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# Social Connectivity and Cognitive Instability*

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## Abstract

This report attempts to translate findings on the link between connectivity and stability in large, highly connected networks to systems where complex networks are established through social ties between individuals. In the abstract theory of complex networks, their intrinsic tendency toward dynamic instability can be mitigated through various measures. Here, we present some basic findings on complex networks and then apply them to situations of social interaction. We select a few real-world examples of social instability generated by connectivity and ultimately focus on the problems of connectivity, particularly that which occurs through digital social networks among adolescents.

## Keyphrases

Complexity versus stability in complex networks; stabilization procedures in highly connected networks; instability and stability in highly connected social communities.

## Contents



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## Introduction

Research in the early 1950s by Ross Ashby gave the first indications that highly connected systems had a strong tendency to instability as the size of the system increased (Ashby 1950). These early investigations, conducted by a psychiatrist using artisanal methods (small matrices, use of tables of random numbers, Routh-Hurwitz criterion for assessing stability), nevertheless assumed that the stability of the stationary states of a nonlinear system could be investigated by linear expansions around those states leading to the matrices that Ashby investigated.

These experiments were ratified twenty years later by Gardner et al. (1970) using the computational methods of the time and also adding the degree of connectivity, in addition to the size, of the system. In 1972, May (1972) using Wigner's results on the distribution of eigenvalues of random matrices, gave a theporic confirmation to the empirical results of Gardner et al. (1970).

But a decade earlier, Simon (1962) had proposed a way to stabilize complex and highly connected systems. He spread his idea in a now classic essay "The Architecture of Complexity". This essay disseminated the results of a mathematical analysis of the problem published a short time before Simon and Ando (1961). The basic concept of Simon's idea was that only a complex system was stabilized, creating stable systems loosely connected to other subsystems of the overall structure.

These important investigations of so many decades ago acquire a remarkable relevance in our time, where through communication networks extreme connectivity has been reached. This connectivity has a very positive side, such as the access to the general or specialized public of information that was previously almost inaccessible, such as the wonders of literature, philosophy, art and science, sometimes incunabula stored in highly specialized libraries that are now digitized.

But along with this, there is an alarming and dangerous side. We will avoid here the various forms of conventional crime (drug cartels, arms sales, explosive design, etc.) promoted from both the light and dark nets. Instead, we will refer to the effect of social networks on the formation of the cognitive life of young people in the stages of consolidation of their personality. And we will point out the high risk of disintegration of the *Self* that (we will say metaphorically) the multiplicity of divergent *social vectors* acting on young people can produce.

## Instability of highly connected networks

After a period in which communication networks remained restricted to few areas, following Berners-Lee's invention an information network emerged that superimposed itself on the physical network that was the Internet and created a field of free use of software that gave rise to the emergence of the World Wide Web. Thus, a computer could have multiple websites connected to each other by hyperlinks, which generated a gigantic graph of connections that exceeded by order of magnitude the graph of connections between machines that supported the Internet. The antecedents and events subsequent to this epic that radically marked our era, and abundant technical references, can be found in *Linked: The New Science of Networks* by Barabási (2002).

On the threshold of the twenty-first century, two key articles appeared. The first, authored by Watts et al. (1998), described the structure of *small worlds* of strongly connected systems, but with well-established neighborhoods and eventually scarce connections between diverse neighborhoods; these systems were represented by graphs, and the article details several real systems that satisfied the condition of being small worlds (Watts et al. 1998). The second foundational article was that of Barabási and Albert (1999) who described a property of complex networks that was to be scale-free, which implied having *hubs* that had preferential connections. Their analysis added a theory about how scale-free networks could be generated. It is important to note that both articles defined procedures for deciding whether a network possessed any of these properties.

From these articles, a plethora of theoretical and experimental investigations were unleashed on the now baptized *complex networks*, many of which had the property of being both small worlds and being scale-free. At the same time, and inspired by the environment prone to the creation of communication networks supported by a physical network such as the Internet, communication systems were developed that constituted the well-known social networks such as Facebook or Twitter (today X). These social networks were physically stable. But at the same time, these social networks created other networks, where the components were people. And these human networks, echoes of the technological networks involved in them, are subject to the conditions of instability or stability of the old research of the 1960s and 1970s.

## Stabilization of complex networks

In the case of small-world and scale-free networks, the problem arose if they were subject to Ashby's and May's findings obtained on random networks. Leskovec et al. (2005) found a somewhat unexpected fact: if a small graph (let's say 3x3) that naturally corresponds to a matrix with 1's and 0's is iterated using Kronecker products, a Kronecker power arrives where the graph acquires properties of small world and scale free (Leskovec et al. 2005). This idea showed an easy procedure for exploring the ideas of stability and connectivity. This is achieved by using these Kronecker powers as a skeleton to inject random numbers representing variations in connectivity into non-zero components. But on top of this arose another possibility: looking for ways to stabilize unstable networks in a simple way. We show below simple experiments on these topics.

