Complectere

What is complexity?

Oliver López Corona

Basic principles for decision making in a complex world

Dr. Oliver López Corona is an applied mathematician and interdisciplinary physicist. A member of the national system of researchers in Mexico, he is an explorer of life who, giving Lévy flights, studies and practices Antifragility.

To my clan, the Featherclaw;
to my mentors;
to my academic father, Pablo Padilla.

PREFACE

We live in a complex world, highly interconnected that changes rapidly, but at the same time we are immersed in a lifestyle and political systems that try to systematically and artificially isolate us from randomness (i.e. combat every wildfire), a process known as fragilization that produces several unintended consequences (i.e. yuge wildfires). It is also a time in which, as never before, those who make these fragilistic decisions that hurt us individually, collectively, and even our natural environment; are isolated from the consequences of their decisions and do not pay for their errors (no Skin in the game), but do benefit every time they can.

In response to this, it is important to speak out openly against those processes that isolate us as individuals and society from the forces of chance and evolution. On the contrary, it is key to promote all decisions, strategies, and processes that minimize catastrophic and scalable risks in exchange for assuming lower and manageable ones; at the same time that they maximize the benefits of those decisions, even allowing themselves to expose themselves to unexpected gains. This work is part of the recognition of the need to continue generating a deep understanding of the concept of Antifragility while promoting its responsible practice.

Complectere book is my personal contribution, that will be delivered into individual chapters/essays to give my readers optionality about what parts of the book they really want to read.

In this way, this is a strange book because it deals with a subject that requires two different but complementary approaches. On the one hand, I will talk about the scientific bases of complexity and randomness, but later in order to enter the subject of decision-making, I will do so from my experience as a practitioner and risk-taker, mainly using my years as a mountaineer and explorer. As a scientist, I have about twenty articles in specialized international journals and a similar number of presentations at national and international conferences. As an explorer, I’ve participated in various expeditions such as 1) Exploration in the jungle of Alta Verapaz, Guatemala (1999). First absolute world climb in El Escudo, the North wall of more than 1000m of La Encantada, Cumbre de Baja California (1999). 2) Tour of the Sierra de Cuchumatanes in Guatemala (2000). 3) Journey through the desert of Coahuila, Mexico (2001). 4) Crossing the Iberian Peninsula by bicycle, 2000Km pedaled. (2002). 5) Probable first western crossing in the Great Altar Desert (Sonora), in just 34 hours without stopping, being the fastest (2002). Crossing a variant of the previous route (2003). 6) Cycling through the Atacama desert, Chile, from the sea to the Andes on the border with Bolivia (2005). I was named one of the three best student mountaineers in the history of the Association of Mountaineering and Exploration of the UNAM and I was nominated for the Student-Athlete award of the UNAM (2002).

The term "Complectere" that gives the book its title is constructed from the Latin root plectere which means "to braid, to bind" to which the prefix com- is prepended, with which the word acquires the sense of the duality of two opposing elements that are intimately intertwined, but without canceling their duality. Thus, the term complexity that comes from Complectere, refers to that which remains intertwined due to the effect of opposite and complementary forces: emergence (randomness) and self-organization (order). Systems in a dynamic regime between order and randomness reach the highest level of computational capabilities and achieve an optimal configuration between robustness and flexibility. The empirical evidence indicates that it is in this state that living organisms, ecosystems, and the Earth itself are healthy.

Another interpretation of complectere from a more random process perspective is that it describes what is known as Lévy flights, which are processes of exploration of the space of possibilities where a completely random local process is combined, with some infrequent jumps of much greater magnitude than typical first process steps. This has been shown to be the way in which the foraging patterns of most animals have evolved. Reinterpreted as an investment strategy, it could well correspond to what Maestro Taleb calls the Barbell strategy, where most of the money (say 80-90%) is invested in very safe instruments and the remainder (20-10%) on very volatile instruments. This avoids the risk of catastrophe (at most you lose the volatile bottom) and at the same time exposes one to the possibility of positive Black Swans.

This understanding of the probabilistic origin of complexity puts us in a position to understand how we can make good decisions in contexts of high uncertainty and complexity. It is here that the current formal tools are somewhat limited and it is better to jump to the practical knowledge, codified by Taleb in his concept of Antifragility. Antifragility is not just robustness or resilience, it is as its name suggests the opposite of fragility.

Fragile systems are the one which loses, which are broken by volatility or time (time allows the expression of volatility). The opposite of fragile is what gains from volatility or time.

In this sense, one of Maestro Taleb's many genius ideas is having realized that in terms of decisions it is impractical if not impossible to try to predict, control, or avoid the random nature of our environment, specifically the Black Swans. So instead of pursuing that chimera, Maestro changed his focus to looking for the best strategy in the face of the unknown, volatility, or time.

Thus, one can go on identifying some basic principles to achieve Antifragility, for example exposing oneself to the right kind of randomness; never take catastrophic risks for example. Make a lot of small and local mistakes, because they get a lot of experience and information about the systems (Barbell strategy). I will discuss these ideas through examples of mountaineering and exploration expeditions. Many of them are famous because their participants or the events that surrounded them, others are my experiences; but in all of them, it is about exemplifying an important characteristic of decision-making in complex contexts.

From there I propose a set of everyday applications of these ideas and concepts to achieve what I have called an Alpine lifestyle or a Lindy lifestyle. All these applications make very intensive use of the idea of a via negativa, that is, to subtract the trivial, the artificial, not necessary, from our lifestyle.

Finally, we are moving towards a transgenerational understanding of risk, understanding our responsibility at different times, and grouping scales. Arriving at what I have called Taleb's Maximum Antifragility Principle, which states that the best decision in a context of complexity and uncertainty is one that avoids damage and maximizes convexity in payments.

Finally, I review a work in progress by Taleb on his proposal for Multiscalar Locality as an organization proposal based on a complex perspective that recognizes the random nature of the world and the ideas of Antifragility.

A few words of caution may be necessary at this point. My experience as a writer is restricted to academia, so this is obviously not a literary book. Also, perhaps I should recommend reading directly to the teacher NN Taleb who of course is ahead of me in erudition, clarity, and philosophical depth. You would also benefit from reading the original chronicles of Carlos Rangel. So I sincerely recommend you not to read my book. I want to be very clear about this ... most of the ideas in this writing most likely come from one of these teachers: NN Taleb, Alejandro Frank, Carlos Rangel, among others. I doubt that I have introduced many new things except the connections between them, that is, between the unknown, complexity, and risk-taking in the adventure. When one has read and admires a teacher as much as I admire them, a kind of intellectual intertwining invariably forms. I have tried to be careful about citing and referencing whenever necessary and I hope I have not omitted anything (unless otherwise stated, the images used come from wikipedia or wikicommons and are under a CC free use license), from being so, I ask you to let me know dear reader.

If despite these warnings you decide to buy and read it, I hope you will find connection nodes for your own ideas

What is complexity?

Complectere is constructed from the Latin root plectere which means' ”to braid, to bind” to which the prefix com- is prepended, with which the word acquires the sense of the duality of two opposite elements that are intimately tangled, but without canceling its duality. Thus, the term complexity that comes from Complectere, refers to that which remains intertwined as a result of opposite and complementary forces: randomness and self-organization.

In general, these two forces act through very simple components that interact with each other and with their environment, often non-linearly, and without central control. These forces thus give rise to a set of properties that we have identified common to most of what we call complex systems: the existence of heterogeneity, hierarchical order, openness, adaptation, memory, emergence, and anticipation.

The consequences of this are that complex systems generate new information not contained in the original description of their parts, but rather arises from interactions. Furthermore, it is common for these interactions or the properties that emerge from them to change at an observable rate. This implies that complex systems are generally unpredictable and uncontrollable.

But we have gone too far towards this, which would be our proposal for the definition of complexity.

One of the most impressive characteristics of complex systems is that they are very simple at heart, in the sense that their components are very simple. Take for example what is known as the game of life.

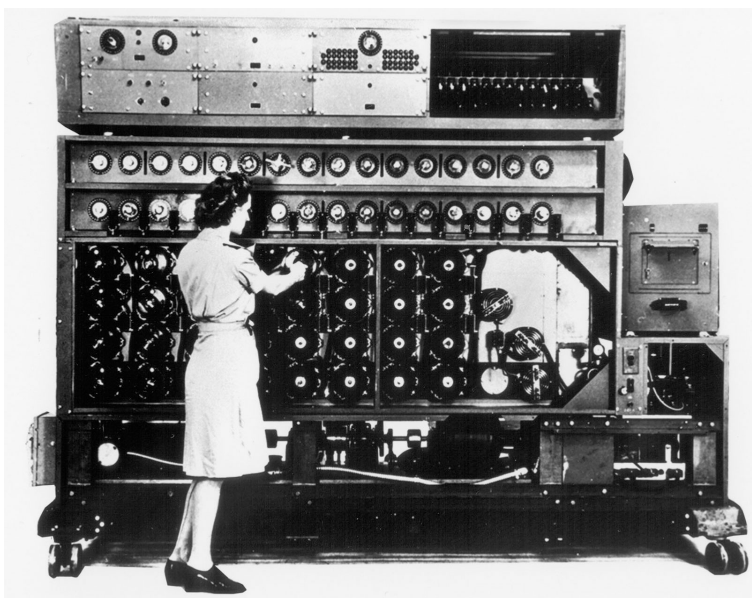
British mathematician John Horton Conway's game of life was first featured in the October 1970 issue of Scientific American magazine, in Martin Gardner's mathematical games column. From a theoretical point of view, it is interesting because it is equivalent to a universal Turing machine, that is to say that everything that can be computed (algorithmically) can be computed in the game of life.

You may have heard of Truing from the film that takes part in his life as the main plot, Enigma (2001). The title of the film was taken from the encryption machine used by the Nazis during WWII and finally cracked by the first Turing-built computer, Ultra (reminds you of Ultron?).
In the image, a public domain photograph is taken from Enigma's Wikipedia.

Of course, that oversimplified version is very unfair to the heroic work of the Poles before the appearance of Turing who not only intercepted a non-military grade Enigma machine before the war but also from their study, Marian Rejewski, Jerzy Rozycki and Henryk Zygalski managed to break their code from a formal mathematical perspective. However, as the character Fat Tony would say in the monumental work on the role of randomness in life and decisions, *Uncertainty* Taleb's, and that is largely the source of inspiration for many parts of this work. "In theory, there is no difference between theory and practice, in practice there is" Taleb

And it is that one thing is to solve a formal mathematical problem and quite another is to be able to perform the calculations to be able to apply it in the real world. It was there that the genius Turing and his collaborators (excuse me for being systematically unfair) put a twist on WWII by being able to effectively decode Enigma-encrypted war messages using their Ultra (mechanical) computer.

In honor of Turing, a device that manipulates symbols on a strip of tape according to a table of rules is called a “Turing machine”. Despite its simplicity, a Turing machine can be adapted to simulate the logic of any computer algorithm. In the same way, a Turing machine is defined as a device that is capable of simulating any other Turing machine. So, when we say that the game of life is a universal Turing machine, we are not saying anything.



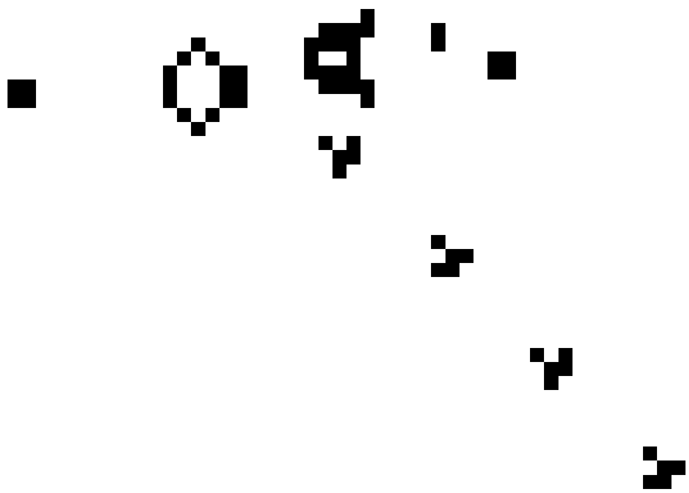
An American-made version of the Bombe, a machine developed in Britain for decrypting messages sent by German Enigma cipher machines during World War II.
The National Museum of the US Air Force (070918-F-1234S-006)

The amazing thing is not that it is a universal Turing machine, but the simplicity of the game of life.

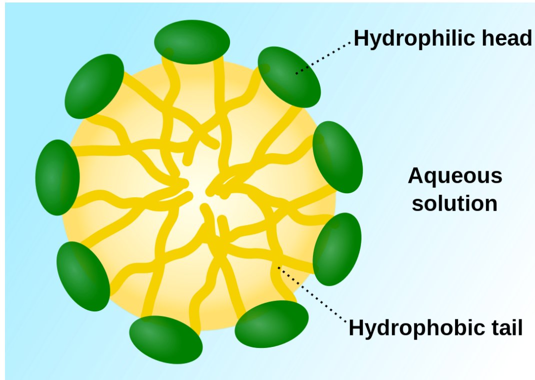
The game of life is a zero player game, which means that its evolution is determined by the initial state and does not require any subsequent data entry. The game takes place on a virtual board thought of as a flat rectangular mesh in the style of a chessboard in which each square is called a "cell" and which has a set of variables or properties defined in it. The state of all the cells is taken into account to calculate the state of the cells the next turn, in a scheme of first neighbors (the eight cells contiguous to anyone in particular). All cells are updated simultaneously on each turn, following these rules:

(1) a dead cell goes to a living state, with exactly 3 neighboring cells alive (that is, the next turn it will be alive); (2)
a living cell with 2 or 3 living neighboring cells is still alive, otherwise, it dies (from "loneliness" or "overpopulation").

The interested reader could explore this implementation of the game of life online: https://pmav.eu/stuff/javascript-game-of-life-v3.1.1/ or if you even want to learn how to program or modify it, you can visit the implementation in NETLOGO which can be explored either online or by downloading:
https://www.netlogoweb.org/launch#https://www.netlogoweb.org/assets/modelslib/Sample%20Models/Computer%20Science/Cellular% 20Automata / Life.nlogo
In the image above taken from wikipedia with a CC license, with these very simple rules

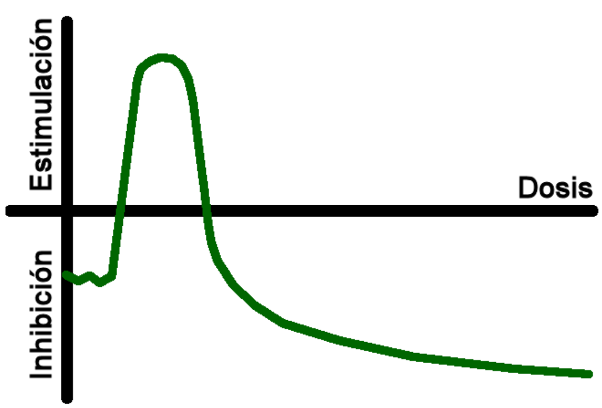


we can observe how space-time patterns arise (or emerge) like these patterns that travel from the upper central part diagonally down to the left. These patterns known as sliders cannot be predicted based only on the initial state of the system.



Another great example of this is surfactants, molecules for example in the form of sperm that can have hydrophilic heads and hydrophobic tails like those shown in the image on the left taken from Wikipedia with a CC license. One can perfectly know all the physical-chemistry of a surfactant molecule and we could not predict the emergence of spatial structures such as micelles (these spheres of surfactant molecules) once a certain critical concentration is exceeded from which these molecules are they self-organize (evidently without central control).

