Artikulu honek RIEV-en sistema teknosozial handiei (LTS) buruzko zenbaki berezi hau aurkezten du. LTS-ak teknologia eta gizartea lotzen dituzten azpiegitura intrintsatuak dira. Maila eta eskala anitzeko sistema hauek gizarte-araudi dinamiko baten eta merkatuaren indarren mende daude, eta, beraz, barne eta kanpoko aldaketetara egokitu behar dira. Murrizketekiko sentikortasuna eta hauskortasuna nabarmentzen dugu, eta LTS-ak eraginkortasunez ezartzeko eta betetzeko erregulazio-geruzak eta tokiko patroiak kontuan hartzea funtsezkoa dela eztabaidatzen dugu.

Giltza-Hitzak: Sistema tekniko-sozial handiak. Azaleratzea. Gizarte-ongizatea. Sistema Teknikoak. Ondorioak. Erronkak.

Este artículo introduce este número especial de la RIEV sobre los grandes sistemas tecno-sociales (LTS). Los LTS son infraestructuras intrincadas que entrelazan la tecnología y la sociedad. Estos sistemas multifacéticos y multiescala están sujetos a unas normativas sociales dinámicas y a las fuerzas del mercado, por lo que deben adaptarse tanto a los cambios internos como a los externos. Destacamos su fragilidad y sensibilidad a las restricciones, y sostenemos que la consideración de las capas regulatorias y los patrones locales se vuelve crucial para la implementación efectiva y el cumplimiento de los LTS.

Palabras Clave: Grandes Sistemas Tecno-Sociales. Emergencia. Bienestar Social. Sistemas Tecnológicos. Implicaciones. Desafíos.

Cet article introduit ce numéro spécial du RIEV sur les grands systèmes techno-sociaux (LTS). LTS sont des infrastructures complexes qui entrelacent la technologie et la société. Ces systèmes multiformes et multidimensionnels sont soumis à une réglementation sociale dynamique et aux forces du marché et doivent donc être adaptés aux changements internes et externes. Nous soulignons leur fragilité et leur sensibilité aux restrictions, et nous soutenons que la prise en compte des couches réglementaires et des modèles locaux devient cruciale pour la mise en œuvre efficace et la conformité des LTS.

Mots-Clés : Systèmes Techno-Sociaux Grandes, Urgence, Protection sociale, Systèmes Technologiques, Implications, Défis.

Foreword: Large Techno Social Systems. Emergence of Social Welfare Techno Systems = Hitzaurrea: Sistema teknosozial handiak. Gizarte-ongizateko teknosistemen sorrera

Introduction

Large Techno Social (LTS) systems are infrastructures composed of different technological layers interoperating within society in order to provide global, both public and private services of technological character. They deploy their operations in the “real” material world and in the virtual “digital” world alike. Canonical examples of LTS systems include, Global Transportation and Mobility Facilities, Power distribution Grids, Food and Water Supply Infrastructures, Gas and Oil Pipelines, the Internet, the World Wide Web, Stock and Financial Markets, and the like.

In essence, they are multifaceted and multiscale in nature, and more importantly, they feature complex interconnected networks operating in complex (societal) environments. All this poses substantial difficulties for their full modeling and subsequent understanding. However, recent availability of processable massive datasets and advances in the theory and modeling of physical complex systems provide tools for the construction of an integrated framework towards making reliable predictions of the behavior of both the techno-social systems at stake and the society making-use of them. Thus, it is worth mentioning that recently it has been established, beyond any reasonable doubt, the existence of some physical complex systems which never reach equilibrium[1]. Their dynamical equations of motion yield an unsolvable mathematical problem in a close form. Even more, letting the system to evolve by itself it will not get convergence in a finite period of time. Such systems appear to be extremely fragile, in the sense that they tend to be very sensitive to small both exo- and endo-genous constraints alike, and their dynamical evolution turns out to be irregularly patchy[2]. Remarkably, similar phenomena are also observed in LTSs.

The LTS systems are constrained by the applicable social regulations and market developments which operate in place, sharing their values, aims, public/private tensions, etc. However, the web of interactions between LTS systems and societal regulations and market developments is dynamic. Consequently, they must adjust to “internal” changes, e.g., the changes due to developments of the LTS systems themselves, and to the “external” changes, meant: the evolving “environment” as determined by the actual changes operating within the society which they serve. This dynamic character, carries a time lapse of events which, for the models aimed at describing the behavior of the LTS systems, pinpoints to the requisite of accounting accurately for the responses of LTS systems to changes of their environment in real time. In other words, models need to lay the basic time-ordered features leading to predicting trends, anticipating risks and providing clues for the managing of future events.

Weather forecasting represents a canonical example to illustrate further this point. For our purposes weather forecasting can be seen as the set of “operations” of collecting large real-time climate datasets[3], which assisted with a big set of (consistent) libraries of historical climate patterns, and on-purpose created computational algorithms, after carrying out large-scale computational simulations ends up with

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[1] Ott, A.; Bouchaud J. -P.; Langevin, D.; Urbach, W. (1990). “Anomalous diffusion in “living polymers”: A genuine Lévy flight”, Physical Review Letters, 65, 2201- 2204.
[2] Barthelemy, P.; Bertolotti, J.; Wiersma, D. S. (2008). “A Lévy flight for light”, Nature, 453, 495-498.
[3] Satellite images of atmospheric turbulences, maps of sea-level water temperature, barometric pressure maps, etc.

the weather forecast for the day[4]. A process that starts off from the established physical laws of fluid and gas flows, generates valuable and reliable societal information, which turns into recommendations which are normally positively, but often insufficiently taken by the individuals. Let us emphasize that knowledge resides at the beginning of the process, e.g. the physical laws. Technical competence, rather sophisticated in many instances, for the processing of large and often unstructured date-sets makes the remaining and, finally, experts issue the recommendations. The end societal goal being the recommendations to make an effect on human "behavior" this day. This, nonetheless, depends on external factors, like risk perception in different communities, tendencies to adopt certain positive individual attitudes towards recommendations, local and global mobility patterns and infrastructure, etc.

