The closeness centrality C_i of a node i is given by the inverse of its *farness* l_i. If d_{ij} is the geodesic path between nodes i and j, then

$$l_i = \frac{1}{n} \sum_{j} d_{ij}, \tag{4.11}$$

$$C_i = \frac{1}{l_i} = \frac{n}{\sum_j d_{ij}}. \tag{4.12}$$

- *Betweenness Centrality* – embeds a different concept of centrality mea-

suring the importance of a node as being part of the communication between other two nodes [41]. A node with high betweenness could charge or control the information flow of the network. Betweenness centrality x_i of node i is the number of geodesic paths between any pair of nodes that pass through i, and it is given by

$$x_i = \sum_{st} n_{st}^i, \tag{4.13}$$

where

$$n_{st}^i = \begin{cases} 1 & \text{if } i \text{ lies in the geodesic path between } s \text{ and } t, \\ 0 & \text{otherwise.} \end{cases} \tag{4.14}$$

- Others – there are many other metrics such as *Eigenvector Centrality*, *Katz Centrality*, and *Page Rank*, please refer to Newman's book for further details [70].

Communities

An interesting concept often applied in network analysis is community detection. It consists in partitioning the network into concise groups. Clustering coefficient and betweenness centrality are commonly used by community detection algorithms since their goal is to separate the nodes in such way that maximizes the clustering within the groups. There are several algorithms for this purpose, but to cite few: miminum-cut [68], modularity maximization [69], clique percolation [73], and SOCIAL (self-organized entropy-based algorithm) [22].

Chapter 5

Conclusion

In this work, we can see how old and new studies can be bound together, as seminal theories still motivate new research and new data can be used to provide new theories. Although network science is a recently field, it has already revealed its potential to advance our economics and societies to a more egalitarian reality.

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