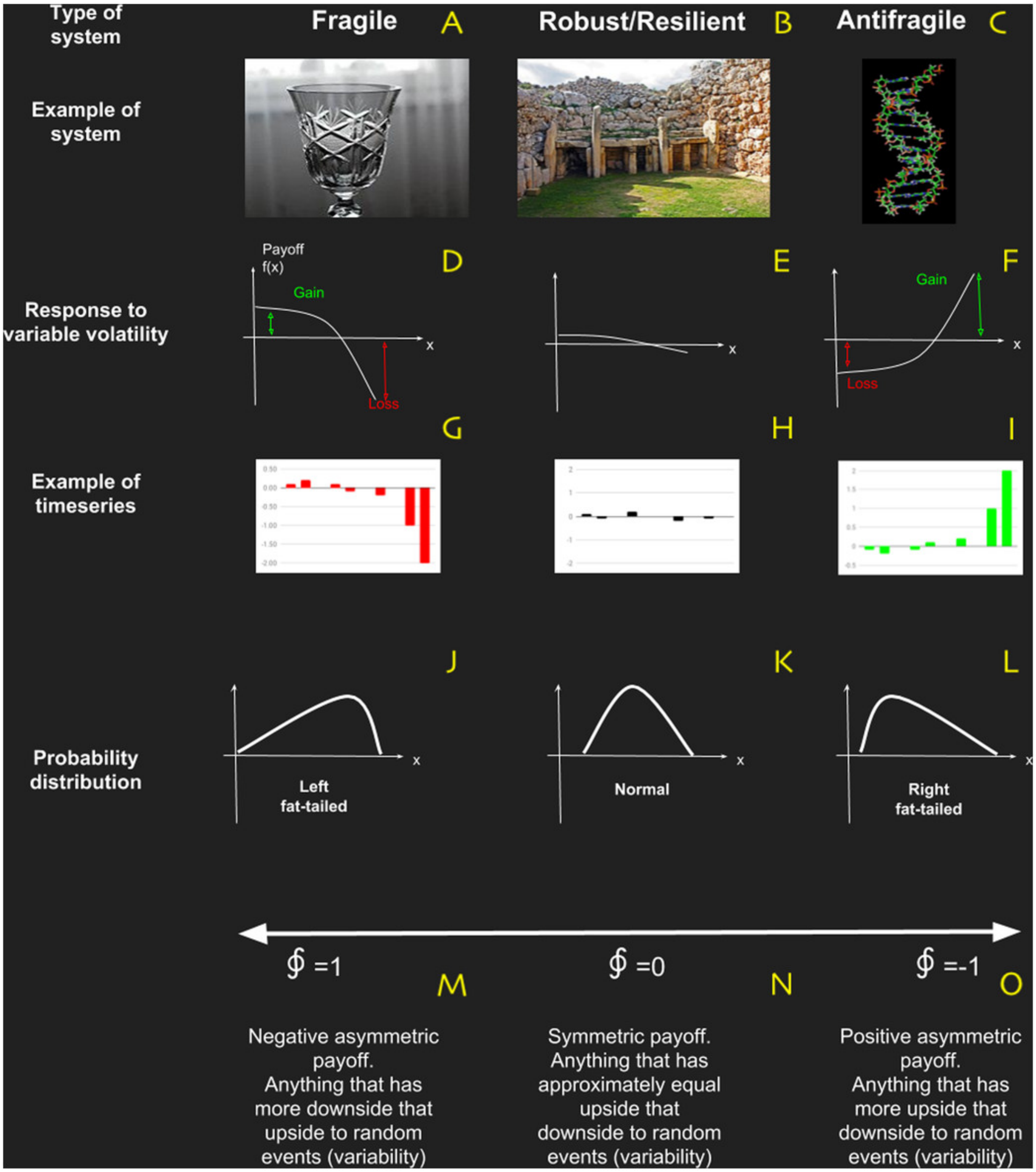
Although it is not restrictive to be considered a complex system, most of the interactions between these simple elements tend to be non-linear. The simplest metaphor to understand what non-linearity means has to do with how our body reacts to stimuli or disturbances. Consider that we are climbing on a platform that can increase in height from a few centimeters to ten meters. While a jump off the platform from a few inches would be barely noticeable, a drop from half a meter to one meter can even be stimulating to the muscles and skeletal system. From that height, in most cases, the body would begin to suffer damage and eventually die from the impact. That is, the body's response to a fall from a height Y changes depending on the magnitude of Y.



The same happens for example when a chemical is supplied (see figure on the left taken from Wikipedia with CC license), how the human body reacts typically dependent on the dose that is administered. At very low doses there may be no effect, then as the dose is increased, beneficial effects may appear, until a maximum benefit is reached at a critical dose, beyond which the benefits begin to disappear and become harmful, and eventually, there would be poisoning and death. Much attention in this regard has been given to determining the appropriate doses of exercise to obtain the maximum benefit from it[1] This non-linear response idea

[1] https://pdfs.semanticscholar.org/474f/ca21c496f489c26f4ea8c10e69a88d95f44b.pdf

of the body around food has received a lot of attention recently. While it is clear that not eating leads to death, various authors in books, popular articles and in peer-reviewed scientific journals point to the benefits of intermittent fasting[2]. Not surprisingly, these practices exist in virtually all classical cultures. We will cover this in more detail in the applications section.



[2] http: // online. anyflip.com/oeaj/thrh/mobile/index.html).

The most abstract argument regarding the effect of randomness, stressors, volatility in our life, has been masterfully explored by Nassim Nicolas Taleb in the fourth volume of the Incerto, Antifragile.

"*Some things benefit from crashes; They thrive and grow when exposed to volatility, randomness, clutter, and stressors… they love adventure, risk, and uncertainty. There is no word for the exact opposite of brittle. Let's call it antifragile.*"Taleb, antifragile

Let us consider the image above[3] that shows the basic characteristics of systems in terms of Antifragility, which is the property of a system to respond in a convex way to perturbations or variability.(A–C) are examples of fragile, robust/resilient and antifragile systems respectively; (D–F) are examples of profile responses to perturbations; (J–L) are examples of typical probability distributions; and (M–O) are the characteristic values obtained with the metric based on complexity change.

The simplest idea to define fragile-robust-antifragile is to see the type of response (non-linear) that a system has either to a stressor or volatility. If the system responds concavely (downward curve) this implies that it has more losses than gains and then it is fragile. If it has practically no response, it is robust and if its response is convex (it gains more than it loses) it is antifragile.

To exemplify how fragile-robust-antifragile systems behave in terms of their values over time (last line of the figure), let's think of a public official with a good salary, named Alicia who for 6 years has enjoyed an additionally stable entry month by month. No matter what happens to the economy Alicia receives her fortnight on time. On the other hand is his brother Bruno, who works as a dentist. Bruno's money input can change from day to day but not too much. Finally his cousin Carlos is an entrepreneur. With the recent change of government, Alicia has been asked to resign from one day to the next, Bruno continues working as usual because people will always need to have healthy teeth (Bruno is a good dentist) and Carlos benefited from the laws. Alicia is fragile, her brother is robust, and Carlos, her cousin, is in this antifragile scenario.

The example teachings from an Antifragility point of view include:

1. Limit potential losses by not relying too heavily on a few large customers and expand your options
2. Don't be a turkey
3. Recognize the possibility of extreme events and watch for them to lessen their negative effect or take advantage of them.

The second point is perhaps the central theme of the second volume of Taleb's Incerto, The Black Swan, which represents a simplified metaphor for the problem of induction and which we will present in some detail below.
The six-year term of Miguel de la Madrid (Dec / 82-Dec / 88) in Mexico was characterized by a continuous rise in inflation and the price of the dollar, as well as the

[3] Taken from https://peerj.com/articles/8533/

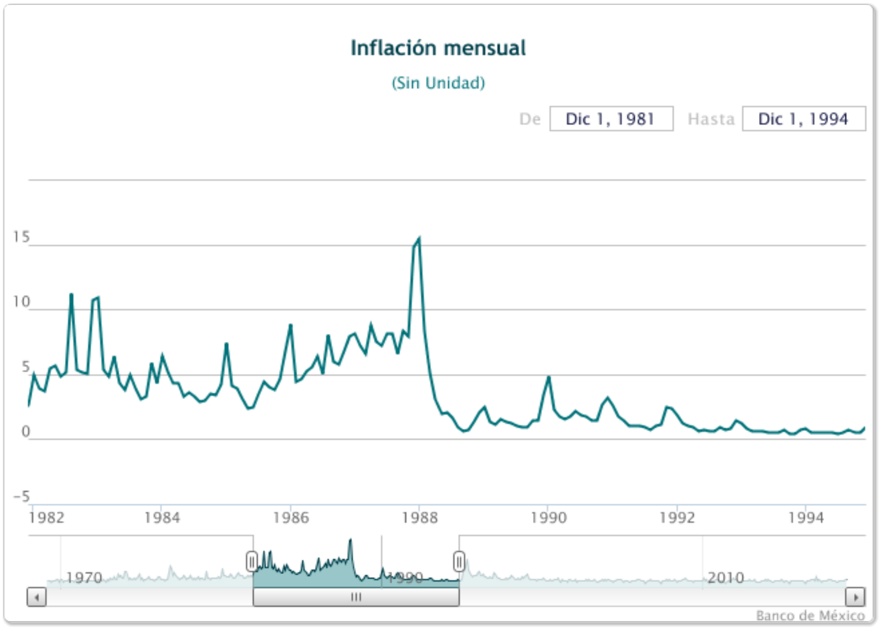
great earthquake in Mexico City (8.5 on the Richter scale with more than 40,000 deaths). So when Mexico came with Salinas de Gortari to what was called "The Mexican Miracle", we all felt like happy turkeys in the fattening season. With the entry into force of the North American Free Trade Agreement (NAFTA it was called in Mexico), we were suddenly in awe of the arrival of the Sams Club, Costco, Nike tennis (not in Tepito or Pericoapa), etc. But it was not just a consumer whirlwind (which it was) throughout the world, it was thought that the country had finally made the leap to developed countries. This (false) image of development and well-being was promoted by Drs Pavo (many of them educated in the Harvard Soviet) who boasted of excellent macroeconomic indicators such as low levels of inflation and the stable price of the peso against the dollar.

“[The fragilista] defaults to thinking that what he doesn't see is not there, or what he does not understand does not exist. At the core, he tends to mistake the unknown for the nonexistent. " Taleb, Antifragile.

However, this type of Dr. Pavo was nothing but fragile who by incorporating mechanisms to suppress randomness in macroeconomics believed they were controlling it, when in fact they were weakened the system.

Don't be a turkey

The Turkey metaphor was introduced by Taleb to show how we are continually deceived by chance. Imagine an academic turkey (in the bad sense of the word, academic! = Scientific) that based on 11 months and so many days of data on, for example biomass of the turkey colony, explains how humans have served their community, everything is running smoothly, etc ... of course until Thanksgiving!
In the same way, the Dr. Pavo of Mexico took their Thanksgiving (a Black Swan event in Taleb's narrative) in what Salinas called (according to our analysis wrongly) "The December error." What was one of the worst crises in modern Mexican history unleashed a worldwide cascading effect "The Tequila Effect."



Data (from Banco de México) that any Dr. Pavo from the Mexican Ministry of Economy could have used. On the vertical axis is inflation during the six-year terms of Miguel de la Madrid and Salinas.

In Taleb's terms, a Black Swan (and capitalized) is an event with the following three attributes:

"I stop and summarize the triplet: rarity, extreme impact and hindsight (though not prospective). A small number of Black Swans explains almost everything in our world, from the success of ideas and religions, to the dynamics of historical events, to the elements of our personal lives. " Taleb, The Black Swan

Without a doubt the December Error qualifies for it, since no Dr. Pavo considered that the crisis could occur, the social repercussions that this crisis had were enormous: in many cases they translated into economic losses for families ; many lost the homes and cars they had purchased on variable rate contracts; others lost everything. And of course, a posteriori, Salinas and others explained everything under the umbrella of the "December error" attributing the crisis to the incoming Ernesto Zedillo. In an upcoming article (https://www.researchers.one/article/2019-01-3), we showed that this is false and that the Salinas stability was an unstable stability by measuring Fisher's information from the inflation time series.

So don't be fooled by chance. While a Black Swan is unpredictable by definition (there are reasons in probability theory that show this), we can generate strategies to lessen its effects or even take advantage of them. In fact, Taleb proposes that the greater the role of randomness in the phenomenon, the more uncertainty in the results, the greater certainty there is regarding the decisions to be made, which we will present later as Taleb's principle of maximum Antifragility, which suggests that the best decision in a context of complexity and uncertainty is one that avoids damage and maximizes convexity in payments.

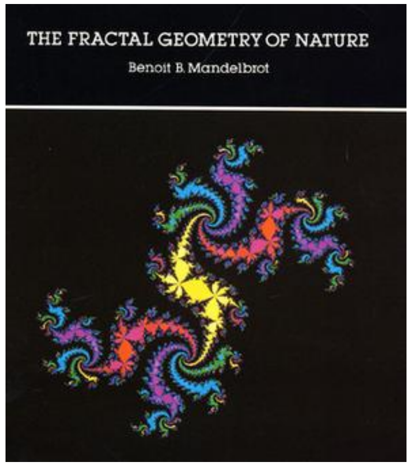
Both losing your job from one day to the next as in Alicia's case, gaining a lot for taking a good opportunity like Carlos or an economic crisis, share a common characteristic, the presence of extreme events like Black Swan. These types of infrequent and unpredictable events are another typical characteristic of complex systems, related to what is known as scale invariance or long-tailed probability distributions.

Scale invariance

"The great book of Nature is always open before our eyes and true philosophy is written in it. ... But we cannot read it unless we have first learned the language and the characters in which it is written. ... It is written in mathematical language and the characters are triangles, circles and other geometric figures. " ***Galileo***

Reading this, one cannot help but wonder if Galileo, the great Galileo, lived without windows. Just open his window and look at a little around him to realize that practically nothing that is not of human manufacture has straight lines, circles, etc. The real dominant geometry in the world is the fractal characterized by power laws and scale invariance.

Of course, this obsession with abstract geometry was inherited from Galileo to Newton, even if the latter was not the reincarnation of the former. A belief that was held for a long time given the dates of death and birth and that Newton was born on Christmas day after his father died, which in the English tradition was a sign of greatness, of being a kind of chosen one. Newton always had a disposition for the study of geometry, but what made him a She was obsessed with the interview with her teacher Isaac Barrow to enter Trinity College, Cambridge. In that interview, it is said that Barrow made Newton look and feel like a true incompetent in geometry, which for us was a very good thing because from then on Newton studied the Elements of Euclid day and night to the degree that in his library this was the most worn book. The importance of Newton becoming the master of geometry is that it was in it that the seed of Calculus was hidden, in fact even though Newton had already developed the calculus well enough when he wrote his Principia, he did so in geometric terms. using a primitive concept of calculus that he called the method of fluxions that he developed in a work of the same name in 1671 before the Principia (1687) but which became known until 1736.

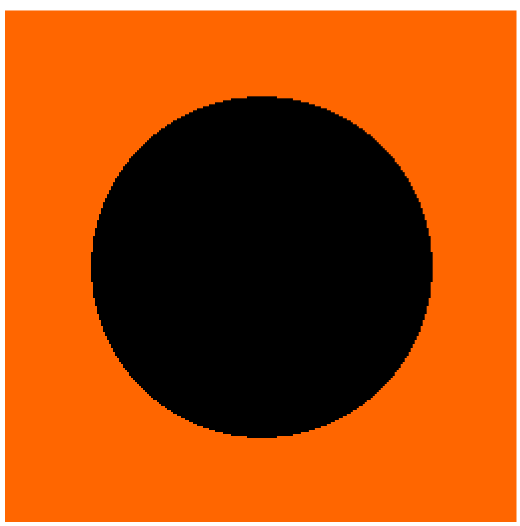


Thus modern Physics, of Newtonian heritage, the predominant idea of geometry is deeply rooted. This is a contrasting fact because, as we have said, the geometry of nature is fractal.

On the one hand, the genius, originality, and sensitivity of the poet of mathematics Benoit Mandelbrot were needed; and on the other, the beginning of the data revolution (we will talk about this in detail later)

so that the true geometry of the world entered science.