Here we can identify a number of "layers". One layer concerns regulations. Thus, for the weather forecast operation to be successful, full consideration should be paid to (i) on-site regulations for the retrieval of physical data, (ii) the ownership of such data, (iii) the on-site existing regulations/patterns for the mass media organizations, whether they are publicly of privately owned/operated, for the dissemination of the recommendations, and/or (iv) the on-site regulations for the treatment of the recommendations issued. Another layer concerns the local patterns to put in place such regulations. Thus, one should also consider (i) whether the issued recommendations should be turned into mandatory actions to be adopted by the citizens in accordance with the gravity of the predictions, (ii) who is to be taken that decision, and (iii) who is to enforce the measures, let them be, for instance, mandatory fleeing of cities, deployment of police/military forces on the ground, etc. Furthermore, the latter ones are inextricably intertwined with local regulations, which needless to say, can vary enormously from place to place, and bring to the fore the complexity of their mutual interactions.

1. A Scientific Twist

The large majority of LTS systems along with the social environments into which they are deployed are customarily modeled as networks which consist of selected segments of the population interconnected by means of exchanges through the LTS system(s). A large body of earlier studies has reached the consensus that these exchanges are strongly dependent on the scale, both spatial and temporal[5]. Their short- and long-range features differ substantially, thus, requiring a differential treatment as a function of the scale chosen to be investigated. Even more, most real-world networks exhibit a strong dynamic self-organization over time due to the evolution of their internal connectedness, even without the intervention of external factors. In spite of these efforts, LTS systems are yet poorly understood, a fact that often is ignored, until the crash comes. We need a deeper understanding of both the foundations and the time evolution of the LTS systems operating in complex societal environments to get a better grip in order to respond efficiently and responsibly to their changes and failures.

Recent advancements in the science of collective phenomena can offer a fresh view of the dynamics of the evolution of complex systems[6]. Opposite to "primary laws" which put forward their dominant linear terms, complex phenomena science introduces non linearities and multiple causalities (multiscale approach) in the description of phenomena which do not evolve towards equilibrium (stability), but instead instability builds up in a recurrent manner following the newly discovered scaling laws[7]. These

[4] Weather is what you get, climate is what it is. See: Schiermeier, Q. (2018). "Climate as culprit", Nature, 560, 20-22.
[5] Vespignani, A. (2008). "Predicting the behavior of techno-social systems", Science, 325, 425-428.
[6] Helbing, D.; Balietti, S.; Bishop, S.; Lukowicz, P. (2011). "Understanding, creating, and managing complex techno-socio-economic systems: Challenges and perspectives", European Physical Journal, Special Topics, 195, 165-186.
[7] A. Brú, A.; Alós, E.; Nuño, J. C.; Fernández de Dios, M. (2014). "Scaling in complex systems: a link between the dynamics of networks and growing interfaces", Sci. Rep., 4, 7550.

scaling laws are already familiar in epidemics and earthquakes, but they also appear in the growth of cities, stock market behavior, etc. The bottom-line here is that complex systems do not evolve randomly, buy in accordance with underlying forces which trigger their evolution yielding a critically self-organized structure which applies equally to socioeconomical and technological systems. The criticality of their self-organization leads to sudden breakdowns. This is what we see and most of the times suffer.

Fortunately, the multiscale approach as it stands today, has paved the way towards the understanding of the statistical and dynamic laws governing the functioning of LTS systems coupled to complex social "environments". Certainly, there are a number of LTS systems which appear to fit better than others, within this multiscale framework. Thus, infrastructures for human, raw materials, and manufactured goods transportation, as well as large scale operations aimed at delivering large amounts of gases and fluids over long distances, do nicely fit for multiscale type approaches. The large techno systems for the transportation, distribution and assurance of enough power to supply electricity at every electric plug, constitutes one additional example.

Ephemeral, to say the least, matter is also, nowadays in particular, processed by large techno social systems distributed physically around the world, and in reality, in the so-called "cloud", where the custody, either designated or open, the accessibility and delivery of data, big data, through the Internet is carried out by the administrators of such cloud. These include the network of microwave antennas for mobile phone communications, and the channels for the dissemination (or occultation) of "sensible" data for the operations of financial stock markets, to name a few.

2. The Web

Perhaps the canonical LTS system is the Internet and its associated World Wide Web, the web for short. Customarily, the Internet and the web are used to describe the same, but they refer to two very different things. The web refers to the means to get access to the pages that we browse on the computer's monitor when it is online. We can browse pages, edit them, share their location, etc., by means of a standard on-purpose language, the HyperText Markup Language (HTML). The Internet, on the other hand, refers the network made of a myriad of interconnected computers, serves, and countless of other devices which support the web.

The web cannot be conceived without an explicit reference to human society. On the one side, the Internet is the most globally shared technological infrastructure of the modern world. On the other side, the web consists of the materializations of the activities of humans on such an infrastructure. Humans are here producers and viewers of the web's content. This dual nature of human agents is the driving force of the hyper-evolving nature of the web, resulting in an emergent information dissemination, creation and sharing infrastructure on a global scale. The web is, therefore, a LTS of computer mediated cognition, communication and collaboration for humans[8]. It is the only LTS system where users contribute effectively to its technical development for they adapt the code to their social communicative needs. Neither the detailed structure nor the precise content of the web can be predicted at any given time. Pages appear and disappear in accordance with the users' needs. But one thing can be predicted for sure, its complexity grows with the passing of time, as the number of web sites/pages, web search engines, linking patterns and their interconnections increase. Additionally, one more agent has made recently its debut in the web's world, the artificial intelligence[9], which brings to the fore that the hyper-evolving nature of the web refers

[8] Raffl, C.; Hofkirchner, W.; Fuchs, C.; Schafranek, M. (2023). "The Web as Techno-Social System: The Emergence of Web 3.0", https://api.semanticscholar.org/CorpusID:46997037. Accessed: Sept. 19th 2023.

[9] See the special issue "Artificial Intelligence its Potential and Limits", Rev. Int. Estud. Vascos, 67(2), (2022).

not only to its content's diversification, but also to the appearance of new stakeholders. Naturally, yet a satisfactory and sufficient understanding of the reality of the field, just for not going all the time chasing its development's tail so we could properly manage its implications without impeding advances, remains to be achieved. In particular, artificial intelligence powered with quantum computing, a combination that is sought to be within reach in the near future, deserves an attentive close watch because it has the potential to lift biotechnology, nanotechnology and robotics to a such level that could utterly reshape the world that we live in today.