The matrix of the initial graph that we use, following an example from Leskovec, is:

$$K_1 = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix} \quad (1)$$

Table 1: Kronecker matrices $K_1$ to $K_4$

| | $K_1$ | $K_2$ | $K_3$ | $K_4$ |
|---|---|---|---|---|
| Dimension | 3 | 9 | 27 | 81 |
| Ones | 7 | 49 | 343 | 2401 |
| Components | 9 | 81 | 729 | 6561 |
| Ones/Components | 0.778 | 0.605 | 0.471 | 0.366 |

The second Kronecker power of this matrix is

$$K_1 \otimes K_1 = K_2 = \begin{bmatrix} K_1 & K_1 & 0 \\ K_1 & K_1 & K_1 \\ 0 & K_1 & K_1 \end{bmatrix} \quad (2)$$

which is a 9x9 matrix. In Table 1, we see the properties of the four matrices from the initial $K_1$ to the power of 4 with $K_4$.

On this data we proceed as follows: for each matrix every 1 outside the main diagonal is replaced by a randomly distributed number in a uniform distribution in [-1, 1]. The 1's on the main diagonal are exchanged for random numbers evenly distributed in [-2, 0]. Under these conditions, the stability of the matrices for each of the 4 dimensions is evaluated, performing 20 experiments for each case. The probability of stability P(d), with d dimension of the matrices with random connections, averaged over 20 experiments is: P(3) = 0.85; P(9) = 0.3: P(27) = 0; P(81) = 0.

For this elementary model, we created a stabilization parameter that consists of a negative auto-coupling of the main diagonal elements, enough to stabilize most situations without completely canceling connectivity. Below we show the stabilization parameter $F$ as a function of the number of elements connected from the network for the elementary experiments we have described. These networks described by matrices assume they refer to a single stationary system (and therefore a fixed point) consisting of a multidimensional vector that includes all the nodes of the system interacting linearly. This represents local stability. However, this does not preclude the possibility that the real large and complex system is nonlinear, and similar matrices can be defined to evaluate the local stability of those other stationary states.

There is another type of stability in complex networks: the stability of communication lines between nodes, which is not the dynamic stability we are referring to here. This communicational stability consists of the network's ability to maintain communication between most nodes in the face of the destruction of several of them. This property is found in complex networks, with the important detail discovered by Barabási's team being that scale-free networks were robust against the random destruction of their nodes, but extremely fragile against attacks targeting hubs. This important finding, along with the technical references, is described in the book *Linked* (Barabási 2002).

In the article by Luboeinski et al. (2023), the dynamical approach was refined. There the dimension and complexity of the matrices were expanded, and in addition to considering the case of Leskovec's graphs, the connectivity-stability effect in small-world and scale-free networks was investigated. There it is reported that after many explorations in the different kinds of networks, for dimensions of the graphs matrices between $N = 100$ to $N = 1500$, the stabilization parameter is adjusted to the following equation:

$$F(N) = A(N-1)^P \quad (3)$$

where the empirical parameters are such that $A > 1$ and $P < 1$.

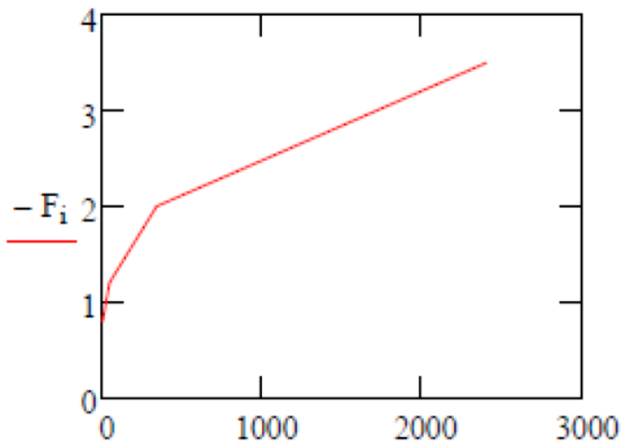


Figure 1: Effect of the stabilizing force. The horizontal axis shows the number of connected elements for each array, and the vertical axis shows the brake F of the instability (a negative number).

## Instability in human social networks

Many research articles have been devoted to the study of the effect on mental health of people's attachment (often a severe form of dependence) to social networks (Zhu et al. 2025). An important situation in this regard is related to the critical ages of consolidation of self-esteem and personal identity: adolescence.