Fortunately, Mandelbrot was vaccinated from becoming an IYI by cementing his initial training as a mathematician by studying aeronautics and later working with large volumes of financial data. Very telling is the fact that most of his career was spent in rare freedom thanks to working at IBM rather than a university.



A very unusual aspect of fractals compared to traditional abstractions in physics is that there are no shortcuts, the only way to build a fractal like the one on the left is to follow a very simple algorithm, iteration after iteration. This, which is known as computational irreducibility, is another reason why the true geometry of nature was ignored in favor of the Platonic Euclidean. Until this moment in history we would not have had the computing power necessary to study fractals.

Some of the clearest examples of fractality are the spatial patterns on the earth's surface.[4]

But not just on the earth's surface, in all sides are fractal structures, as in the lungs in the image on the left taken from Wikimedia under CC license. In fact, given that gas exchange (like many physical-chemical processes) is a surface phenomenon, the evolution of fractal structures would have an enormous advantage due to the effect of natural selection, which is much more efficient than entire geometries.

Some years ago when I was a student of Earth Sciences I took a fantastic class on "Soils, geomorphology and vegetation" with two great professors Christina Siebe and Lorenzo Vázquez. They, as good empirical scientists with many years of experience in fieldwork and not only theorizing processes doing geo-fiction, told us how they suspected that the true parent material from which soils are formed is not the layer of "mother rock" but unconsolidated materials, precisely because of the enormous differences in the speed of the physical-chemical processes that the soil requires to form.

Scales and Science

During an interview with Stephen Hawking in January 2000, he was asked - Some say that while the 20th century was the century of physics, we are now entering the century of biology. What do you think about this? - to which he replied - I think the next century will be the century of complexity. But why would Hawking declare this?

[4] :http://paulbourke.net/fractals/googleearth/

To understand this statement, it is convenient that we do a quick review of how science works, in particular Physics.

The scientific method in very simple terms begins with a systematic observation of Nature or a phenomenon; then it continues with a process of measurement and experimentation that allows us to formulate an initial hypothesis, which is tested by subsequent measurements and new experiments, which in turn leads us to modify the hypothesis.

In this way, the first thing that one builds is a Phenomenology or body of knowledge that relates the empirical observations of the phenomena to each other, in a way that is consistent with the fundamental theory but does not derive directly from the theory. Subsequently, a process of classification of the acquired knowledge or Taxonomy begins. Finally, the objective is to recognize, characterize, and, as far as possible, mathematically model universal patterns that we call laws.

In this sense, it is important to highlight that a law of physics is not only its mathematical model but rather a statement that raises the assumptions underlying the model, its domain of application, and restrictions. To illustrate, let's take Newton's second law that everyone thinks they know but that they know incompletely or erroneously.

Try the experiment of asking your friends what Newton's second law is and they will almost certainly answer F = ma. Formulated this way, it is even presented in college-level entrance exams, this is how it is taught in most cases in high school, and it is not surprising then that people confuse a simplified model of the second law with the law.

Let's think for a moment that this is indeed the law then we could consider an experiment to try to show that even in the absence of a force F (push, or pull) an object, let's say a balloon inside a van, can move.

Experiment. Take a helium-filled balloon to float and tie it with a string to the floor of a van. Then perform the following experiments: (i) accelerate; (ii) brake; (iii) drive in a straight line at a constant speed; (iv) drive at a constant speed but back. If you do this experiment you will see results like the ones shown in this video https://youtu.be/y8mzDvpKzfY and you will discover that the only experiment where the balloon stays still in the absence of forces (pushes or pulls) is in (iii) We physicists call this type of experimental context inertial reference systems. Then Newton's second law states should refer to the fact that the law is only valid for inertial frames of reference. In the van experiment, every time the vehicle (the frame of reference) is accelerated, effects that cannot be explained by Newton's second law arise.

In principle, everything is fixed, for example, if now it is analyzed from the street that we could think of as an inertial reference system (at least at this scale). From that reference system, the only thing that is happening is that the balloon follows Newton's first law where an object will maintain its state of motion unless a force modifies it. Of course, the suspicious reader will already be thinking that the street is not an inertial reference system (SRI) either because the earth is rotating and revolving around the Sun. You could then think of the sun as the SRI, but we know that the sun also moves relative to the galaxy. Oh-oh, the galaxy is also in motion. Plus everything in the universe is in motion, so is there a site that is actually an SRI? That is a fundamental question. For Newton the answer was yes, and that SRI was the place where God was. Yes, dear reader, Newton was an extremely religious person. In fact, when he died it was found that within his library there was relatively the same amount of writings on science, as on theology and alchemy.[5]

Now we propose a second thought experiment. Consider the little robot from the movie Wall-e when in the space scene when he wants to rescue his beloved robot EVE uses a fire extinguisher to move. With the simplified version of Newton's second law, we cannot explain this. In order do this, we must remember that what the law states is that the change in the state of motion is proportional to the total force applied and that state of motion is measured by the linear momentum p = mv, in such a way that in reality, the law says Force = Change (p). To use the typical symbols in Physics

$F = d(mv) / dt,$

where the change in time is known as a derivative and considering the multiplication derivative rule, we get

$F = (dm / dt) v + m (dv / dt) = (dm / dt) v + ma.$

In this manner, the simplified form F = ma is only true when the mass does not change over time, which is precisely what happens with Wall-e or any rocket, which loses mass in the form of the jet that drives them and that change in mass. it is the source of movement.

Without further elaboration, the correct form of Newton's second law is:

In every inertial reference frame, the change in the state of motion of a mass particle is proportional to the resultant force applied to it, such that F = dp / dt.

Formulated in this way we know under what contexts the law is valid. Indeed, the laws of Physics are not UNIVERSAL in a formal sense. They are what in mathematics we call theorems, they are valid only in a specific experimental context. Of course, as long as we satisfy that context, the law will be valid.

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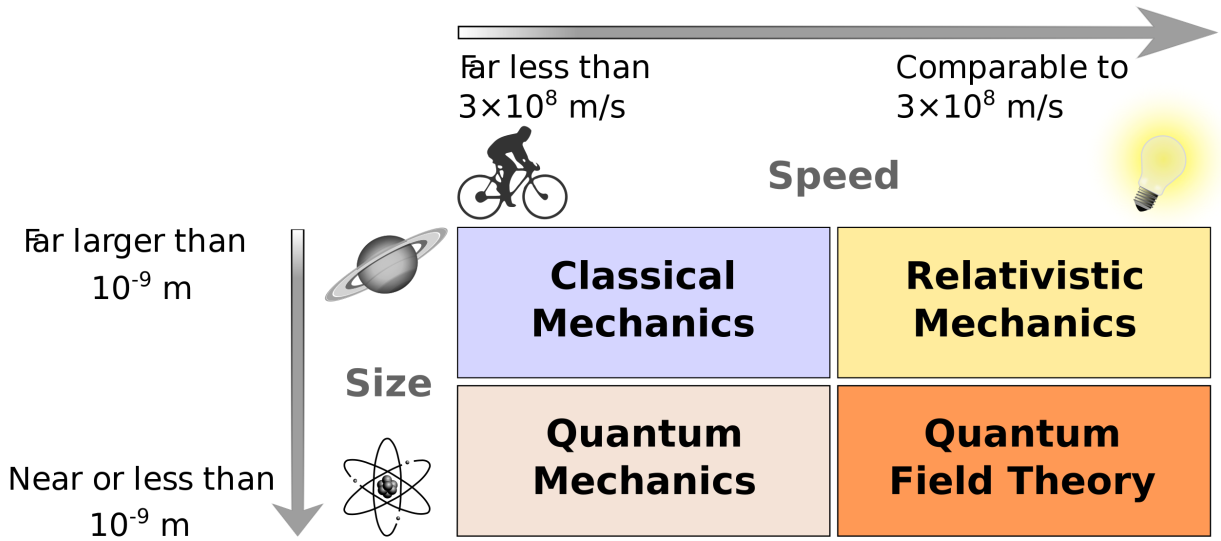
[5] see for example http://www.newtonproject.ox.ac.uk/ or the dissemination talk by the student of Newton José Marquina, professor at the Faculty of Sciences of the UNAM https://www.youtube.com/watch?v=pFLmSMQnBHo

One of the fundamental aspects of Physics is that as you can see in the following figure (from Wikipedia with CC license), in general, we have four domains or well-defined space-time scales within which there is a consistent complete theoretical body, well-validated and that in general does not communicate with the others.



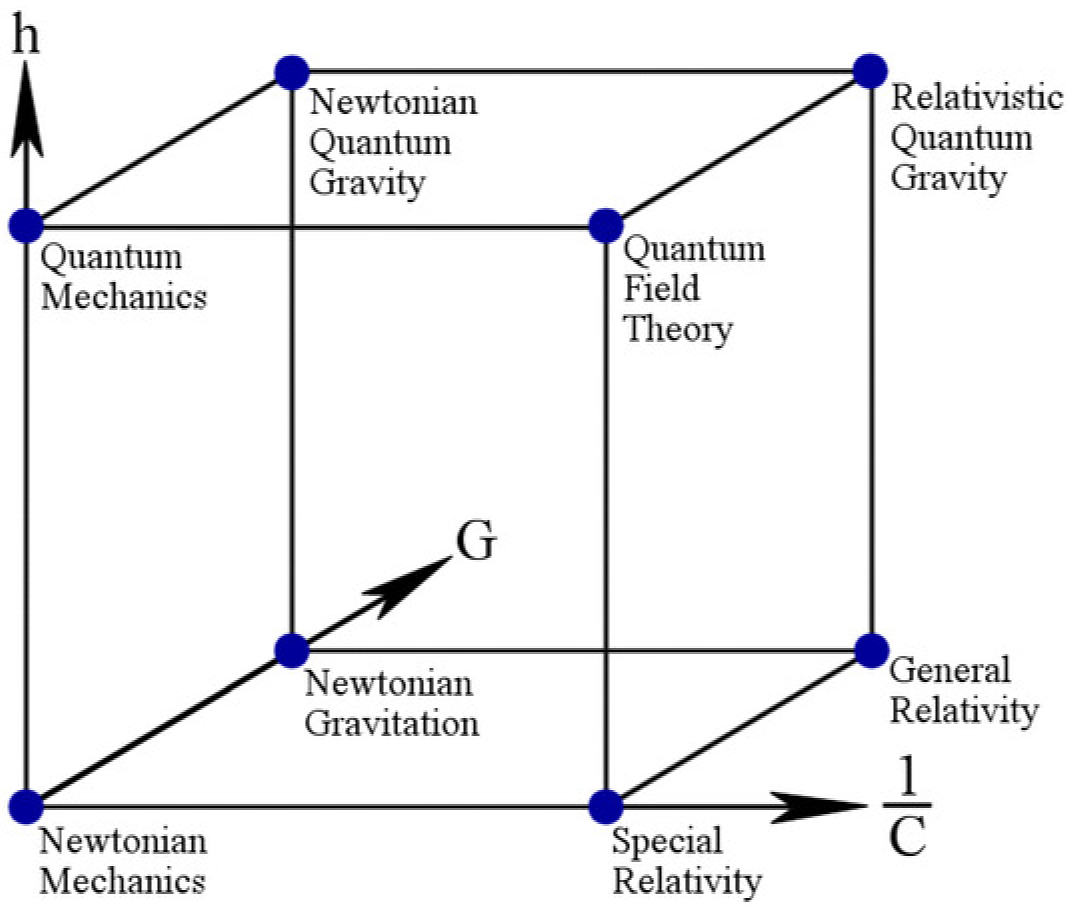
A deeper version of this idea was developed by Okun[6] who took the three fundamental constants of the universe: (1) speed of light in vacuum; (2) Planck's constant; and (3) the universal constant of gravitation.

The importance of the speed of light in the vacuum (c = 3x10 ^ 8 m / s) is not so much that it is the speed of light but that since there really is no true SRI, for the laws of the universe to be the same for all observers, it is necessary that the speed of light in the void is the same for all observers in any CRS and that this is the speed limit in the universe. This restriction gives rise to a new phenomenology that did not exist in the Newtonian description of the universe where space and time are unified in space-time on the one hand and on the other hand energy, mass, and momentum are also unified. For its part, Planck's constant (h), as in the case of the speed of light, establishes another limit in the universe, in this case, that of the maximum inference that can be had in a physical measurement (physical equivalent to inequality of Cramer-Rao in probability) or better known as Heisenberg Uncertainty principle. This establishes that the level of uncertainty (Δ) of a physical measurement of some conjugate variables is always greater than Planck's constant. For example, if we want to simultaneously measure the position (x) and the linear momentum (p) of a particle, we have an uncertainty relation $\Delta x \Delta p \geq h / 4\pi$. This means that one can either measure position or moment very precisely, but never both simultaneously. Additionally, Planck's constant also unifies the energy of a photon with its frequency, E = hf, or in other words, it unifies the corpuscular and wave nature of light.

[6] Okun's cube image taken from https://www.mdpi.com/2218-1997/5/7/172/htm#

The third universal constant (G) relates to the so-called Planck length, time, and mass.

With these three universal constants, Okun proposed putting together a cube in a space of suitable units so that c = h = G = 1, in such a way that the cube has three axes, one for each constant that goes from 0-1. In this way, Okun identifies at each vertex with scales and theoretical bodies of Physics.



At each specific scale, Physics seeks to define what we know as its field theory. A field theory (classical or quantum) describes the set of principles (axioms) and laws (theorems) that allow studying the dynamics (change in time) and spatial distribution of physical fields. Thus, for example, field theory allows us to specifically describe how a physical field changes over time due to its interaction with itself and with the environment. Where we understand a field to represent the Spatio-temporal distribution of a physical magnitude; that is, it is a property that can be measured in the environment of each point of a region of space for each instant of time.

The key point to highlight again in all this is the fact that Physics so far tends to generate theoretical domains (scales). In this way, physics that describes well the phenomena on the scale of the atomic nucleus has little or nothing to do with Physics on the scale of the atom and in the same way, atomic physics does not inform us or explain the phenomena on the scale of the atom. universe itself. There is no theory of everything, a single set of principles and laws that allow us to properly calculate physical fields. This theory of everything was the ultimate pursuit of Einstein and many others.

Scale invariance and probability

So far one might think that there is no major problem, everything is fixed by training specialists in each domain scale and voila. However, precisely in complex systems, this is not possible. Let's think for a moment about the most complex phenomenon that I can recognize, life. What is the characteristic scale of life? Is it the individual, the systems, organs, cells, molecules, atoms? On the scale of ecology, one individual of a species is not enough, life is a web of biotic and abiotic interactions that use multiple spatial and temporal scales. Is a tree a forest? Certainly not. In longer time scales where evolution comes into play, we need to understand, on the one hand, physicochemical aspects of the DNA molecule up to geological effects that make up different contexts of natural selection. Life does not have a characteristic scale.

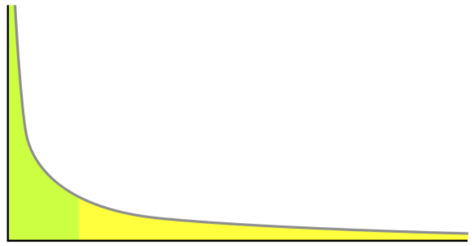
Even if we think about how the life phenomenon manifests itself in the mammalian taxon, we know that the size varies 8 orders of magnitude from a shrew with a mass of 8g, elephants with 2,000,000g, to blue whales with 200,000,000g. Furthermore, the way in which the expression of, for example, the metabolic rate (B) varies with respect to the mass (M) of a mammal is not arbitrary, but rather follows what we know as a power law (a straight line in a logarithmic scale) B ~ M3/4. The same happens, for example, with heart rate (T) and mass (M), which again follows a power law T ~ M-1/4. This has the consequence that in the typical lifespan of each mammal, we all share approximately the same number of beats 1 trillion (1000,000,000).
In other words, regardless of the scale of the mammal in question, they all share the property of having 1 billion heartbeats in their lifetime. The phenomena that follow this type of behavior are generally called scale invariants.