3. Cities

However, there are other LTS systems which are less prone to fit into this scheme. Consider for instance the urbanism criteria which informs the planning for the rational development of the layouts of cities, homes, houses, along with roads, railroads, and additional means of connections among them like, for instance, rivers as transportation means, which implies the deployment of fluvial ports, locks for raising or lowering boats around cliffs, docks for the ships to be repaired, etc. In this case the demarcation line between the LTS and the services provided is rather blurry. Cities can be viewed as a complex system connecting individuals and communities - bearing their specific economic and cultural characteristics - with technical matters, including planning, (re)construction, maintenance, etc. Consequently, they can be viewed as LTS, an approach that can help enormously to set the problem into proper perspective. Furthermore, it does not escape to our attention that progress in the theoretical formulation of the problem can represent a significant advancement in terms of practical applications, for it will provide rational tools to design better city development planning strategies.

It is estimated that more than half of the world's population lives in cities, a proportion that is increasing along with the problems associated with settlements of dense communities. This is one of the great paradoxes of our ages. Namely, new technologies offer individuals and companies alike greater freedom than ever to choose their location and mobility, yet more than ever people choose to live in close vicinity of each other. This irrational[10] behavior is, surprisingly, well described by the Shelling model[11]. The model assumes that every individual prefers to live in a "moderately" dense city, because the accessibility to communal services is easier than in highly dense cities, and they offer better opportunities for "socializing" than deserted cities. Also, it is assumed that each individual is free to move to another city if she considers that its density is closer to the optimum, i.e., moderate. This freedom of movement is expected to act as a density equilibration factor. But in the long run it does exactly the opposite to equilibration. Namely, some cities end up overpopulated (relative to the optimum) and some totally emptied. Instead of equilibration it yields segregation, and consequently accumulation of the population in the big cities.

The genius of the big cities resides on the fact that they are a physical space of (high) density of human interactions which facilitate the rapid dissemination of information and the surge of new ideas[12]. This nonetheless brings to the fore the claim that computerized information technologies, ICTs, reshape the concept of "space", and this profoundly affects cities[13]. Indeed, ICTs mark the emergence of the so-called

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[10] The term "irrational" can have multiple meanings. Herein it is used, with some ambiguity, to represent illogical or unreasonable behavior.

[11] Schelling, T. S. (2006). "Micromotives and Macrobehavior", WW Norton & Company.

[12] Glaeser, E. (2011). "Triumph of the city: How our greatest invention makes us richer, smarter, greener, healthier, and happier", The Penguin Press, London.

[13] Castells, M. (2020). "Space of Flows, Space of Places: Materials for a Theory of Urbanism in the Information Age", in The City Reader, R. T. LeGates, F. Stout (Editors), Routledge, London.

“space of flows”, which refers to the flows of computer bits of information which overlaps with the physical “space of places”. Both having nowadays similar impact on the growth of cities.

All in all, since cities are bound to grow, they have to find strategies to allow a rational growth without falling under their own growing impetus. The scaling law of accelerated production, “growth stimulates growth”, makes attractive to people to move to the city. But then growth jeopardizes the infrastructures and services of the city, resulting in increasing numbers of individuals struggling to make its space in increasingly overcrowding environments. This might occasionally result in a crash. Detroit is canonical example, but recent events like the one occurred in Birmingham, where its City Council has declared itself effectively bankrupt preventing all but essential spending to protect core services[14], remind us how little is needed to cause systemic failures. Construction of suburbs has been seen as a solution, but it puts pressure on transportation services to begin with, and in the long run seems to be non-sustainable. At what size does the “repulsion” exerted by the inhabitants causes a city to collapse? At the time being, cities avoid collapsing by relentless innovation. The larger the population the shorter the time for the next innovation. We are now beginning to set the foundations to understand the mechanisms of these non-linear saw-toothed patterns[15]. However, further analysis is foreseen on such sensible issues, including the validation of the proposed approaches.

4. Research and Technology

Global research, development and innovation initiatives where a large number of laboratories and companies dispersed around the globe do networking and cooperate to produce one final product, constitutes one example of LTS oriented towards social service. Consider for instance the European Organization for Nuclear Research (CERN) which operates the largest particle physics laboratory in the world. The components of the CERN’s large hadron collider are normally manufactured, and sometimes even partially assembled, in places very distant from the laboratory’s venue at Geneva, Switzerland. Another example is the International Thermonuclear Experimental Reactor (ITER). The ITER project is a well-known large techno social initiative with thousands of engineers and scientists of 35 nations collaborating since 1985 to build a magnetic fusion device designed to prove the feasibility of nuclear fusion as a large-scale and carbon-free source of energy, based on the same principle that powers our Sun and stars. This brings to the fore the scale of the complexity of the technological LTS systems.

Developing a new and useful technology is and has always been a laborious process. Implementing it is even more laborious, because it has to replace, partially or in full, an old but well tested and optimized one. Thus, efficient technological societies are resilient to change. Exceptions occur when they are driven by imperious outside stimuli. The development of synthetic nitrates for securing production of ammunition or the nuclear bomb project are examples of responses to military stimulus. The synthetic rubber and the mass production of penicillin and COVID vaccines were successfully implemented in a short period of time driven by economic stimulus, and perhaps a little bit of altruism. But in general, technological development is complex, hard to predict, and full of unexpected surprises around many corners.

Gone are the days in which research centers, universities and companies conducted their research and development (R&D) operations in their own laboratories. Today, R&D is conducted globally. Technology is often acquired from external suppliers, start-ups, other research centers around the world, etc. In fact, the overwhelming majority of knowledge is generated externally, within the global (planetary) technological LTS systems’ network. Thus, initiatives aimed at capitalizing R&D done elsewhere, are

[14] https://www.bbc.com/news/uk-england-birmingham-66715441. Accessed: Sept. 5th, 2023.

[15] Batty, M. (2008). “ The size, scale, and shape of cities”, Science, 319, 769-771.

nowadays part of the system itself, and have become a critical innovation hot spot for many nations. The old schema of Government financed basic research which permeates the local public/private sector's R&D centers to generate innovations which finally creates economic value is deeply flawed, instead products come into existence after a long process of many steps interconnected by intricate ways. The majority of these products do not yield radical changes in society, but some do. And when this occurs it leads to a complete overhaul, known as Schumpeterian waves[16]. This mimics phase transitions in self-organizing critical systems. A characteristic of them is that they are recursive and repetitive[17]. Understanding their evolution requires coming to grips with the overall complexity of the technological LTS system.