In the research of Vernon et al. (2017) they focus on the sleep disorder that frequently produces the addiction of adolescents to screens. The sum of the disturbance of the circadian light-dark cycle and the problems that are installed in the adolescent who uses his social networks at night have psychopathological consequences such as elevated depressed mood and problem behavior. A recent article by J. Wang, N. Wang, Liu, et al. (2025) with a similar approach to the previous one, emphasizes sleep disorders as triggers of psychopathological problems. Note that these articles do not focus on the problem of social interactions and their effect on adolescents.

On the other hand, this topic is dealt with in depth in research on Chinese adolescents by J. Wang, N. Wang, Qi, et al. (2025). A conclusion of this article is the following: "This study sheds further light on the psychological mechanisms linking bullying victimization and social network site addiction among adolescents. Depression, anxiety, stress, and inhibitory control act as mediating factors in this relationship. These findings highlight the importance of targeting these variables in understanding and developing interventions for social network site addiction among adolescents." Another effect reported by J. Wang, Xiao, et al. (2025) in adolescent populations is the link between social media addiction, decreased physical activity, and the emergence of a phenomenon designated as "ego-depletion" (Hagger et al. 2010). In this condition, mental activity is slowed, self-control is impaired, which can promote violent behaviors or extreme withdrawal.

A special mention of the effect of social networks on adolescents and young people, both for the tragic consequences it entailed, and for the very abundant bibliography it generated from 2016 onwards, is the development of seductive recruitment techniques of adolescents and young people, especially girls, by the terrorist group ISIS. This event produced great family tragedies, especially in Europe and Asia, where families who believed they were living in harmony with their teenage children suddenly experienced the radicalization of their children and the existence of a careful mechanism to move them mainly to Syria or Iraq. In-depth study of this process of radicalization and the psychosocial conditions that promote it can be found in Ramakrishna (2016); Rocca (2017). An important aspect of Islamic State recruitment focused on young Muslim girls, who had not shown an affinity for radicalism in their families. Windsor (2020) was able to carry out a case study of the radicalisation of a young Scottish woman who detailed the stages of her ideological evolution in a blog.

We end this section with a comment by Tolis (2019) since it mentions critical aspects of the affective and cognitive instability of some young people: "It is argued that ISIS has had notable success in recruiting young people, as adolescence and early adulthood can be regarded as delicate life stages during which people are more insecure and can be influenced more easily by their surroundings (Tse 2016). This is also amplified by a global nihilism and a sense of alienation that are both found in young people who live in Western societies."

## Can a complex human network be stabilized?

Of course, we are not referring here to humanity in its entirety. History shows the continuous instability of our species where wars and massacres have accompanied us since we appeared on the planet. Some thinkers who like to be unconventional (e.g. Koestler (1978)), assume the idea that our brain, despite its magnificences, is poorly designed and that this bad design threatens the conservation of our species. In fact, the approximately 200,000 years of existence of *homo sapiens* cannot be compared to the approximately 350 million years that varieties of cockroaches have inhabited the Earth. Surely we have not yet passed the test of evolution.

But here we will refer to the complex human collectivities, today highly interconnected, and we will take a high school as a basis to argue. To simplify the arguments, we will collapse the connectivity-stability relationships we saw earlier, using the second equation of the Kermack-McKendric model of epidemics evolution (currently also called the SIR model). This second equation shows in a very simplified way how a population of infectious agents $I$ can transmit its infection to a susceptible population $S$ in a total population $N$. The model is kinetic and is expressed by the following differential equation that shows the tendency of the infectious population to grow (or decrease) (Weisstein 2026).

$$\frac{dI}{dt} = aSI - bI \tag{4}$$

where $a$ is the contagion coefficient, $b$ is the exit rate from the infected status, and this equation assumes $S, I \ll N$.

In the context of this article, this equation can be expanded and we can consider that in a community of high school students, population $I$ is the most likely to create deleterious effects on the susceptible population. For example, $I$ can represent influential young people who convince those susceptible to the pleasure they will obtain through the use of recreational drugs and thus make addicted a good part of the population over which they have influence. $I$ can also be made up of a group of social prestige, which the susceptible would like to integrate, but to do so they have to share the aggressiveness and bullying against ethnic, economic or psychosexual minorities of the group of students. And so we could go on listing the great collection of temptations that trap insecure, low-esteem students who yearn to belong to a group that, in a sense, creates armor against their insecurity. We do not exclude from this contagion dynamic, the recruitment of young students for terrorist groups, developed in several countries of Europe and South America during the 1960s and 1970s.

Now, this contagion equation generates the famous threshold theorem $T$:

$$T = aS - b. \tag{5}$$

Contagion can only occur if $T > 0$. In the cases of the populations we are studying, $b$ is not usually large, because in order to recover his identity and exclude himself from the category of $I$, the young person must possess the willpower that he did not have when he entered category $I$. Therefore, in the situations we studied, there is a subpopulation $S$ that is going to be 'infected' (that is, captured) and population $I$ grows.