A logical consequence of this type of scale invariance in heart rate is that if we have an approximate of 1 trillion beats, we had better reduce our resting heart rate as much as possible to gain a little more time to live. In that sense, what type of exercise is better? A very interesting debate in this regard took place on twitter pointing out that possibly carrying heavyweights (for example deadlifts) is better than running, because with both the resting heart rate is reduced but during training, it increases much less while carrying weights than running.

Also, carrying heavyweights has a very positive effect on maintaining the integrity of the skeletal system. In the photo, I am lifting 170Kg (three 20s and 1 of 15s on each side) deadlift at one rep, my current maximum (180Kg).

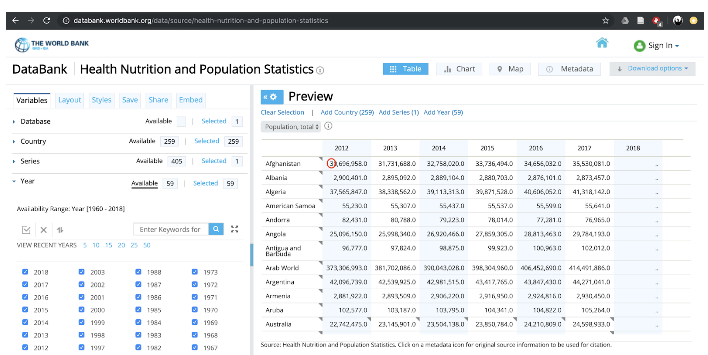
This topic has been extensively studied by Geoffrey West in his book "Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies". Trying to understand why these types of power laws exist in multiple phenomena, he discovered that most of the scaling coefficients were ¾ or close multiples, which led him to propose a universal mechanism that could explain this. Its simplified model is based on the idea that any organism needs to transmit flows of matter, energy, and information and that for this it occupies a pipe system that goes from a maximum thickness and is subdivided into increasingly thin pipes. Effectively using this model he was able to show that the spatial structure of said transmission system effectively gave the coefficient of ¾ (or multiples) as the optimal value that the geometry presented by the system is fractal.

To understand what fractal geometry is, let's think of a sea sponge. The sponge occupies a defined volume, that is to say, that in principle it is three-dimensional. However, being a sponge, it has little holes, so that it does not completely fill the entire volume it occupies. So in reality it is not three-dimensional, its dimension must necessarily be between the plane (2D) and the volume (3D). That is to say that its dimension is a fraction and hence the name of a fractal.

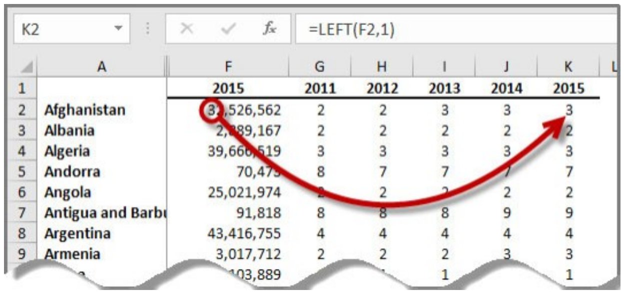


There are many types of power-law behaviors, a very famous example is the so-called Pareto principle (not in the same sense as a principle of Physics) (also known as the 80/20 rule, the law of the vital few or the scarce factor principle) states that, for many events, approximately 80% of the effects come from 20% of the causes.

Another example is Zipf's law (not in the sense of Physics) states that given a corpus of expressions in natural language, the frequency of any word is inversely proportional to its rank in the frequency table. Therefore, the most frequent word will appear approximately twice the frequency of the second most frequent word, three times more frequent than the third most frequent word, etc.: The range frequency distribution is an inverse relationship.
Benford's law (by physicist Frank Benford), also known as the first digit law, ensures that, in a wide variety of numerical data sets that exist in real life, the first digit is 1 much more often than the rest of the numbers. Also, as this first digit grows, the more unlikely it is that it will be in the first position. The law also ensures a certain frequency for the following digits. This particular Bendford law has an interesting application in terms of detecting data fraud.



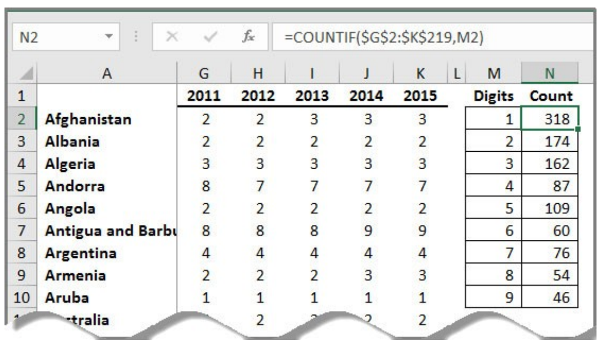
Let's examine the populations of the world's 258 countries from 2011 to 2015, as reported by the World Bank Group's World Data Bank (databank.worldbank.org), using data from the World Population Prospects from The United Nations.



K2 =LEFT(F2,1)

	A	F	G	H	I	J	K
1		2015	2011	2012	2013	2014	2015
2	Afghanistan	32,526,562	2	2	3	3	3
3	Albania	2,889,167	2	2	2	2	2
4	Algeria	39,666,519	3	3	3	3	3
5	Andorra	70,473	8	7	7	7	7
6	Angola	25,021,974	2	2	2	2	2
7	Antigua and Barbu	91,818	8	8	8	9	9
8	Argentina	43,416,755	4	4	4	4	4
9	Armenia	3,017,712	2	2	2	3	3

If you download this database to a spreadsheet you can follow this example to extract the first digit of each population number using the LEFT function (see screenshot "First digit extraction"). As shown in cell K2, the function formula = LEFT (F2,1) reads the population in cell F2 (32,526,562 in this example) and returns the first digit of that number (the digit 3 in this example). This simple formula is then copied across and down to extract the first few digits of all populations (columns G through K in this example).



N2 =COUNTIF($G$2:$K$219,M2)

	A	G	H	I	J	K	L	M	N
1		2011	2012	2013	2014	2015		Digits	Count
2	Afghanistan	2	2	3	3	3		1	318
3	Albania	2	2	2	2	2		2	174
4	Algeria	3	3	3	3	3		3	162
5	Andorra	8	7	7	7	7		4	87
6	Angola	2	2	2	2	2		5	109
7	Antigua and Barbu	8	8	8	9	9		6	60
8	Argentina	4	4	4	4	4		7	76
9	Armenia	2	2	2	3	3		8	54
10	Aruba	1	1	1	1	1		9	46

The next step is to count the occurrence of each number from 1 to 9 within the extracted digits using the = COUNTIF function.This is accomplished by numbering a range of cells from 1 to 9 (as shown in cells M2 to M10), entering in cell N2 the formula = COUNTIF ($ G $ 2: $ K $ 259, M2) and then copying that formula to cell N10.

In this example, we see that the number 1 appears 318 times; the number 2 appears 174 times; the number 3 appears 162 times; and so. To do the exercise, the reader can use this spreadsheet with the data and functions suitable for Excel.[7] As can be seen despite the fact that it is a small base (the test is more reliable the greater the number of data), it follows Benford's law.

In all these cases, these phenomena follow a power law-type probability distribution, that is, the way in which the probabilities are distributed is scale invariant. The notion of a probability distribution is relatively straightforward (to a first approximation). Following

7 http://www.journalofaccountancy.com/content/dam/jofa/issues/2017/apr/benfords-law-workbook. xlsx

a thought experiment proposed by Taleb in El Incerto, let's think about going for a walk down the street asking the height of everyone we meet, recording it in a notebook. Then at home, we ask ourselves, how many people between 1.5 and 1.6m are there? How many people between 1.6 and 1.7m are there? and so on, we can then graph it in what is called a histogram, from that histogram one can build the probability distribution. If we organize the data to see, for example, how likely it would be to find a person who measures 10cm, 20cm, etc. above the average of 1.67m, we will see something extraordinary: the probability of observing someone above the average is non- linear decreasing extremely fast. In such a way that if one wanted to observe a person with a height greater than 2.27 he practically has to visit the current population of the planet. In the same way, observing someone with a height greater than 2.37 is in practice impossible for a population with that mean. The shape of this probability distribution is known as a bell shape, normal curve, Gaussian and Taleb call this type of randomness governed by the mean in a much more suggestive way as “Mediacristan”.

On the other hand, if one repeats the same mental experiment but instead of asking about the height, the total wealth of the individual is measured, one would find something completely different. While in the case of height the rate of decay increases very strongly as we move away from the mean, in the case of wealth the rate of decay typically remains constant. This translates to the probability distribution of wealth decaying much more slowly than a Gaussian in power law form with what is called a “long-tail” on the right, as with the Pareto law seen above. This means that a deviation from the mean that in Mediacristan would have a probability of being observed of 1 in 886,000,000,000,000,000 under a distribution of long tails is 1 in 4,000. If in the randomness described by the Gaussian the mean dominates, in the long-tailed distributions (scale invariant power laws) the extremes dominate and hence the name Taleb gives it: “Extremistan”.

centimeters above the average of 1.67m	height greater than	probability of observing that person 1 in
10	1.77	6.3
20	1.87	44
30	1.97	740
40	2.07	32,000
50	2.17	3,500,000
60	2.27	1,000,000,000
70	2.37	780,000,000,000

On the one hand the phenomena of Mediacristan seem to be restricted by physical limitations in such a way that they cannot climb, while those from Extremistan, on the other hand, seem to have no ceiling to limit them. On the other hand, if the great great majority of events in Mediacristan are very very very close to the mean, then we can make very good inferences or predictions of future events. On the contrary, in extremistan, on the one hand, the data passed by many that are really we do not know how representative they are of the population and therefore we cannot make good inference or predictions, without becoming Turkeys.

If one studies the mathematical foundations of when a random process is Gaussian, one of the indispensable conditions is that each event is independent. If we flip a coin the current result should not depend on any previous results, it should not affect future results. In other words, Gaussianity is the product of the lack of memory in the processes and if they have multiple causes of the sequence of interactions. On the contrary, long-tails arise from processes that have memory or where there are interactions. Midastan is the land of the simple while Extremistan is the home of the complex.

In a 2018 article[8], Taleb showed that in a pareto-type distribution (80/20) much more data (10^9) is needed than if the phenomenon were Gaussian. In other words, if in a scientific study where the variable of interest lives in mediantán statistical rigor can be achieved with, say, 100 data, for a phenomenon from Extremistan, around 1000,000,000 data are needed. The discerning reader will realize that this by itself invalidates a very large number (perhaps most) of studies in the so-called social sciences including economics, sociology, and psychology (not neurosciences).

In addition to the epistemological consequences (on knowledge), understanding that there are two types of randomness helps us just for that pure fact to understand the decision-making process a little better. In particular one might wonder what is the role of chance for example in success. But what does it mean to be successful? it is one of the philosophical questions that we should all ask ourselves. For several years I have thought a lot about it and I still don't know what it is. However, I am convinced that it is associated with having free time and the physical capacities (let's simplify it to money) to pursue our passions, our dreams. And here the problem that many of us have discovered, in general one can have free time or money. So typically one is successful in one of those dimensions, but how can we be successful in both? To understand that question we must first understand the role of chance in our lives.
Right in the days before the computer apocalypse that never happened, join a successful expedition that capped a 23-year process of explorations that began with an event of bad luck.

“After two days of walking and overcoming all the obstacles that the ravine presents, Manuel Casanova and I are high above the river, on the spur of a hill of pure granite rock through which the eyes glide freely in search of a route. We have ascended as

[8] https://arxiv.org/abs/1802.05495

much as possible and from the rocky terrace where we are, we can see for the first time, to the south, the mountain to which we were heading: El Picacho del Diablo.
But we are far, too far from the top and everything has been due to an error: the map marks with the name "La Providencia" the canyon in which we are and another one that is further north: the Diablo canyon, which was at that we should have managed from the beginning. " Carlos Rangel

That bad luck allowed Carlos Rangel, who was later my mentor in mountaineering and exploration, to meet for the first time on El Escudo the north face of El Picacho del Diablo, the highest mountain in Baja California. It was about a thousand meters of imposing vertical granite whose climbing would become a personal obsession that would make him return for 23 years in 10 different expeditions until he managed to ascend it in an adventure in which he participated during the winter of 99.
“The wall is enormous, huge. It rises meters and meters until it loses itself in the blue sky, that sky so dry that it has sucked up the water wells… ”

Being successful in 1999 was the product of a lot of sustained effort. Which is related to two of the laws of success that Barabasi has proposed in his most recent book "*The Formula*" which summarizes several years of his study in complex systems and network theory.

The first establishes in part that performance (being really good at something) effectively leads to success and the second proposes that if you have perseverance (and high performance), success can come at any point in your career. Debunking the myth that success is found only in youth or early career. Carlos was definitely at the top of his scouting performance and boy, was he persevering. Throughout the 23 years that he explored El Escudo, he explored the three access gullies to the mountain.

He explored it in summer: *“The heat is intense. It is the May sun in the desert. The hands are burned on this white rock, but it is necessary not to let go. I am 250 meters above the ground. Although they are with me, my colleagues have decided not to climb a single meter. Thus, one long after another has passed. The protections are scarce and weak. I know I must not fall because even the bushes that serve as assembly anchors are precarious. That's how 250 meters have passed and now I rise ten more meters and after turning a rocky corner, I realize that I have reached a dead end: what follows is almost a hundred meters of friction climbing and without protections ... . " Carlos Rangel, expedition of 79.*

He explored in winter (under conditions of -25ºC and heavy snowfall) and alone, *“The mountain is incredibly snowy. From the desert, it looked white and my friend Roberto Quiroz was even more concerned when I told him that I was going to enter alone ... So I spent three days and nights in that small hollow in search of a route that would allow me to ascend to the summit of the most upright way and fight with the personal demons that had been unleashed inside me and that made me doubt whether to continue up or to go back and confess that I had failed. The weight of loneliness. After many attempts, I decided to go back and when I had put the backpack on to back up, I turned to the wall and wondered how long it could be climbed. Then I saw it: an imaginary line where it could go up, along a ridge to the false summit to the north. From there it would be easier for me to get to the top. " Carlos Rangel, expedition of 82.*

A total of 10 expeditions at the end of which, performance and perseverance delivered the desired success.

Summary of expeditions by Carlos Rangel in 23 years

May 1976

First exploration of San Pedro Mártir. Providence Canyon. Six members.

May 1977

Ascent through the Diablo Canyon to the northern secondary peak and descent through the La Providencia Canyon. 27 participants.

May 1979

First reconnaissance exploration of the wall. Four climbers. Three of them climb to 260 meters and descend because of the difficulties and the heat. The north wall is named El Escudo. Carlos Rangel makes the first ascent to Cerro La Providencia alone.

May 1981

First exploration through the Toledo Canyon (El Cajón). Ascent to the secondary southern summit and recognition of the two slopes of which the canyon is formed. Finding of petroglyphs. Six participants.

December 1981

First ascent to the south summit through the Toledo Canyon (El Cajón). Four participants. You also go through the Pinnacle Ridge to the base of Cerro La Paloma.

October 1982

First ascent to the north summit, through the Devil's Canyon. 22 participants.

December 1982

Solo exploration of the El Escudo wall. Ascent to the north secondary summit and descent through the Devil's Canyon.

May 1989

Exploration of the San Antonio River, during the Californias Walk, where the base of the waterfall that comes from the top of the mountain is found. Two participants.

July 1994

Survival Course in the mountains. The Devils and La Providencia canyons are explored in search of better ways to attack the wall. Eight participants.

December 1999 and January 2000

First world ascent to the Shield, north face of Picacho del Diablo. Five participants: Juan Samuel Leal García, Oliver López Corona, Pavel López Corona, Julio César León Morales and Carlos Rangel Plasencia.