5. Failures in LTS Systems

Things, though, may go wrong due to failures of LTS systems. This may have various types of consequences depending on the nature and services provided by the LTS system(s) which have suffered the failure. Two types of failures can be foreseen, e.g., conventional and systemic. Conventional failures can be constrained in space and time, they follow linear cause-effect relationships and can be addressed with effective and pointed interventions into the cause-effect chain, and are often restricted to a given single societal domain. Systemic failures[18], however, are characterized by high complexity, far reaching effects, stochastic relationships, non-linear cause-effect patterns with tipping points, and often receive less public attention than required. Part of the problem for properly handling such failures resides in the poor fundamental understanding of their nature, which impedes a proper and fair perception of the risk of systemic type failures.

Although it is well known that practical tools for properly assessing the significance of systemic failure risk have recently been started to be put in place, systemic failure risks seem to be irrationally attenuated in public risk perception[19]. This has been named as the "systemic risk perception paradox", namely, social perception of systemic failure risks and the empirical reality as reflected by publicly available data, counter-match[20].

Systemic failures constitute complex, trans-domain, non-linear phenomena often showing non-return points and causing cascade events which harm various societal domains at a time. LTS systems in general and specifically those engaged in economy and finance, naturally fall into systems prone to tough to detect in advance systemic failure episodes. Schumpeter argued[21] that part of the problem stems from the very nature of the social dynamics, which is a "process" with so many sources of error and variables, most of them not attainable to precise enough measurement, so that making the correct diagnosis of certain situations becomes a matter of chance.

In this vein, the new complexity science approach for social dynamics can give us a fresh view of systemic failures and their social impact from a different viewpoint largely routed in methods coming from complex

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[16] Kleinknecht, A. (1990). "Are there Schumpeterian waves of innovations?". Cambridge Journal of Economics, 14, 81-92.

[17] Devezas, T. C.; Corredine, J. T. (2002). "The nonlinear dynamics of technoeconomic systems- An informational interpretation", Technological Forecasting and Social Change, 69, 317-358.

[18] Tanzi, V (2020). "The Economics of Government: Complexity and the Practice of Public Finance". See Chapter 8. "Systemic Failure, Complexity, and Public Policies", Oxford University Press. London.

[19] Schweizer, P. -J.; Goble, R.; Renn, O. (2022). "Social perception of systemic risks", Risk Analysis, 42, 1455-1471.

[20] Renn, O. (2014). "Das Risikoparadox. Warun wir uns von dem Falschen fürchten", Frankfurt/Main, Germany: Fisher. [In German].

[21] Schumpeter J. P. (2002). "Kapitalismoa, sozialismoa eta demokrazia", Klasikoak, Bilbo, pp. 75-76. [In Basque].

systems studies and non-equilibrium statistical physics[22]. This can be seen by many as a non-solicited incursion of newcomers (physicists) into a field (social sciences) not of their expertise to which they can certainly provide some novelty, but at the same time, undoubtedly, it must be recognized that they arrive with an exaggerated self-confidence and naivety believing that they truly can overhaul old prejudices and contribute a fully new perspective. Under such circumstances, normally, the ones that have been in the field for many years do not expect great “revelations”. And yet fresh perspectives are welcomed for they allow us to spread doubts onto venerable ruling doctrines that have been establishing fond conceptions and dictating professional practices in many matured fields.

6. Economy and Finance

In view of the above, consider the venerable doctrine comprising market equilibrium economic models aimed at describing market interactions of rational agents. The resulting equilibrium balances prices, cost, demand and supply, and is supposed to be sustained and preserved forever without ever suffering from any sort of crisis[23]. However, this assumption is at odds with the reality of the statistics of price variations in financial markets which shows abrupt changes of all sizes, given rise to a truly non-equilibrium like evolution.

The crises of 1987 and 2008 constitute a convincing confirmation of the latter. Consequently, the “equilibrium assumption”, although it can be useful, seems to be false, stricto sensu. Namely, crisis do occur. Why do they occur? Three factors stand prominently in the explanation of crisis breakouts: (i) unknown tiny bits of information about relevant matters, (ii) the concurrent irrational behavior of the trades, and (iii) the fact that trader’s behavior is driven by their expectations concerning the future evolution of the economy, and in consequence the evolution of the economy is driven by those expectations. That is, the economy and peoples' expectations about it coevolve[24]. This brings to fore the idea that the economy nowadays is better seen as a rational exercise based on incomplete information, lack of knowledge, and uncertain expectations. The rationale behind this statement is that the only hope to deal with swings, bubbles and crashes lies in the competent rational behavior of the traders, based on a deeper knowledge of the underlying non-equilibrium mechanisms of the complex, hyper-connected financial large techno social system.

The fresh perspective provided by the advent of massive amounts of data along with new means for handling large data repositories in “unconventional” manners is opening new avenues for collaboration between experts of different disciplines[25]. In particular, given the enormous amount of available data on human behavior, econometricians are nowadays actively engaged in processing their data by taking into account non-linear, non-equilibrium considerations. These effects are crucial to understand and predict, minimally at least, seemingly “irrational” market behavior, which in turn allows us to study how markets either remain steady or change abruptly. As L. Hansen put it “little jiggles within the system today can

[22] Lazer, D.; Pentland, A.; Adamic, L.; Aral, L.; Barbási, A. L.; Brewer, D.; Christakis, N.; Contractor, N.; Fowler, J.; Gutmann, M.; Jebara, T.; King, G.; Macy, M.; Roy, D.; van Alstyne, M. (2009). “Computational social science”, Science, 323, 721-723.

[23] Doyne Farmer J.; Geanakoplos, J. (2009). “The virtues and vices of equilibrium and the future of financial economics”, Complexity, 14, 11-38.

[24] I. Palacios-Huerta, personal communication.