But if it is an infection for which there is a previously well-established immunization, the dynamics of the infection shown by equation (4) are modified, and become

$$\frac{dI}{dt} = a(S - pS)\,I - bI, \tag{6}$$

where $p$ represents the fraction of the previously immunized susceptible population. Under these conditions, the threshold $T$ becomes

$$T = aS\,(1 - p) - b \tag{7}$$

therefore, if the immunization rate is significant, it is feasible to ensure that $T < 0$ and that the contagion process of infection $I$ is minimally transmitted to the population of remaining susceptible people (it is not transmitted if $p = 1$ and all susceptible people are immunized).

To establish a link with the previous treatment of complex networks, let us note that, although the epidemic equation (4) is a great collapse of complexity, in both cases there is a spontaneous tendency to instability (in the latter case if the susceptible population is extensive), and in both cases, stabilization depends on "brakes" that fall on individuals. In fact, these equations from epidemic theory can be interpreted as a statistical simplification of the dynamics of an epidemic in a large network with well-mixed nodes. Thus, $S$ represents a subpopulation of nodes that communicate with each other and are also connected to the subpopulation $I$ of infected individuals. The graph is directed, and some links are virtual (each pair of nodes is connected by two arrows in reciprocal directions, weighted by a connection probability based on the effectiveness of the link). Therefore, the parameter $a$ is the transmission probability of the infection, weighted by the connections of the nodes belonging to $I$ with the nodes in $S$. The parameter $b$ is the probability that the arrows point from some node $I$ to $S$. In the case of prior vaccination, the parameter $p$ measures the fraction of nodes in $S$ that are functionally disconnected from the links originating in subpopulation $I$. It is important to note that the preceding argument is highly schematic and does not take into account that the parameters $a$, $b$, and $p$ of the differential equation have dimensions because time is involved. However, we prefer to avoid this formal fact because it does not change the idea we wish to convey here.

Now, what are the versions of immunization methods in the social framework of a high school and adolescent population? A natural condition is to assume, in the stage prior to adolescence, an affectionate and cultured family environment, capable of transmitting values and ensure a solid education for their young children. We are not unaware of the fragility of these conditions in the times in which we live, with the widespread frequency of ill-prepared or involuntary parenthood, children displaced and voluntarily given over by their parents to electronic games to avoid disturbances at home, and so many social alterations at home and the lack of references that threaten a solid construction of the children's self and their self-esteem. These deficiencies are high risk factors in adolescence.

Another aspect is educational. Partially, family deficits can be compensated for by a solid education that is attentive to the students' situations. But there, teachers, unless they have a great talent for facing children's difficulties with affection and fortitude, are often defeated by a socially harsh and conflictive reality.

In short, the situations are mixed, and that means that the $S$ population of model (4) is fortunately not the entire population of our high school that we have taken as models for this section. Those who are not included in $S$ are those who have been lucky enough to have a solid self and a well-formed self-esteem, which make them immune to temptations. In the family and educational framework, this is equivalent to constructing the $p$-factor of the model (7). It is this group of actions that will exclude the adolescent population from the risk of being susceptible to the negative temptations of a subpopulation of 'infected' $I$. Before concluding this section, we must mention a critical point on which Ann Cavoukian has worked intensively: the necessary effort by families and educators to convey to young people the importance of keeping their privacy (Cavoukian et al. 2010). This preservation of privacy is a critical part of the consolidation of the self, and avoids exposing risky intimacies in an unpredictable social network.

## Conclusion

Complex systems and their tendency to instability can create vast economic crises that lead to the ruin of countries that could not foresee or stop the magnitude of events. Economic history is full of these events and this is not a topic we address here, but we incorporate it as consolidated facts for the theory we mentioned about complexity-instability. In this sense, the creation of economic communities, which create territorial compartments in the economic world, was intended to be a defense, in the style of Herbert Simon, against the risk of instability.

In the nodal part of this work, we have focused on the severe risks of instability of adolescent communities. It is clear that adolescent rebellion must never be extirpated. It is part of the neuroendocrine mechanisms that human beings naturally go through to reach adulthood. The point is that this natural and necessary rebellion is ideal and strongly desirable to occur in people who have previously consolidated their values and their basic identity, as best as possible. This situation gives a positive value to the exploratory nature of adolescence in the search for an adult identity, where rebellion plays a constructive role.

But in our time, this is a painful and conflictive stage of life for these young people who seek refuge, affection and support, often without finding it. As a synthesis of this section, in this year 2026, given the dilemmas of young communities, perhaps nothing better than to mention the already iconic TV series "Adolescence", where director Philip Barantini closes the final scene by superimposing onto the images a touching choir of teenage voices singing Sting's "Fragile".

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