Carlos Rangel was in many ways a stoic hermit who dedicated his life to exploring Nature and with it to exploring his own human spirit. Scholar of the history of exploration, of the history of Mexico, of philosophy and many other subjects; he lived reading, training, traveling and writing. An extraordinary human being who, despite having great expeditions, did not achieve worldwide success. Why? According to Taleb, the big success is due fundamentally to the variance and to chance.

“Mild success can be explainable by skills and hard work, but wild success is usually attributable to variance and luck”. NN Taleb in Fooled by randomness

> For example, out of a population of thousands of musicians all at the top of musical ability, why does one of them in particular achieve worldwide fame? Essentially luckily. Taleb in his book *Fooled by randomness* proposes a randomness experiment in a

computer simulation in which there are a very large number of virtual stockbrokers. Each broker is given a certain level of performance (probability of generating money given a virtual transaction) and a random starting amount of money. If success is to be achieved solely through talent and hard work, then the best performing gifted virtual brokers should be the richest (successful) at the end of the simulation. However, the results show that there is no meritocracy and the results are purely due to chance in this virtual world.

This original approach by Taleb has been strengthened by the work of Barabasi, McNamee (Meritocracy Myth) among many others, such as Pluchino and collaborators (https://arxiv.org/abs/1901.03607) who, studying the bibliographic database of the American Physics Society found that:

“On the one hand, the results highlight the crucial role of randomness and serendipity in real scientific research; on the other, they shed light on a counter-intuitive effect indicating that the most talented authors are not necessarily the most successful ones. " Pluchino et al. 2019

These results of course do not mean that it is useless to cultivate talents, "hard work" and perseverance. But if you point out that GREAT success requires something more, it requires luck.

*“Let me make it clear here: **Of course chance favors the prepared! Hard work, showing up on time, wearing a clean (preferably white) shirt, using deodorant, and some such conventional things contribute to success - they are certainly necessary but may be insufficient as they do not cause success.** The same applies to the conventional values of persistence, doggedness and perseverance: necessary, very necessary. One needs to go out and buy a lottery ticket in order to win. Does it mean that the work involved in the trip to the store caused the winning? Of course skills count, but they do count less in highly random environments than they do in dentistry. "* Taleb, in Fooled by randomness

But can we do more than sit down to have a stroke of good luck? According to Barabasi, yes. We can connect in networks and by doing so in a certain way we multiply the number of potential opportunities to which we are exposed. The second part of your first law of success says that where there is no clear performance metric, it is our networks that determine our success. Furthermore, via connectivity, Barabasi proposes in its second law that although performance is always limited, connectivity is not, and therefore the type of success it brings with it is not either. Performance lives in Mediacristan connectivity in Extremistan.

So many times it's not just you. Despite your talent and effort, you may not achieve the success you seek. Many times it is a chance![9] So we better learn to hack chance, learn how to make it work in our favor and not against us.

9 Not just any kind of chance, especially that of the land of Extremistan, the one that follows long lines described by power laws and that implies scale invariance.

Complectere

The great Mexican physicist Marcos Moshinsky used to tell his students that it is always advisable to understand what one is doing in the simplest possible model. So if we want to understand complexity, following his advice, we should ask ourselves what is the simplest model suitable to represent a complex system.

Moshinsky received practically all the awards that our country grants to its distinguished scientists and many more internationally, among them the awards of the Academy of Scientific Research (1961); the National Science Prize (1968); the “National University” Award for Exact Sciences (1985, the amount of which he donated to those affected by the September earthquakes); the “Prince of Asturias” Award (1988); the “Bernardo Houssay” Award from the Organization of American States (1991); the UNESCO Science Prize (1997), the Wigner Medal (1998), the Weizmann Prize in Sciences and Humanities from the Weizmann Institute (2004), and the “Justo Sierra” Medal for University Merit from UNAM (2005), as well as Honoris Causa doctorates from UNAM (1996) and Goethe University (2000) in Frankfurt, Germany.

His contributions to world scientific knowledge are numerous. His famous work on diffraction in time, from 1952, has been increasingly used from the second half of the 90s. Finally, Marcos Moshinsky made use of the simplest of physical systems, the harmonic oscillator, to solve problems in fields of physics as diverse as molecules and quarks.

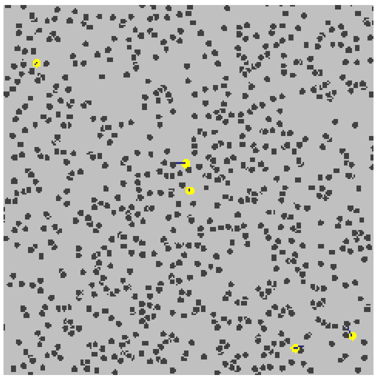
The teacher of teachers, entered El Colegio Nacional in 1972, presented by Dr. Manuel Sandoval Vallarta, with the inaugural lecture: "Symmetry in nature." When one of his students, now an emeritus researcher at UNAM and director of the Center for Complexity Sciences, Alejandro Frank also entered the National College, his inaugural lecture "From the elemental to the complex" was precisely on the subject of symmetries, scales, and complexity.

Just as Moshinsky continually used the harmonic oscillator for a simple model of countless systems, Frank has been using the Ising model as the "as simple as possible" kind of model to understand the complexity. But let's go in parts.

I met Alejandro around 2012 in a postgraduate course from which we published a very simple but beautiful article, where we already proposed some basic aspects of complexity and its relationship with 1 / f noise.

Using probabilistic arguments, we conjectured that 1 / f noise is a fingerprint of a statistical phase transition, from randomness (disorder) to predictability (order), and that it emerges from the contextuality nature of the system which generates it.

The work in question is based on a very simple model that I worked on during my undergraduate degree to understand the foraging patterns (animal movement in search of resources) of spider monkeys. While the group I worked with had real field data on this, my work at the time consisted much more of understanding these patterns, as an anomalous diffusion process in disorderly environments. For us, as physicists and mathematicians, it is very common to make analogies and analogies of analogies. In this sense, spider monkeys moving in the tropical forest can be reinterpreted as electrons moving in a messy material (like a loaf of bread) or as ink diffusing in a turbulent container (eddies).



In turn, this is the same as thinking of an agent (similar to the game of life) that moves by taking random steps in an environment (board) that has resources that are distributed under different forms of randomness (Mediacristán Vs extremistan). Analogy of analogy. In this way, in my undergraduate thesis, I implemented a model of random walkers where initially on the board, trees with different food contents are spatially distributed at random. Given this distribution, a foraging agent (animal) moves to the next closest point with the highest food content.

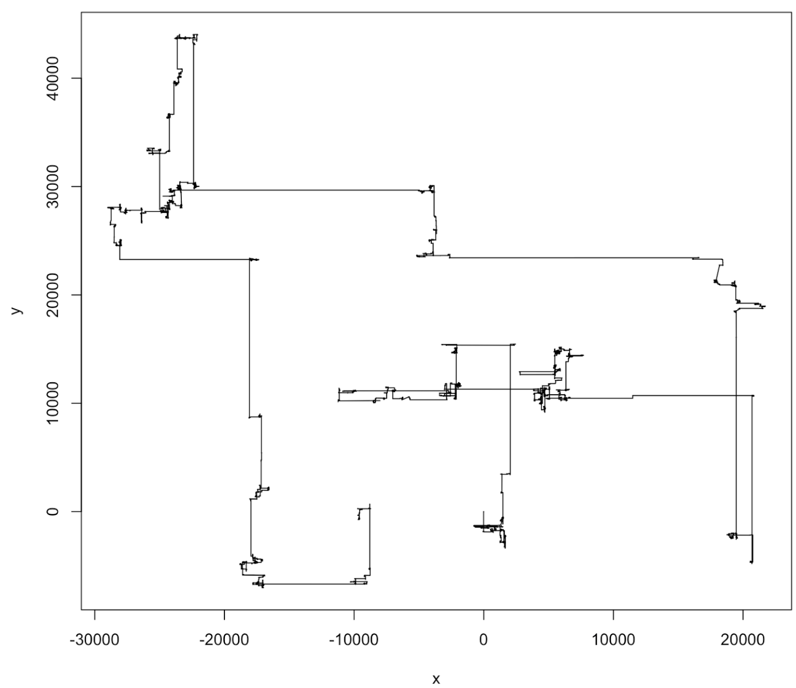
If the food distribution follows a power law (as in real forests) then the slope or scaling coefficient, somehow measures the homogeneity of the resource. When the distribution of resources (food) is very homogeneous (spatial order), the walker moves as a Brownian motion; when it is very heterogeneous (spatial disorder) it does so with what is known as a confined random walk; But if the food distribution is neither very orderly nor very disorderly, but rather follows a fractal geometry (spatial complexity), then the walker performs Lévy flights.

In general, random walkers, with the exception of Lévy's flights, live in Mediacristan, that is, there is a well-defined average value and how much the steps vary with respect to that average (dispersion) is, as we have seen previously, very, very, very little. Lévy flights like the one shown to the left (only an approximation) are made up of two processes, the first a Brownian process and from time to time much larger than average flights or steps. Formally this can be achieved using a Cauchy distribution[10].

This type of foraging pattern has been studied intensively since the seminal work of Viswanathan and colleagues who reported this behavior for the first time in albatrosses searching for fish. From these works, a hypothesis of the optimal search for Lévy flights was formulated, which establishes that due to their statistical properties and the greater speed of diffusion with respect to other patterns, this type of walks described by

[10] The Cauchy distribution does not have first moments (deviation, kurtosis, skewness) defined (they diverge) -> data that have a Cauchy type distribution could not satisfy the TLC, regardless of the sample size. In other words, they can never be modeled by a Gaussian.

scale-invariant power laws , they should be highly represented in nature due to their potential adaptive advantages.



Later, my thesis supervisor, Denis Boyer, and collaborators proved, in a now-classic work, that this Scale invariance(complexity) in the pattern of movement (probability space) was the product of the spatial complexity (fractal geometry) of the resources. In my thesis work, which we later published in a specialized scientific journal, we show with a simple model that it is very likely that there are positive feedback processes between the scale invariance in the distribution of resources and the scale invariance in the dynamics of movement. The idea is very simple. Given a spatial distribution of resources, the foraging agent moves following a random (search) process, be it Mediacristan or Extremistan type. The interesting thing is that, for example, if we think of spider monkeys moving in the tropical forest, these animals consume a lot of fruits and of course after eating them they necessarily have to defecate, so that many times in their feces there are seeds. After some time, if the conditions were right, a tree grows in that place that will eventually have food and that will attract the spider monkey. In this way, the spider monkey moves as it does because of the spatial distribution of resources, but that distribution is as it is because of the type of movement that the spider monkey makes.

Now, if one now looks at the value of the size of steps given by the foraging agent and graphs not that value but its fluctuations (which is so far away step by step from the average value), we obtain what is known as a series time of fluctuations. What is very interesting is that the time series of the fluctuations of any process contain a lot of information about its dynamics.

In particular, if one wonders how frequently an event of a certain magnitude occurs and is plotting that using the horizontal axis is the frequency and the vertical as the magnitude, we can ask ourselves if these data live in Mediacristan or Extremistan. In mathematics, this is called Fourier analysis (the interested reader can see https://www.youtube.com/watch?v=spUNpyF58BY&feature=youtu.be).

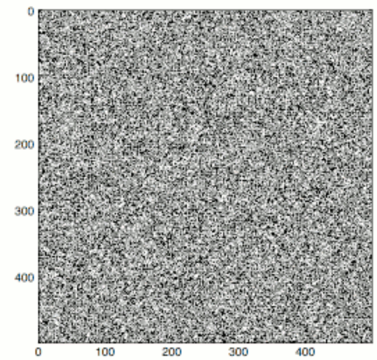
It turns out that many processes in nature, such as animal foraging patterns, follow power laws in this Fourier space (frequency Vs magnitude of the event).

One can show that scale invariant random processes with small negative slopes less than 0.5 are characterized by a lack of memory (little auto-correlation), very little predictability, that is to say, a kind of dynamic "disorder". If, on the other hand, the slope is negative and greater than 1.5, then the process has a lot of memory, it is very predictable and in a certain sense it represents dynamic “order”. It is right there between order and disorder with negative slopes between 0.5-1.5, called 1 / f dynamics, that systems show many of the characteristics of complexity.

Recapitulating, we have much evidence that points to the fact that spatial scale invariance induces dynamic scale invariance and that if this state of scale invariance is in a region of balance between order and disorder, the properties that identify complex systems are manifested.

And this is where we return to the search for the simplest possible model of complex systems since it turns out that the magnetization model of materials known as the Ising model, precisely represents the competition of two processes, one that seeks to order the material and the other that messes it up. What is important is that the Ising model has a critical phase transition (from unmagnetized to magnetized) well-characterized and understood by physics. Hence the name by which this quality of scale invariance and balance between order and disorder is known: Criticality. Thus, even when defining a complex system is very difficult, the concept of criticality can be strategic not only because of how much it is found in nature but because it represents an epistemological anchor that prevents us from becoming complex systems when studying in charlatans.

The Ising model is a physical model proposed to study the behavior of ferromagnetic materials. It is perhaps the paradigmatic model of statistical physics, partly because it was one of the first to appear, but mainly because it is one of the few useful models (not only pedagogically) that has an exact analytical solution (that is, without approximate calculations). This makes it very useful for testing new types of approximations and then comparing them with the actual result.

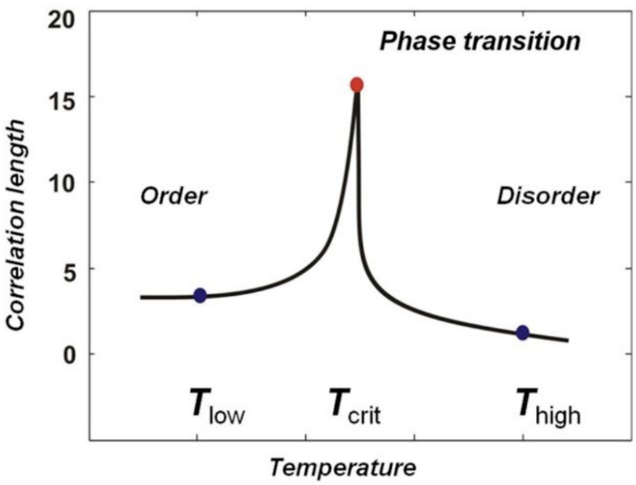


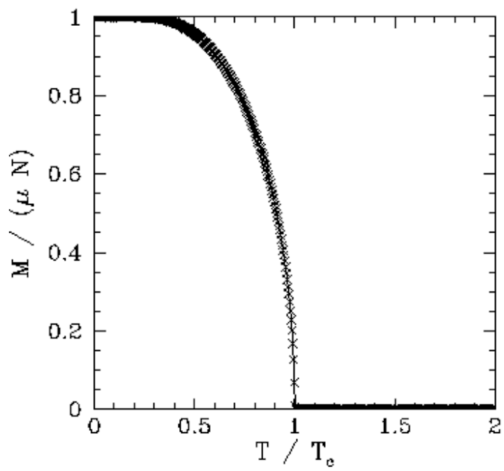
It was invented by the physicist Wilhelm Lenz (1920), who conceived it as a problem for his student Ernst Ising to show that the system had a phase transition. Ising showed that in one dimension there was no such phase transition in his 1924 thesis. This result, although important to Science, caused him profound demoralization and caused him to give up statistical physics. Later people began to study the two-dimensional Ising model which is in fact much more difficult, and for which an analytical description was given much later by none other than Lars Onsager. The 1968 Nobel Prize winner in chemistry demonstrated that the two-dimensional Ising model was indeed capable of describing phase transitions.

The Ising model has essentially two rules. (1) the spins or states of magnetization can only take two values 1 or 0, equivalent to having bar magnets and putting north up or down; (2) the state of a spin is determined by the average of its first neighbors.