[25] (a) Anderson, P. W.; Arrow, K.; Pines, D. (1988). “The economy as an evolving complex system”, CRC Press. (b) Darlauf, S. N.; Arthur, W. B.; Lane, D. (Eds.) (1997) . “The economy as an evolving complex system II”, Addison-Wesley (c) Blume, L.; Darlauf, S. N. (Eds.) (2006). “The economy as an evolving complex system III”, Oxford University Press.

have a big impact in the future"[26]. This could provide the means for dampening wild fluctuations to tame future crisis by properly quantifying the impact of uncertainty[27].

7. Health

Among the most pressing challenges that modern societies face nowadays, the provision of a universal health system for the population ranks high on the policy agendas of many countries. In developed societies, this means not only keeping citizens alive but, allied with medical technological advances, to provide individuals with good enough health, as to enjoy high quality living standards during an increasing period of their lives. Developed countries allocate some 10% of their gross domestic product for the health provision systems, which beyond the usual political-party fights, in most European democracies at least, enjoys a massive consensus of pride towards what it is considered to be one the foundation stones of the so-called "European social model"[28]. Certainly, this amount of funding represents a substantial portion of the public resources, which highlights the enormous size and complexity of the LTS health systems. Recall additionally, that the LTS health systems are constituted by a mélange of public institutions and private foundations and/or companies given rise to an overwhelming diversity of legal and regulatory structures operating simultaneously and concurrently. The first lesson to be learned is that organizational issues will be a standing out matter of discussion in this context, consisting of the deployment of increasingly sophisticated medical technologies for an increasingly "sophisticated" and diversified society.

Recent modeling of collective social behavior shows that emergent phenomena can sprout under special circumstances. Small variations of social conditions, in the edges of internal tension situations, are enough to push the whole system into a systemic crisis, which in fact propagates through the social network affecting the individuals severely[29]. Since public policies to manage such scenarios are a matter of social engineering, deep understanding of the mechanisms responsible for the outbreak and subsequent spreading of such phenomena are particularly important.

Thus, in addition to the unexpected and yet not fully understood long-term effects of the SARS-CoV-2 on humans' physical health[30], the outbreak of mental illnesses supposedly linked to the social constraints imposed during the COVID-19 pandemic, has come as a surprise to many[31] and has raised red flags towards the need of changing old methods to treat mental health problems triggered by large periods of large stress on the population, under the additional pressure exerted by modern infodemic[32] scenarios. Under these circumstances, systemic failures -we have discovered it recently, can also be caused by the lack of fast enough adaptive response of the LTS health systems themselves to sudden changes of their social environments. The nowadays consensus on these matters seems to be that the outbreak of the COVID-19 pandemic created an environment where poor mental health found the conditions to become ubiquitous and, consequently, brought to the fore, in almost every country of the world, the need to put

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[26] https://larspeterhansen.org/meet-lars/. Accesed October 20h, 2023.

[27] Hansen, L. P.; Sargent, T. (2023). "Risk, ambiguity and misspecification: Decision theory, robust control, and statistics", J. Applied Econometrics, 1-31.

[28] Piketty, T. (2014). "EL capital en el siglo XXI", Fondo de Cultura Económica, Madrid, pp. 531-534. [In Spanish] .

[29] Sousa, J.; Barata, J.; Woerden, H. C. V.; Kee, F. (2022). "COVID-19 Symptoms app analysis to foresee healthcare impacts: Evidence from Northern Ireland", Applied Soft Computing, 116, 108324.

[30] Davis, H. E.; McCorkell, L.; Moore Vogel, J.; Topol, E. J. (2023). " Long COVID: major findings, mechanisms and recommendations", Nature Reviews Microbiology, 21, 133-146.

[31] Harrison,P. J.; Taquet, M. (2023). "Neuropsychiatric disorders following SARS-CoV-2 infection", Brain, 146, 2241-2247.

[32] "Infodemic" stands for too much information, including false or misleading information, in digital and physical environments during a disease outbreak.

into question the fundamental assumptions that for many years past have been at the core of the balance between the physical and mental health care provision protocols in most LTS health systems. This leads to a scenario of a large (techno) social system adapting to a changing, disruptively in this case, environment, requiring among other actions to be taken, monitoring more closely than ever before early signs of the mental health deterioration within the population, in order to properly face along with physical health issues, also mental health problems too.

In this issue, a number of conventional LTS will be put side by side with some of a less conventional nature, and them all will be revised thoroughly. The intrinsic complexity of their structures will be emphasized with the aim of bringing to the fore the necessity of a multifaceted approach in order to get a clear glimpse of the connections with the societal environment where they operate. Noteworthy, efforts will made to highlight the common complex mechanisms that underlie the basic features of most LTS systems, which characterize their surprising similarity.

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Hitzaurrea: Sistema teknosozial handiak. Gizarte-ongizateko teknosistemen sorrera

Sarrera

Sistema Teknosozial Handiak (STH) hainbat geruza teknologikoz osatutako azpiegiturak dira, gizartearen barruan elkarri eragiten diotenak. Haien helburua da zerbitzu teknologiko global publikoak zein pribatuak ematea. Beren eragiketek mundu material «errealean» zein mundu birtual «digitalean» moldatzen dituzte. Honako hauek dira, besteak beste, STH sistemen ohiko adibideak: garraio- eta mugikortasun-instalazio globalak, energia banatzeko sareak, elikagaiak eta ura hornitzeko azpiegiturak, gasbideak eta petroliobideak, Internet, World Wide Web, eta burtsa- eta finantza-merkatuak.

Funtsean, alderdi eta eskala anitzekoak dira, eta, are garrantzitsuagoa dena, ingurune (sozial) konplexuetan jarduten duten sare interkonektatu konplexuak dituzte. Horrek guztiak zailtasun handiak eragiten ditu haien modelizazio osoa sortzeko eta, ondorioz, haiek ulertzeko. Hala ere, azken aldi honetan eskura dauden datu prozesagarrien multzo handiek eta sistema fisiko konplexuen teorian eta modelizazioan egindako aurrerapenek tresnak eskaintzen dituzte esparru integratu bat eraikitzeko, dagokion sistema teknosozialen eta horiek erabiltzen dituen gizartearen portaeraren iragarpen fidagarriak egite aldera. Baina, esan beharra dago ere berriki ezarri dela, arrazoizko zalantza guztietatik harago, inoiz oreka[35] lortzen ez duten sistema konplexu fisiko batzuen existentzia. Haien higidura-ekuazio dinamikoek hurbiltasunez ebatzi ezin den problema matematiko bat dakarte berekin. Are gehiago, sistemari bere kabuz eboluzionatzen uzteak ez du ekarriko konbergentziarik denbora-tarte mugatu batean. Sistema horiek oso hauskorrak dirudite; izan ere, muga exogeno eta endogeno txikiekiko oso sentikorrak izateko joera dute, eta haien bilakaera dinamikoa irregularra[36] da. Harrigarria bada ere, antzeko fenomenoak antzematen dira STHetan ere.