If one analyzes the Ising model in detail, it is clear that it is a universal model that captures the dynamics of any system that presents two antagonistic mechanisms, one of ordering (interaction between neighbors) and the other random (temperature). That is why it is an excellent study model for criticality because it allows testing the hypothesis that criticality (in this case well understood and described physical) coincides with a balance configuration between order and disorder.

The interested reader could play around with the ising model in NetLogo online. If you do, you can see that there is a critical temperature that can be accurately calculated of approximately 2.27, above which the magnetization drops sharply, the correlation distance has a maximum and in an article that we are about to send to Evaluation for its publication, we show that there is also a maximum complexity, measured as we will see in the chapter on the topic.



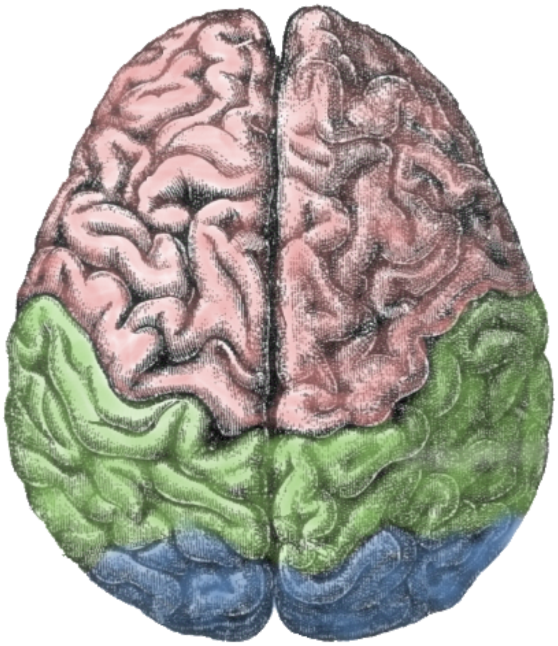


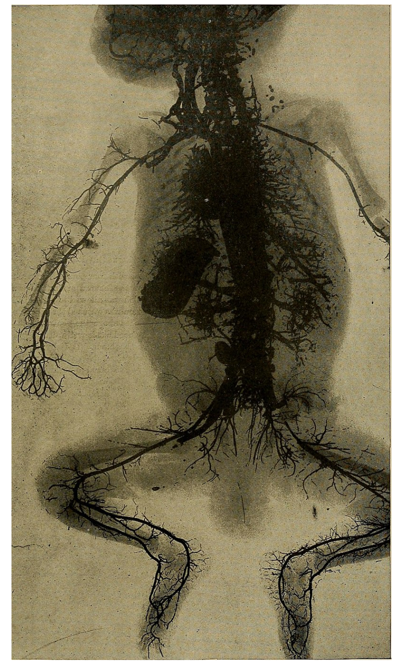
A surprising fact is that many of the life support systems in living beings and particularly in humans have fractal geometry. As we have discussed a bit before, this type of fractal structure has several advantages, such as maximizing the area susceptible to physicochemical processes within a minimum volume, which is extremely useful for gas exchange functions in the lungs for example. Another important advantage is the maximization in the process of transport of matter, energy, and information, as would be the case of the circulatory system, which we can see in the images below, taken from Wikimedia under CC license.

In addition to this spatial fractality (scale invariance), it has been extensively documented that many physiological processes are also scale invariant. In this way, doctors such as Ary Louis Goldberger have begun to speak that health is characterized by a fractal physiology. His pioneering works in the study of the electrical signal of the heart, followed by many others, showed that healthy and young hearts are in criticality, scale invariance in Fourier space, and type 1 / f dynamics. Luca Cocchi et al., Along with many other teams, have shown that as with the electrical activity of the heart, the human brain also works in a state of criticality.

Based on this evidence, what is known as the criticality hypothesis has been formulated, which proposes that:

Systems in a dynamic regime between order and disorder reach the highest level of computational capabilities and achieve an optimal configuration between robustness and flexibility .





Name	Type of randomness	Memory / predictability	Level of organization	Response to environment	Response to randomness
White noise	Mediacristan	Low	Order	Adaptation	Fragile
Pink noise o 1 / f	Extremistan	Critical	Complexity	Complexity	Antifragile Brown
noise	Mediacristan	Much	Disorder	Robustness	Resilient / Robust

A very simplistic argument and caricature to exemplify this hypothesis is to think of a Paleolithic human having a chance encounter with a saber-toothed tiger. In the presence of those terrifying canines, the human would have essentially two options: fight or flight. Now let's think that said fellow had a too adaptable heart, as soon as the saber-toothed tiger roared at him, his heart would fluctuate too much and he would die of an attack. In this way, by natural selection, humans who, due to variability, had too adaptable hearts, would not be represented in current human populations. Symmetrically, an overly robust heart would not allow the heart rate to change to send more blood to the extremities and would be eaten. Again, as a result of natural selection, humans who, due to variability, have too robust hearts, would not be represented in current human populations.

In the same sense, within Alejandro Frank's group where I participate in the Center for Complexity Sciences of the UNAM (https://www.c3.unam.mx/), we think that criticality is precisely a fingerprint of health, for different animal systems (including man), ecosystemic and even planetary.

In relation to this, we have carried out several studies with patients with obesity, diabetes and old age, analyzing the time series of fluctuations in the electrical activity of the heart. Our results[11] suggest that in the presence of natural degenerative processes or diseases the heart loses health, leaving the state of criticality. In all cases with both human and mouse patients, what we have observed is that this loss of criticality occurs on the side of robustness, that is, with age or degenerative diseases we lose cardiac adaptability.

As it is an interdisciplinary center, a fellow anthropologist (Ali Ruiz) proposed to Rubén Fossion another colleague from the expert group in analysis of physiological time series to now become a group of homeless people. As she has many years of experience working with these types of populations, she thought it would be interesting to measure their cardiac criticality because it is well known that these people go through a premature aging process. In this way she thought that a loss of adaptability should be seen as in older adult patients. However, to everyone's surprise, the opposite happened. Surprised by the result, they considered trying to repeat it with an analogous system of "street mice", which were laboratory mice that were subjected to a set of stressors, such as variability in the amount and feeding times or hours of sleep. As in the case of humans in the street, the mice also showed loss of robustness. Based on this result we are conceptualizing this as a social degenerative process.

In this way, as a result of natural degenerative processes, biological systems seem to lose criticality, becoming too robust (they lose adaptability. While due to social degenerative processes, they lose criticality, becoming too adaptable (they lose robustness).

Following this same line of thought, we ask ourselves If we could define an environmental physiological signal equivalent to cardiac activity and analyze it from this criticality perspective Elvia Ramírez, lead author of the article, proposed using ecosystem respiration because it is a process that integrates various spatial and temporal scales and biogeochemical processes in the ecosystem. It is important because not every physiological signal is useful in a criticality analysis, only those that are systemic. Having defined the environmental physiological signal, we analyzed an international database of the Ameriflux consortium, with time series of said variable for

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[11] A summary of this can be seen in this talk by Ana Leonor Rviera: https://youtu.be/PA4FpDpvVT4

many to years with data every half hour. In this way we expand the concept of health as criticality to ecosystems.[12]

Later I began to work in the National Commission for the Knowledge and Use of Biodiversity in collaboration with the Institute of Ecology in Xalapa on the subject of Ecosystem Integrity (see https://www.biodiversidad.gob.mx/sistema_monitoreo/), which gives an account of the state (photography) of the ecosystems considering aspects of composition, structure and function. To estimate the indicator, about twenty variables are used, both from the field and from remote perception, which then feed a model of Bayesian networks.

However, we consider that this is not yet a complete health model because it is necessary to include, on the one hand, some measure of stability / homeostasis and on the other an indicator that tells us how the system responds to disturbances. For this we propose to use Fisher's information and the concept of Antifragility. In this way, our complex model of Ecosystem Health encompasses: the current state of health in terms of composition, structure and function (Integrity); its dynamics (criticality) and the type of response to external disturbances (homeostasis / Antifragility).

In the examples that we have been dealing with throughout the book such as the game of life, random walkers or the ising model, a common denominator is that they are made up of very simple components, the first property of complex systems.

Now we will see one more, the model of the world of daisies. The idea for this model arose from Lovelock's groundbreaking work on the coevolution of atmospheric chemistry and life, which would eventually give rise to his well-known hypothesis of Gaia or the planet as a living being. The Gaia hypothesis proposes that living organisms interact with their inorganic environment on Earth to form a complex, synergistic and self-regulating system, which helps maintain and perpetuate the conditions for life on the planet. At first Lovelock's ideas were discarded, accused of being teleological and not compatible with evolutionary theory by natural selection. However, thanks to Margulis's work on the effect of symbiosis on evolutionary processes, as well as the bases of self-organization and dissipative systems by Prigogine or later Per Bak; the idea of the Earth as a great living being stopped sounding crazy and began to be taken seriously by the bulk of the scientific community. In this way we now have Axel Kleidon's work on the thermodynamics (out of equilibrium) of the Earth as a system[13]; or the ideas of the origin and evolution of life as a thermodynamic imperative[14]. The role of the microbiome as a rapid evolutionary network that enables host organisms to react to

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[12] See the full article here: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0200382

[13] https://royalsocietypublishing.org/doi/full/10.1098/rstb.2009.0310

[14] https://www.intechopen.com/download/pdf/31340

sudden environmental changes[15]; or the general idea of the holobiont[16] ; as well as our own ideas about ecobionts and the technocene[17] that we will discuss in depth later.

In response to these initial criticisms, Lovelock teamed up with Andrew Watson to create a model of an imaginary planet called Daisyworld, which tries to capture in a very simple way the self-regulation of climate by the effect of the interaction of two species of life on its surface: black and white daisies.

For simplicity it is assumed that the daisies have no moisture or nutrient restriction, for example assuming atmospheric water vapor and CO2 concentration remain constant. The planetary self-regulation process has only three components, the incoming energy and the populations of black or white daisies, which of course change the albedo (how much light is reflected by the planet)[18].

At the beginning of a simulation like the ones originally made, the sun's rays are weak so the Daisyworld is too cold to support any life. As the energy received through the sun's rays increases, the germination of black daisies becomes possible and by absorbing more radiant energy from the sun, the planet becomes more habitable for white daisies, whose competing population grows to rival the population of black daisies.

As the two populations reach equilibrium, so does Daisyworld's surface temperature, which sits at the most comfortable value for both populations. Then one can explore what happens to daisy populations under different scenarios of solar activity.

This very simple model is the basis on whichhave been working Alejandro Frank, Juan Toledo and Ana Leonor Riverain combination with global climate time series to show that in recent decades, the planet itself has been losing criticality or planetary health (https://www.youtube.com/watch?v=ETTnUtiBMGc&list=PLZlVBTf7N6Gpc690KyysAO5J8iuc-ffyP&index=66&t=2s).

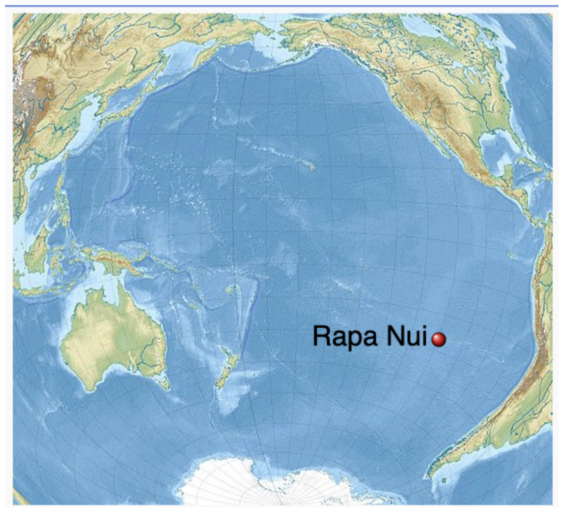
Complexity and civilization

This idea of simple components is the basis of what is now known as agent-based modeling (MBAs), which are a type of computational models to simulate the actions and

[15] https://www.frontiersin.org/articles/10.3389/fphys.2018.01836/full
[16] http://extendedevolutionarysynthesis.com/wp/wp-content/uploads/2017/12/Roughgarden2017.pdf
[17] https://www.researchers.one/article/2019-01-1
[18] https://en.wikipedia.org/wiki/File:This_World_Is_Black_and_White.ogv

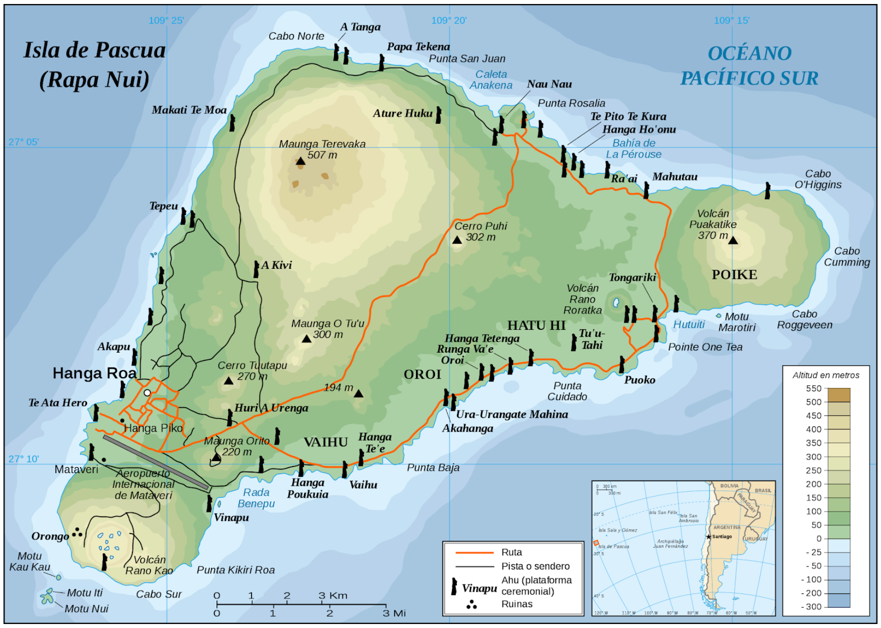
interactions of autonomous agents (individual or collective entities, such as organizations or groups) in order to assess their effects on the system as a whole.

In general terms the MBAs combine elements of game theory, complex systems, computational sociology and evolutionary programming. To show how it deals with it, we will discuss Elisa Schmelkes's model of her bachelor thesis for the collapse of Rapa Nui, which we work on later in terms of complexity and the emergence of cooperation[19].



Easter Island (abov and below, taken from Wikipedia under CC license), also called Rapa Nui by its inhabitants, is a place so remote that its civilization never contacted any other human group since the time of its settlement (c. 000-1200 AD) until the year the first Europeans arrived on the island around 1722 AD. This civilization flourished for several centuries, developing an impressive economy and culture. However, between 1600 and 1800 BC, the Rapa Nui civilization suffered an ecological, social and economic collapse. From an initial population of around 13,000 people, the island's population fell to 3,000 in less than two hundred years. While the reason for this collapse is still unknown, the most widely accepted hypothesis is that the island's excess deforestation caused a food shortage that led to internal warfare and an eventual radical decline in population.

[19] O Lopez-Corona, P Padilla, E Schmelkes, JC Toledo-Roy, A Frank, A Huerta, D Mustri-Trejo, K Perez, A Ruiz, O Valdes, F Zamudio, P. (2017) .Measuring Social Complexity and the Emergence of Cooperation from Entropic Principles. The Collapse of Rapa Nui as a Case Study. International Journal of Environment Agriculture and Biotechnology (ISSN: 2456-1878) .2 (3), 1038-1045.10.22161 / ijeab / 2.3.5 (under CC license)



The population of Rapa Nui got prosperous by growing taro and bananas; raising Polynesian chickens, fishing for tuna, dolphins, and collecting mollusks from shallow waters. Although the island has been barren since we have modern records of it, there is evidence of pollen that suggests that the island was once completely covered by palm trees. For this reason it is assumed that the people of Rapa Nui must have cut down these trees to clear land for agriculture and build boats to fish in the open ocean for example.

On the other hand, the monumental stone statues on the island, called moai, were built during this period of growth and prosperity. It is also believed that the construction, transport and installation of the moai required many resources, for example logs to be able to move the large masses of rock, thus contributing to the systematic deforestation of the island.

According to archaeological evidence, sometime in the 17th century, obsidian spearheads begin to appear in the records, such that after a thousand years of peace, war between the clans of the island appears to have broken out. When the island was first contacted by Europeans, the large statues were still standing, but each successive European visitor to the island during the 18th and 19th centuries recorded more and more toppled moai. By 1850, all the statues had been pulled down and the island had changed to a different religion and form of government.

The fact that this autonomous ecosystem sheltered a population that had no contact with any other civilization, and therefore no trade, migration or military activity, makes it a very interesting natural economic experiment. In her bachelor's thesis, Elisa Schmelkes produced an MBA from the island that could bring us closer to understanding what caused the collapse of Rapa Nui. In the model there is a human population and a finite amount of natural resources that follow a certain regeneration dynamics

In this model, the variable that determines the kind of result obtained in the simulation (stability, oscillation or collapse) is the technology, defined here as access to the scarcest resource in the system. This variable, which is related to labor productivity, affects the speed at which the population grows and, therefore, the speed with which it can recover from ecological shocks.

When a population has little access to its most scarce (renewable) resource, it cannot grow fast enough to erode it and it manages to achieve ecological balance. At intermediate levels of technology, when the population begins to erode the resource, as the population grows, the resource levels decline, allowing the resource to recover and oscillate. Finally, when a population has high access to its scarcest resource, through higher levels of technology, the population grows too fast, exceeding the island's resilience. Once this happens, it is too late for the resource to recover, and both (human population and natural resource) collapse.

To further study the dynamics of the system, the model was later extended to a model based on space agents with several different clans. Each clan is an agent and grows organically according to the rules of the previous model. The finite area of the island is subdivided into patches containing resources, determining the carrying capacity. Each of the patches can be harvested to obtain resources, and its resources can be renewed according to the erosion of the entire island. Each clan initially owns a single patch of land. As clans grow and require more food, they begin to acquire more land by occluding nearby patches, until the entire island is settled.

We also introduced a measure of competence by including in this expanded model several strategies that can be adopted by each of the agents. Following the bacterial coexistence model proposed by Kerr et al. (2002), each of the agents (that is, clans) can use their human resources to (a) be more productive and grow faster, (b) be more aggressive and take the patches of other clans more easily, or (c) defend yourself from the attacks of other clans. Aggression is considered more expensive than resistance and therefore imposes a greater load of resources, generating a similar dynamic to that of rock paper scissors. Besides, each turn the clans see if their strategy has worked by checking if they have grown in the last two turns. If they haven't, they choose another strategy at random.

This generates interesting new dynamics. Initially, clans that invest their resources in growth tend to dominate the landscape and then to fight aggressive clans. At medium and high tech levels, aggressive clans generally win and dominate in the end. However, at lower levels, they mostly coexist when they reach an equilibrium with their environment.

Our results, both mathematical and simulation, suggest that the collapse in the Rapa Nui model occurs only when the socio-ecosystem loses too much complexity.

Of course, the collapse of Rapa Nui is not the only one, in Cem Ānáhuac[20] (what is known as Mesoamerica but which could, according to the independent historian and author Guillermo Marín, range from what is currently Nicaragua to Canada), there are several similar cases of importance highlighting Teotihuacan and Mayan settlements.

In his 2007 article, "Water sustainability of ancient civilizations in Mesoamerica and the American Southwest," Mays establishes the relationship between the availability of water, the capacity of a territory to support a population, and civilizational collapses. In general, he says that many civilizations in America, which were great centers of power and culture, were built in places that could not hydraulically support the populations that developed. To support his idea, he makes several interesting comparisons between Mesoamerican cultures, the Southwestern United States, and the world today in the context of water resource sustainability.

According to Mays, during the period between 150-900 AD (classical) civilizations of great splendor and advance were built in Mexico and the Maya area. These ancient urban civilizations can be divided into two types, depending on the environment in which they developed:

Highlands With "hydraulic" agriculture with irrigation It allowed high population densities.

Lowlands of the tropics With slash and burn agriculture It kept most of the population dispersed in small villages.

[20] From the Nahuatl "cem" (totally) and "Ānáhuac", which in turn derives from the words "atl" (water) and "nahuac" (locative meaning "bypass or surrounded"). It can literally be translated as "land completely surrounded by water", or more formally: "[the] totality [of what is] next to the waters." This expression refers to the continental conscience that already had a reference to the Mexica in front of the American territory, which is surrounded by two important bodies of water or oceans: the Atlantic and the Pacific.

Sanders and Price (1968) proposed that lowland civilizations were maintained without much urban development both by their agricultural system and by the pressures created by urban civilizations in the highlands as was the case of Teotihuacan (image taken from Wikipedia with CC license).

Teotihuacan comes from the Nahuatl, Teōtihuācan which means "place where men become gods" sometimes translated as "city of gods". We must remember that for the Anahuac culture the idea of "God" or "gods" is not the same as for the Judeo-Christian tradition. In fact, in general, people talk about different things when we talk about religions[21]. In this case, the gods are on the one hand philosophical abstractions of essences of nature or qualities and on the other virtues to be cultivated in life. The origin of the name "place where men become gods" suggests that Teotihuacan was a great center for the generation of knowledge and teaching, similar to what we would understand as a university.

The remains of the city are located in the northeast of the Valley of Mexico, in the municipalities of Teotihuacán and San Martín de las Pirámides (state of Mexico), approximately 78 kilometers away from the center of Mexico City. The archaeological monument area was declared a World Heritage Site by Unesco in 1987 and has been continuously studied, constantly offering new knowledge.

Before 300 BC it had a small population spread throughout the valley. By 100 AD, Teotihuacan already covered an area of 12 km2. Its growth has been attributed mainly to the development of “hydraulic” agriculture, with irrigation systems. As the urban area expanded, the socioeconomic diversity and its political influence increased, so that around 600 AD Teotihuacan was totally urban with a population of approximately 85,000 people and an approximate area of 19km2. It is estimated that in 300 BC, the use of irrigation canals spread rapidly in the region. In fact, it is known that in Texcoco irrigation consisted of diverting water from shallow springs to irrigation canals and then to fields that were a few meters away. Recent excavations have also found canals south of Otumba (northeast of Teotihuacan) that are believed to date between 300 and 100 BC.

The heyday of the city took place during the Classic Period in which the city was an important commercial and political node that reached an area of almost 21 km2, with a population of between 100,000 and 200,000 inhabitants. Due to its importance, the influence of Teotihuacán is known to encompass all directions of the Anahuac, as shown by studies in cities such as Tikal (Guatemala) and Monte Albán (Oaxaca).

The city of Teotihuacan was mysteriously abandoned around 600 to 700 AD. During this time, the collapse of civilized life occurred in most of central Mexico. One possible cause was the erosion and desiccation of the region as a result of the destruction of the surrounding forests that were used to burn the lime that was used systematically in the construction techniques of Teotihuacan. On the other hand, it is known that at that time there was increasing aridity of the climate in Mexico, which undoubtedly must have affected the productivity of the soils as suggested by studies by Solleiro and collaborators, which finally affected the entire food production system. According to Mays, skeletal remains indicate severe problems of malnutrition.

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21 https://medium.com/incerto/we-dont-know-what-we-are-talking-about-when-we-talk-about-religion-3e65e6a3c44e

In an extremely interesting work by Tom Froese and Linda Manzanilla (2018)[22] in which they used a network model to capture sociopolitical interactions, they suggest the possibility that Teotihuacan initially had a highly distributed sociopolitical network that became more hierarchical as the numbers increased. divisions within the city, even though the majority retained its heterarchical organization. The results of the model suggest that increased political centralization and social hierarchy might have mitigated the negative effects of increased social divisions, albeit only effectively, along with the continuation of collective practices of ritual integration. This proposal is consistent with the way in which Teotihuacan often represented its leaders within the city, that is, in terms of the religious functions, they performed in the service of the community rather than specific individuals.

In a more general context Diamond (2005)[23], proposed a conceptual framework about the collapse of societies, based on five main causes: (i) the damage that people inadvertently inflict on their environment, (ii) climate change, (iii) hostile neighbors, (iv) decreased support from allied neighbors, and (v) society's responses to their problems.

The abandonment of the city of Xochicalco is another typical example of collapse due to local climate change and fragility in the water supply. After the disintegration of Teotihuacan, populations from the Gulf Coast and the Yucatan Peninsula arrived in central Mexico. From these migratory flows, Cacaxtla and Xochicalco were formed, as two important urban centers, both with a marked Mayan influence, although their architectural style was predominant as that of Teotihuacan. In particular, Xochicalco is located on the top of a hill approximately 38km from the modern city of Cuernavaca. This settlement became one of the largest cities in Mesoamerica during the classical period between 650-900 AD.

Near the city, there are no rivers, springs, or wells to obtain water, so this was essentially collected in the plaza area and stored in cisterns, to later be transported to other parts by means of tubes. The abandonment of Xochicalco is attributed in general terms to the combination of a period of droughts, conflicts with neighbors, and internal political problems. But without a doubt, the dependence on the collection of rainwater made it very fragile in periods of drought. Here we are using the idea of fragile a la Taleb, not in a colloquial way, that is, Xochicalco as a system had a convex non-linear response to variability in precipitation, which incidentally is known to typically have long tails.

This crisis seems to have affected all contemporary Anahuac civilizations. Some anthropologists propose that the crisis was due to a decrease in food availability caused by the desiccation of the land and loss of water sources in the area, the product of a combination of climate change towards more arid conditions (which seems to affect all

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22 http://www.iia.unam.mx/directorio/archivos/MANL510125/2018_FroeseManzanilla-Modelling-collective-rule-Teotihuacan-CSR.pdf

23 Diamond, J. (2005). Collapse: How Societies Choose to Fail or Succeed, Viking, NY, USA.

Mexico during the classical period) and the deforestation of the valleys, where previously there were forests of cedars, pines, and oaks; currently, the vegetation cover consists of cacti, yuccas, agaves.

Of course, these five causes or stressors (disturbances) proposed by Diamond are not mutually exclusive but can act simultaneously interacting with each other in different ways. In fact, in a 2012 article in PNAS[24], Marilyn A. Masson concludes that as more evidence accumulated for the Maya civilizational collapse in the classical era, it was the culmination of a variety of different factors in a diverse political and biotic landscape, in the that it is no longer possible to evoke a single simple causal factor. Although clearly, anthropogenic environmental impacts and premature weather events are among the contingencies that triggered the fall of the most fragile and populous areas in the interior of the Mayan area.

An important aspect recently identified by edaphologists (scientists who study the soil) is that the soils of the jungle are very shallow and poor in nutrients so that crops can only grow for 2 or 3 years, and these lands cannot be reused until after about 18 years. This favored the continuous destruction of the forest and the loss of habitat for the animals, which most likely can generate a waterfall effect.

Due to the advent of these adverse physical conditions and as these societies developed, they were generating more organized social structures, which has been studied from different angles: (1) Agriculture and harvesting (Boserup 1965; Clark and Haswell 1966-1 Asch et al 1972; Wilkinson 1973; Cohen 1977; Minnis 1995; Nelson 1995); (2) Technology (Wilkinson 1973; Nelson 1995);
(3) Competition, wars and the arms race (Parker 1988; Tainter 1992); (4) Socio-political control and specialization (Olson 1982; Tainter 1988); (5) Research and technological development (Price 1963; Rescher 1978, 1980; Rostow 1980; Tainter 1988, 1995a).

Although Tainer in his 1988 work spoke of a concave dose-response curve for what he called the complexity of societies, it is my impression that he was referring rather to one of the components of complexity, self-organization.

Returning to our central concept of complectere, as we have seen, the states of greater complexity coincide with those of criticality where there is a good balance between two antagonistic but complementary processes: one that introduces randomness (called "Emergency" and is associated with adaptability) to the system and other self-organization (associated with robustness). Although there is no universal agreement on how to measure complexity, Yaneer Bar-Yam and Carlos Gershenson have proposed that it must follow a quadratic form as the product of these two processes, in such a way that Complexity = Emergency * Self-organization[25].

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[24] https://www.pnas.org/content/109/45/18237
[25] https://arxiv.org/abs/1205.2026

Thinking again about the criticality hypothesis, it is expected that a society effectively needs to find a structure that generates a balance between the self-organization necessary to be able to organize larger and larger human groups; and sufficient adaptability (emergency) to be able to face, for example, new physical conditions such as the aforementioned climate change of the classic in Anahuac. In that sense, only critical (complex) societies survive. Here I want to take a leap forward and propose that criticality and Antifragility are expressions in the dynamic space or in the space of payments, of the complexity of the system. The first part of this proposal is covered in our results of complexity in the Ising model that we discussed earlier. The second part is covered in a recent article by Gershenson et al[26].

In a later work, in his 1990 book The Collapse of Complex Societies, Tainer describes how societies when faced with inevitable collapse generally assume one or more of the following three models: dinosaurs; flight forward; a castle of cards.

In the dinosaur model, it is generally a large-scale society whose resources are being depleted at an exponential rate and which does nothing to rectify the problem because the current elite is unwilling or unable to recognize the danger and respond appropriately to it. This would be the example of the government of the Great Angry Orange Man regarding, for example, Climate Change, in which there is a tendency to generate opposition to any solution that promotes action changes regarding the status quo.

For its part, in the flight-forward model, these are companies that only work when there is growth, based almost exclusively on the acquisition. Classic examples of this type of society (simplifying the argument a lot) are conquering cultures like the Mongols or in a certain way, according to Tainter, modern capitalism for which things work only under schemes of constant economic growth.

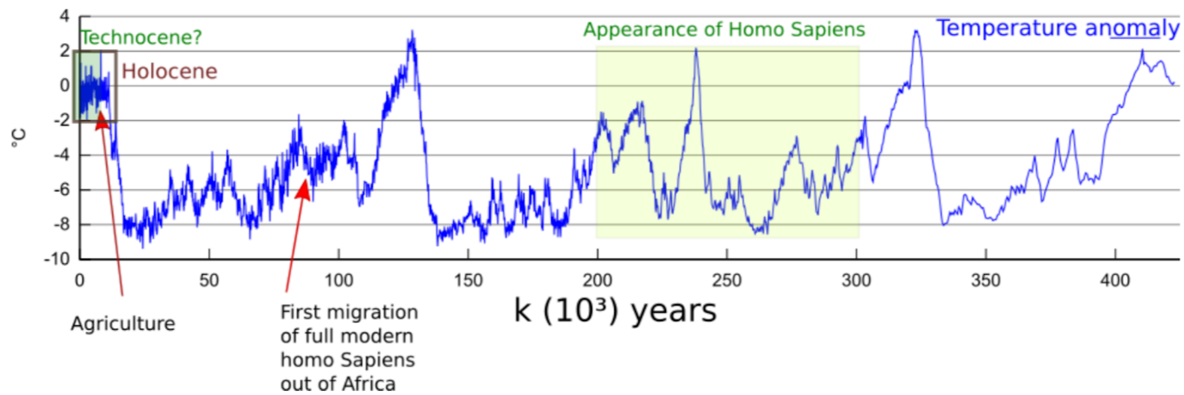
Finally, in the castle of the letter, we have societies that have developed, to the level of including so many different and complex social institutions that can contradict each other, they become inherently unstable and are prone to collapse for that very reason.

The analytical reader will see that the three models of Tainer's collapse correspond to models of loss of complexity: in dinosaurs, there is a lack of adaptability; that of the forward flight there is an excess of it, and in the castle of cards there is an excess of self-organization. In this way, the criticality model is shown as a more universal framework than Tainer's, on the one hand, it recovers previous results but includes other configurations of loss of complexity not considered and therefore other types of paths to collapse.