STH sistemak mugatuta daude dagozkien arau sozialen eta tokian-tokian dauden merkatu-garapenen bidez, eta haien balioak, helburuak, tentsio publiko/pribatuak eta abar partekatzen dituzte. Hala ere, STH sistemen eta arau sozialen eta merkatuaren bilakaeren arteko elkarreragin-sarea dinamikoa da. Beraz, «barneko» aldaketetara egokitu behar dira, hau da, STH sistemen bilakaerak ekarritako aldaketetara, baita «kanpoko» aldaketetara ere, hau da, etengabeko bilakaeran den «ingurunera», zeina zerbitzua ematen duten gizartean gertatzen diren benetako aldaketek baldintzatzen baitute. Izaera dinamiko horrek gertakizunen sekuentzia bat dakar berekin, eta STH sistemen portaera deskribatzeko ereduei dagokienez, STH sistemek beren ingurunearen aldaketei denbora errealean eman beharreko erantzunak zehatz-mehatz azaltzeko beharra ezartzen du sekuentzia horrek.Bestela esanda, ereduek oinarrizko denbora-ezaugarri ordenatuak ezarri behar dituzte, joerak aurreikusteko, arriskuei aurrea hartzeko eta etorkizuneko gertaerak kudeatzeko aztarnak lortzeko.

Eguraldiaren iragarpena da ideia hori argitzeko ohiko adibideetako bat. Gure helburuei begira, klimari buruzko datu-multzo handiak[37] denbora errealean biltzeko eragiketa-sortatzat har daiteke eguraldiaren iragarpena. Datu horiek eredu klimatiko historikoen liburutegi sendoen multzo handi baten eta propio sortutako algoritmo konputazionalen laguntzarekin lantzen baditugu, eskala handiko simulazio konputazionalak egin ondoren, eguneko aurreikuspen meteorologikoa[38] lortuko dugu. Fluidoen eta gasen

[35] Ott, A.; Bouchaud J. P.; Langevin, D.; Urbach, W. (1990). «Anomalous diffusion in "living polymers: A genuine Lévy flight», *Physical Review Letters*, 65, 2201- 2204.

[36] Barthelemy, P.; Bertolotti, J.; Wiersma, D. S. (2008). «A Lévy flight for light», *Nature*, 453, 495-498.

[37] Turbulentzia atmosferikoen satelite-irudiak, uraren itsas mailako tenperatura-mapak, presio barometrikoko mapak eta abar.

[38] Eguraldia emaitza da, klima dena da. Ikus: Schiermeier, Q. (2018). «Climate as culprit», *Nature*, 560, 20-22.

fluxuen inguruan ezarritako lege fisikoetan oinarritutako prozesua da, eta informazio baliotsua eta fidagarria sortzen du gizartearentzat. Informazio hori gomendio bilakatzen da —gomendio positiboak, normalean—, baina, askotan, pertsonek ez dute behar adina aintzat hartzen. Nabarmendu nahiko genuke jakintza dagoela prozesuaren hasieran; adibidez, lege fisikoak. Datu-multzo handia eta askotan egituratu gabea prozesatzeko gaitasun teknikoak —kasu askotan oso sofistikatua— egiten du lanaren gainerako zatia, eta, azkenik, adituek gomendioak ematen dituzte. Xede-gizarteari begirako helburua da gomendioek eragina izatea egungo giza «portaeran». Hori, ordea, kanpoko faktoreen mende dago; hona hemen faktore horietako batzuk: arriskuaren pertzepzioa hainbat komunitatetan, gomendioekiko jarrera indibidual positibo jakin batzuk hartzeko joerak, eta tokiko eta munduko mugikortasun-ereduak eta azpiegiturak.

Hemen hainbat «geruza» identifika ditzakegu. Geruza bat araudiei dagokie. Horrela, iragarpen meteorologikoaren eragiketak arrakasta izan dezan, hau hartu behar da oso kontuan: (i) datu fisikoak berreskuratzeko tokian tokiko araudiak; (ii) datu horien jabetza; (iii) komunikabide-erakundeentzat —izan jabetza/erabilera publikokoak, izan pribatukoak— gomendioak zabaltzeko dauden tokian tokiko araudiak/ereduak, eta/edo (iv) emandako gomendioak tratatzeko tokian-tokiko araudiak. Beste geruza bat araudi horiek gauzatzeko tokiko jarraibideei dagokie. Hala, honako hauek ere hartu beharko lirateke kontuan: (i) emandako gomendioak herritarrek egin beharreko nahitaezko ekintza bihurtu behar diren, iragarpenen larritasunaren arabera; (ii) nork hartu behar duen erabaki hori, eta (iii) nork betearazi behar dituen neurriak. Neurri horietako batzuk izan daitezke hirietatik nahitaez ihes egitea eta tokian-tokian indar polizialak/militarrak hedatzea. Gainera, azken horiek tokiko araudiekin lotuta daude ezinbestean; hortaz, esan gabe doa, izugarri alda daitezke leku batetik bestera, eta agerian uzten dute elkarreraginen konplexutasuna.