[26] https://arxiv.org/abs/1812.06760

The Technocene or the hyper-complex world

The key state variables of the Earth System (that is, the pattern of rainfall, the cycle of N2 or the temperature of the ocean among others) exhibit different levels of natural variability as recorded, for example, in nuclei of 420,000-year-old Vostok (Antarctic) ice.



Interestingly, for most of the last 10,000 years, the Earth has remained within what is known as the stable domain of the Holocene, identified by a red box in the figure above taken from my article on Technobionts[27]. Although *Homo Sapiens* appeared about 200-300 thousand years ago, agriculture and the subsequent development of civilization was only possible under the most stable conditions of the Holocene.

It has been in this box where all the epic stories of promotions and dislocations of societies have taken place; where we discover the numbers and measure the movement of the stars. Without a doubt, that island of stability has played a great deal in our favor.

However, early in the last century, Paul Crutzen and Eugene Stoermer proposed that human modification of the global environment had become significant enough to justify the termination of the current Holocene geological epoch and the formal recognition of a new Anthropocene epoch (Crutzen and Stoermer, 2000; Crutzen, 2002).

In our article we argue that not only are we close to a planetary tipping point like, but we have already pushed Earth away from that stable Holocene dominance in which socially and technologically complex human societies emerged.

In fact, our impact is so great that we are approaching the threshold values of different planetary limits, such as the integrity of the biosphere (see figure on the left, taken from wikipedia with CC license).

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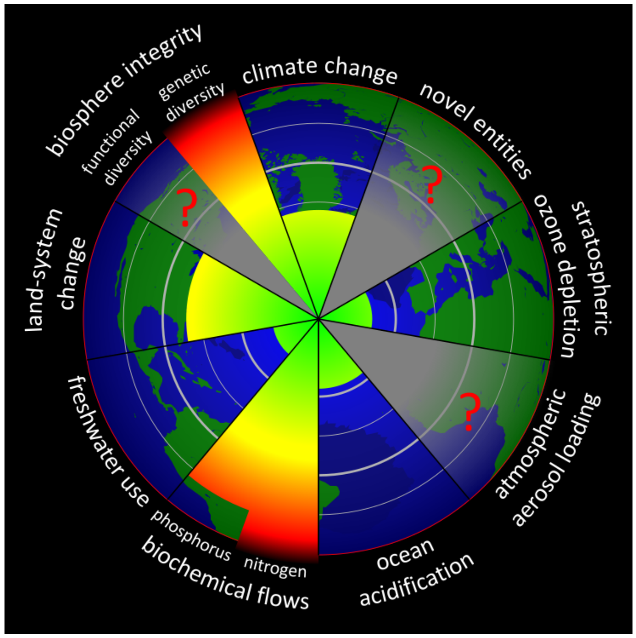
[27] https://www.researchers.one/article/2019-01-1



The planetary boundaries or planetary boundaries (in English: planetary boundaries) are a set of nine bio-geo-chemical processes on a planetary scale that are fundamental for the stability of the Earth system. The approach proposed and developed by Rockström (2009), Steffen (2015) and their collaborators, suggests a series of thresholds for these processes that, if exceeded, can endanger the habitability of the planet.

But how do we get to this? The proposal that Elvia Ramírez-Carrillo and Gustavo Magallanes make in the article that I have been commenting on is that in general living organisms do not evolve in isolation from their socio-cultural processes, but rather are coupled with them in such a way that unity minimal analysis is no longer the organism but the coupled organism. In fact, it is not even the organism of an isolated species, we are always co-evolving with organisms of other species and we are even coupled with our symbionts. The unit of an organism and its symbionts has been called a holobiont.

Of course, bacteria are our symbionts par excellence, which we group together in what we have called the microbiome. As amazing as it may seem, inside us, there can be as many bacteria as we have cells. These bacteria live mainly in our gastrointestinal tract but are also found in the respiratory, urinary, skin, vagina, mammary glands, etc. In addition to their great abundance, they are also very diverse. About 5,000 different genera have been found that interact with our cells in different ways (commensals, symbionts, or parasites).

In particular, the intestinal microbiota is the most diverse and is undoubtedly essential to maintain our health and homeostasis. It is now very well documented that our gut microbiota carries out functions of nutrition, metabolism, protection, and plays an important role in the development and modulation of the immune system. But perhaps most astonishing is the two-way communication between the gastrointestinal microbiome and the central nervous system. Thus, the microbiota has an important impact on a wide range of health-disease processes (dysbiosis of the gastrointestinal microbiota is closely related to the incidence of obesity and diabetes) and has currently been shown to have dramatic effects on brain development and function. of the host, intervening in several neurological diseases.

This relationship is called the gut-brain axis, which includes its bidirectional communication via neural, hormonal, and immunological signaling between both organs. On the one hand, emotional factors such as stress and depression affect our microbiota. It has been shown that stress affects the intestinal epithelium, alters intestinal motility, its secretions, and its mucosa, thus altering the habitat of the bacteria, affecting their composition, activity, that is, it produces dysbiosis. On the other hand, a very recent article (Valles-Colomer et al. 2019)[28] suggests that the presence of specific genera of bacteria affects various variables of the quality of life indicators, including both physical and mental. Particularly the dysbiosis of the genera Coprococcus and Dialister seem to be associated with the occurrence of depression.

We propose to extend the concept of the holobiont to integrate the coupling with the socio-cultural processes through the mechanism of construction of the niche. The idea of a niche is that living organisms are found in physical places where the characteristics that they require and favor their existence coincide. The niche construction mechanism establishes that organisms can carry out transformations in the environment (remember the Daisyworld model) in such a way that it is more favorable.

We call ecobionts to an organisms with all their symbionts (holobiont) coupled with their socio-cultural contexts. An ecobiont can then be considered as the unit of analysis in the co-evolutionary process because they are well-defined interactors, replicators / reproducers, and manifestations of adaptation, through natural selection and niche construction. In this way, we should recognize modulation effects on the anatomy of holobionts (organisms with their symbionts), either in their anatomy, metabolism, in their immune system, or in their development; all of them intervening in the processes of selection and construction of the niche.

As an example, there is a current trend in wearable robotics that is a promising form of human-robot integration. LA portable robotics, tries on the one hand to be a way to replace missing parts of the human body; and on the other hand, a way of making improved humans through prostheses that improve the strength of the human body or its precision capabilities, for example through exoskeletons[29]. Recent developments go beyond this and include building prostheses not to replace but to add functionality to the

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[28] https://www.gwern.net/docs/biology/2019-vallescolomer.pdf

[29] Adam B Zoss, Hami Kazerooni, and Andrew Chu. Biomechanical design of the berkeley lower extremity exoskeleton (bleex). IEEE / ASME Transactions on mechatronics, 11 (2): 128–138, 2006.

human body such as a glove with a second thumb[30]. Furthermore, in a recent detailed article in Science[31], the authors discuss how we are entering a new era in bioelectronics, developing devices that can be seamlessly integrated into nervous tissue. As good as it sounds in terms of innovative human treatments for all kinds of ailments, from blindness and paralysis to brain diseases like Parkinson's and Alzheimer's, this new technology can carry not only input signals but also output signals[32]. So, although it sounds like fiction, we are getting closer and closer to the day when bioelectronics not only monitors the behavior of the animal, but will also control it. These advances are beginning to dissolve the boundary between living organisms and the outside world.

From another perspective, there are clear sociocultural processes that affect the microbiome. There is accumulating evidence suggesting that eating a “western diet” (DO) high in saturated fat and added sugars negatively affects cognitive and microbial functions; the extensive and even excessive use of antibiotics has serious consequences related to microbiological dysbiosis and therefore to obesity, diabetes and even allergies. Recent work[33] suggests that the maternal DO diet can affect female body mass for up to a third generation. In this study, Sarker et al. (2018) show that the offspring born to ancestors with this type of diet, showed similar behaviors of addiction, obesity patterns and insulin resistance until the third generation in the absence of any additional exposure to the diet of their ancestors. In this way, not only are these sociocultural processes that are adverse to the microbiome inherited, but their effect also directly affects subsequent generations.

Finally we propose in our article that the typical (there will be exceptions) modern man who lives in cities is in general terms a type of ecobiont that what we call "Classic Homo Sapiens" (HSC) represented by our hunter-gatherer ancestors or perhaps in contemporary Bushmen of the Kalahari desert.

In a recent article Burger and his collaborators[34] have shown that since pre-industrial Homo sapiens but mostly modern ones who live in cities, they are completely outside

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[30] Domenico Prattichizzo, Monica Malvezzi, Irfan Hussain, and Gionata Salvietti. The sixth-finger: a modular extra-finger to enhance human hand capabilities. In Robot and Human Interactive Communication, 2014 RO-MAN: The 23rd IEEE International Symposium on, pages 993–998. IEEE, 2014.

[31] RF Service. Bioelectronics herald the rise of the cyborg. Science (New York, NY), 358 (6368): 1233, 2017.

[32] https://www.theguardian.com/science/2019/apr/24/scientists-create-decoder-to-turn-brain-activity-into-speech-parkinsons-als-throat-cancer

[33] Gitalee Sarker, Rebecca Berrens, Judith von Arx, Pawel Pelczar, Wolf Reik, Christian Wolfrum, and Daria Peleg-Raibstein. Transgenerational transmission of hedonic behaviors and metabolic phenotypes induced by maternal overnutrition. Translational Psychiatry, 8 (1): 195, 2018.

[34] Joseph R Burger, Vanessa P Weinberger, and Pablo A Marquet. Extra-metabolic energy use and the rise in human hyper-density. Scientific reports, 7: 43869, 2017.

the energy consumption scale relationship valid for all other mammals. The main idea of the authors is that Homo Sapiens, as well as any other species, are subject to fundamental biophysical laws. For example, all species in a given environment are expected to generate on average the same type of matter-energy and information flows, corresponding to a zero-sum game (what one wins is lost by another player).

For us, this type of evidence makes us think that modern Homo Sapiens in cities have a very different technological coupling from that seen in planetary history, which has led us to call them techno-bionts. In the same way instead of considering this new geological as an Anthropocene, we believe that it is much better to identify it as Technocene, which points towards its origin. Additionally, if we think of the Anthropocene, it does not seem that there is much to do, we cannot stop being Human, but we can decouple from certain types of technology. The Technocene is a concept that allows and even induces the search for new configurations of technological coupling that are compatible with our humanity.

In addition to standard technology, technobionts have generated a new dimension of coupling not with physical technology but additionally with information. It is said everywhere that we are in the knowledge economy and we are certainly in the middle of a data revolution. This revolution has three components: the form of acquisition, the quantity, and the way we interact with them.

Until recently, data could only be acquired using our senses, however, with the introduction of electronics, a revolution occurred in the forms of acquisition, passing predominantly to remote and automated acquisition.

Of course this implies a second revolution related to the way that data is stored. Initially, the only way to store data acquired from nature was through biochemical systems, for example DNA that stores between 1kB and 1.5GB. Later, with the evolution of organisms, forms of storage in networks emerged, such as the neural networks of worms that store up to 0.3 MB or, ultimately, the human brain with its surprising capacity of 10-100TB. However, this type of storage implied obvious limitations in terms of spatial and temporal storage restrictions, which promoted the invention of writing and books that together can contain around 30-50 TB (not counting repeated books). The critical reader will say that then a human brain can store all the data that is in the books of the world, however we must not be fooled. One thing is the syntax (the bits that represent the characters of a writing) and quite another thing is the semantics (the meaning of the writing). For example, Boltzman's statistical interpretation of entropy in his famous equation $S = k \log\Omega$ occupies a minimum number of characters, but its meaning could lead us to write several books. With the advent of the computer, human brains or books were no longer the dominant means of data storage. Today computational structures can accommodate on the order of one zettabyte (1 ZB = 10^{21} B = 1 trillion TB). The IBM company estimates that in 2012 around 2.5 ZB were produced per day, which to put in context is on the order of Avogadro's number. This implies that 90% of the world's data has been produced in the last five years, far exceeding human capacity for processing. For example, if we want to understand a complex system as a disease (let's say diabetes), it requires the massive and simultaneous acquisition of many biophysical signals. However, even when that is possible, we now have the problem of how to generate knowledge from said data.

That brings us to the third component of this data revolution, which has to do with the way we interact with it. When we stored data in brains, we had to put them in close enough proximity to be able to transmit them, if we did not want that data to disappear when we died, preservation mechanisms had to be put in place well in advance, reproducing that data in new brains. Books allowed us, on the one hand, to transmit data without the need for brains, and in the same way, to preserve them for much longer and using simpler mechanisms, libraries. Today we can largely do both digitally very easily and at very high speeds. One can, for example, have a conversation with @nntaleb no matter where one is (brain-brain communication) and on the other hand the internet is a huge library of all kinds of data. Additionally, we can now generate a whole new set of narrative forms, not only spoken, written language or simple images, but what has come to be called data visualization. This is an emerging discipline that includes programming skills, deep knowledge of statistics, design, perception theory, etc.

So on the one hand, our world is more complex due to the amount of new interactions between the different components of our society; It is also the intensity of the interactions, never before the human being had had the technological capacity to carry out disturbances on a planetary scale; the rate of change of the components and their interactions is also unprecedented. On the other hand, we are faced with a hypercomplex decision-making context because, in addition to that basic complexity, we now add a new layer, not on a material but on an informational substrate. Never before have we had so much access to information and data of all kinds including news services and probably never before has it been so difficult to understand what is happening around us.

EPILOGUE

As I began to read a proof of the manuscript, my friend Pedro Díaz Meade wrote this to me that I believe is an excellent reflection that captures a good part of the spirit of the book:

“It seems ironic to me that you qualify life as anti-fragile, it pretends to be in the magical network of chance and necessity, in the loom of the interactions of heredity, space and time, but each "individual" that passes through this state, whether marveling or not at the gift of this capricious universe, we are all mortals and fragile ... inexorably fragile. Life is therefore supposedly anti-fragile but volatile in time and space. "

I sincerely hope that reading Complectere has raised many interesting questions and perhaps even provided a couple of answers. But above all, it serves as a first guide to building a Lindy-style life.

During the writing of this book, it was quite clear to me that in this adventure of starting to live in an alpine style, we will most likely need to build a community that motivated us and with which to share the path. My contribution in this sense is to be part of the project http://lindy.otrasenda.org/ which states:

We live in an unprecedented time in human history for two fundamental reasons: never before has our environment been so complex and with very infrequent, unpredictable and high-consequence random events (Black Swans); never before have those who benefit most from development and decision makers (Fragilitas), have been so isolated and protected from risk, its costs and its consequences. In response to this, the Lindy community is outspoken against those processes that isolate us as individuals and society from the forces of chance and evolution. On the contrary, we speak out in favor of all decisions, strategies and processes that minimize catastrophic and scalable risks in exchange for assuming lower and manageable costs, while maximizing the benefits of those decisions, even allowing ourselves to expose ourselves to windfall profits. We seek to generate a rigorous understanding of the concept of Antifragility at the same time to promote its responsible practice.

Children of chance, an almost impossible event, which makes us unique. We are brothers of the fire, which is fanned by the wind. We are the survivors of the survivors. At Lindy we demonstrate in favor of our wild nature that thrives on the unexpected, that finds in the optionality ways to make, build, create. That nature is fully manifested in the classic virtues of scholarship, honor, and aesthetics. In Lindy we speak out in favor of the Greek over the Roman, we seek wisdom over knowledge, the organic over the artificial. We deny the fragile, the one who wants to strip us of the mystery of the unknown, to deceive us with the apparent but deadly stillness of indifference. He who eats the fruit with pride but without the humility and courage that only climbing the tree gives. We express our gratitude and admiration to the hero, the innovator, the entrepreneur, the builder, the craftsman. We are wild creatures, we are fire, brothers of the wind.

Welcome to the tribe