8. Ukitu zientifiko bat

STH sistema gehienak, hedatzen diren ingurune sozialekin batera, biztanleria-segmentu hautatuek osatutako sare gisa modelatzen dira. Biztanle horiek elkarri konektatuta daude STH sistemaren edo sistemen bidez eginiko elkartrukeen bitartez. Aurretik eginiko azterlan asko adostasun batera iritsi dira: truke horiek espazio- eta denbora-eskalaren[39] mende daude, neurri handi batean. Irismen laburreko eta luzeko ezaugarriak oso desberdinak dira, eta, beraz, ikertzeko aukeratutako eskalaren araberako tratamendu bereizia behar dute. Are gehiago, mundu errealeko sare gehienek autoantolaketa dinamiko handia erakusten dute denboran zehar, barne-konektibitatearen bilakaeraren ondorioz, baita kanpoko faktoreen esku-hartzerik gabe ere. Ahalegin horiek egin arren, STH sistemak ez dira oso ezagunak. Maiz, ahaztu egiten dugu datu hori, arazoa sortzen den arte. Sakonago ezagutu behar ditugu gizarte-ingurune konplexuetan jarduten duten STH sistemen oinarriak eta denboran zeharreko bilakaera, haien aldaketei eta hutsegiteei eraginkortasunez eta arduraz erantzun ahal izateko.

Fenomeno kolektiboen zientzian egin berri diren aurrerapenek sistema[40] konplexuen bilakaeraren dinamikaren ikuspegi berri bat eskain dezakete. «Lege primarioek» beren termino lineal nagusiak proposatzen dituzte, baina, horien aurrean, fenomeno konplexuen zientziak ez-linealtasunak eta askotariko kausalitateak (eskala anitzeko ikuspegia) sartzen ditu orekarantz (egonkortasunerantz) eboluzionatzen ez duten fenomenoen deskribapenean; aitzitik, ezegonkortasuna etengabe areagotzen

[39] Vespignani, A. (2008). «Predicting the behavior of techno-social systems», *Science*, 325, 425-428.

[40] Helbing, D.; Balietti, S.; Bishop, S.; Lukowicz, P. (2011). «Understanding, creating, and managing complex techno-socio-economic systems: Challenges and perspectives», *European Physical Journal*, Special Topics, 195, 165-186.

da, aurkitu berri diren eskalatze-legeen[41] arabera. Eskalatze-lege horiek ezagunak dira epidemien eta lurrikaren alorretan, baina hirien hazkundean, burtsen portaeran eta abarretan ere agertzen dira. Ondorio hau atera daiteke: sistema konplexuak ez dira ausaz aldatzen, azpiko indarren arabera baizik, eta indar horiek eragiten dute bilakaera, sistema sozioekonomiko eta teknologikoei berdin aplikatzen zaien egitura kritiko autoantolatu bat sortuta. Haien autoantolakuntzaren kritikotasunak bat-bateko hausturak eragiten ditu. Horixe da guk ikusten duguna eta, gehienetan, sufritzen duguna.

Zorionez, eskala anitzeko ikuspegiak, gaur egun ezagutzen dugun bezala, ahalbidetu egiten du gizarte-ingurune konplexuei lotutako STH sistemen funtzionamendua arautzen duten lege estatistikoak eta dinamikoak ulertzea. Egia esan, STH sistema batzuk beste batzuk baino hobeto egokitzen dira eskala anitzeko esparru horretan. Hortaz, pertsonak, lehengaiak eta manufakturatutako produktuak garraiatzeko azpiegiturak, bai eta gas-eta fluido-kantitate handiak distantzia luzean garraiatzeko eskala handiko eragiketak ere, ezin hobeto egokitzen dira eskala anitzeko ikuspegietara. Entxufe guztiak elektrizitatez hornitzeko behar besteko energia garraiatzeko, banatzeko eta hornitzeko sistema teknologiko handiak dira beste adibide bat.

Mundu osoan zehar fisikoki banatutako sistema teknosozial handiek prozesatzen dute materia iragankorra —besterik ez esatearren—, bereziki gaur egun. Egiaz, «hodeia» delakoan ere prozesatzen da; han datuen (big dataren) zaintza, aukeratua zein irekia, eta Internet bidezko eskuragarritasuna eta eskuratzetasuna hodei horren administratzaileen esku daude. Horien artean daude telefonia mugikorreko komunikazioetarako mikrouhin-antenen sarea edo baloreen finantza-merkatuetako eragiketetarako datu «sentikorrak» hedatzeko (edo ezkutatzeko) kanalak, adibide batzuk aipatzearren.

9. Weba

Beharbada, ohiko SHT sistema Internet eta hari lotutako World Wide Web (labur esanda, weba) delakoa da. Normalean, Internet eta web hitzak gauza bera deskribatzeko erabiltzen dira, baina oso gauza desberdinak dira. Webak ordenagailuaren bidez —linean dagoenean— arakatzen ditugun orrietara sartzeko bitartekoak hartzen ditu barne. Orrietan nabigatu, haiek editatu, kokapena partekatu eta abar egin dezakegu, helburu orokorreko lengoaia estandar baten bidez: HyperText Markup Language (HTML) delakoa. Internet, berriz, elkarri konektatutako ordenagailuek, zerbitzariek eta webari euskarria ematen dioten beste hainbat gailuk osaturiko sarea da.

Weba ezin da ulertu gizakion gizarteari erreferentzia espliziturik egin gabe. Alde batetik, Internet mundu modernoan gehien partekatzen den azpiegitura teknologikoa da. Bestetik, weba gizakiek azpiegitura horretan gauzatzen dituzten jarduеretan datza. Gizakiak webaren edukiaren ekoizle eta ikusle dira hemen. Giza eragileen izaera dual hori da webaren izaera hiperebolutiboaren indar eragilea, eta informazioa mundu mailan hedatzeko, sortzeko eta trukatzeko azpiegitura bat da horren emaitza. Weba, beraz, gizakientzat ordenagailu bidez egindako kognizioko, komunikazioko eta lankidetzako STH bat da[42]. Erabiltzaileek eraginkortasunez laguntzen duten STH sistema bakarra da, garapen teknikoari dagokionez, kodea beren komunikazio behar sozialetara egokitzen baitute. Webaren egitura xehatua eta eduki zehatza ezin dira aurreikusi. Orriak erabiltzaileen beharren arabera agertzen eta desagertzen dira. Baina gauza bat aurreikus daiteke ziurtasunez: webaren konplexutasuna areagotu egiten da denborak aurrera egin ahala, webgune eta orrien, web-bilatzaileen, estekatze-ereduen eta horien guztien arteko

[41] A. Brú, A.; Alós, E.; Nuño, J. C.; Fernández de Dios, M. (2014). «Scaling in complex systems: a link between the dynamics of networks and growing interfaces», *Sci. Rep.*, 4, 7550.

[42] Raffl, C.; Hofkirchner, W.; Fuchs, C.; Schafranek, M. (2023). «The Web as Techno-Social System: The Emergence of Web 3.0», https://api.semanticscholar.org/CorpusID:46997037. Kontsulta-eguna: 2023ko irailaren 19a.

konexioen kopurua handitu ahala. Gainera, duela gutxi eragile berri bat sartu da webaren munduan: adimen artifiziala[43]. Horrek mahai gainean jarri du webaren izaera hiperebolutiboa ez dagoela soilik edukiaren dibertsifikazioarekin lotuta; izan ere, eragile berrien agerpenarekin ere lotuta dago. Jakina, oraindik eremuaren errealitatea behar bezala eta behar adina ulertzea geratzen zaigu, batez ere haren garapenaren atzetik ez joateko etengabe, iritsi ezinik, haren inplikazioak behar bezala kudeatu ahal izateko, aurrerapenak eragotzi gabe. Bereziki, hurbiletik jarraitu beharko genuke konputazio kuantiko bidez elikaturiko adimen artifiziala —etorkizun hurbilean eskura izatea espero den konbinazio bat—, ahalmena izango baitu bioteknologia, nanoteknologia eta robotika goragoko maila batera eramateko eta, hortaz, gaur egungo mundua goitik behera aldatzeko.

10. Hiriak

Hala ere, badira eskema horretan sartzeko joera txikiagoa duten beste STH sistema batzuk. Esate baterako, kontuan har ditzagun hirien, etxebizitzen, etxeen, errepideen eta trenbideen eta horien arteko lotura-bitarteko osagarrien diseinua zentzuz garatzeko plangintzari buruzko hirigintza-irizpideak, hala nola garraiobide gisa erabil daitezkeen ibaiak, berekin dakartzaten guztiarekin: ibai-portuak, itsaslabarren inguruan ontziak igotzeko edo jaisteko esklusak, ontziak konpontzeko kaiak eta abar. Kasu horretan, STHaren eta eskainitako zerbitzuen arteko muga lauso samarra da. Hiriak pertsonak eta komunitateak —haien ezaugarri ekonomiko eta kultural espezifikoak aintzat hartuta— gai teknikoekin —plangintza, (ber)eraikuntza, mantentze-lanak...— konektatzen dituzten sistema konplexu gisa uler daitezke. Ondorioz, STH gisa ikus daitezke, arazoari ikuspegi egokia emateko izugarri lagungarria den ikuspuntu gisa. Gainera, jabetuta gaude arazoaren formulazio teorikoan egindako aurrerapenak aurrerabide nabarmena ekar dezakeela aplikazio praktikoei dagokienez, hirien garapena planifikatzeko estrategia hobeak diseinatzeko tresna arrazionalak emango baititu.

Kalkuluen arabera, munduko biztanleen erdiak baino gehiago hirietan bizi dira. Proportzio hori handitzen ari da, eta, horrekin batera, komunitate trinkoen kokalekuekin lotutako arazoak ugaritzen ari dira. Hori da gure garaiko paradoxarik handienetako bat. Hau da, teknologia berriek inoiz baino askatasun handiagoa ematen diete pertsonei eta enpresei beren kokapena eta mugikortasuna aukeratzeko, eta, hala ere, jendeak inoiz baino gehiago aukeratzen du elkarrengandik oso hurbil bizitzea. Jokabide irrazional[44] hori, harrigarria bada ere, ondo deskribatu du Shelling[45] ereduak. Ereduak ulertzen du pertsona orok nahiago duela neurrizko dentsitatea duen hiri batean bizi, herri-zerbitzuetarako eskuragarritasuna errazagoa delako dentsitate handiko hirietan baino, eta sozializatzeko aukera hobeak dituztelako hutsik dauden hiriek baino. Gainera, suposatzen da pertsona bakoitza libre dela beste hiri batera joateko, haren dentsitatea optimoa izatetik gertuago dagoela uste badu, neurritasunera hurbiltzen dela, alegia. Mugimendu-askatasun horrek dentsitatearen oreka-faktore gisa jardutea espero da. Baina, epe luzera, orekaren guztiz kontrakoa izango da. Hau da, hiri batzuk gainpopulatuta egongo dira azkenean (maila optimoarekin alderatuta), eta beste batzuk, erabat hutsik. Orekaren ordez, segregazioa eragiten du, eta, horren ondorioz, biztanleria hiri handietan pilatzea.

Hiri handiak giza elkarreraginetarako dentsitate handiko eremu fisikoak dira, eta horrek erraztu egiten du informazioa azkar zabaltzea eta ideia[46] berriak sortzea. Hala ere, horrek agerian uzten du

[43] Ikus zenbaki berezi hau: «Artificial Intelligence its Potential and Limits», *Rev. Int. Estud. Int. Estud. Vascos*, 67(2), (2022).

[44] «Irrazional» hitzak esanahi ugari izan ditzake. Hemen, nolabaiteko anbiguotasunez erabili da, jokabide ilogikoa edo zentzugabea irudikatzeko.

[45] Schelling, T. S. (2006). «Micromotives and Macrobehavior», WW Norton & Company.

[46] Glaeser, E. (2011). «Triumph of the city: How our greatest invention makes us richer, smarter, greener, healthier, and happier», The Penguin Press, Londres.

informazioaren teknologia informatizatuek, IKTek, «espazio» kontzeptua birmoldatzen dutela, eta horrek eragin sakona du hirietan[47]. Izan ere, IKTek «fluxu-espazio» izenekoak agertzea eragiten dute; «leku-espazio» fisikoarekin gainjartzen diren informazioaren bit-fluxu informatikoak dira. Biek ala biek antzeko eragina dute gaur egun hirien hazkundean.

Izan ere, hazteko joera dutenez, hiriek estrategiak bilatu behar dituzte hazkunde arrazional bat ahalbidetzeko eta hazteko bultzadaren pean ez erortzeko. Ekoizpen azeleratuaren eskalaren legeak —«hazkundeak hazkundea suspertzen du»— hirietarantz erakartzen du jendea. Baina, orduan, hazkundeak arriskuan jartzen ditu hiriko azpiegiturak eta zerbitzuak, eta, horrenbestez, gero eta pertsona gehiagok egin behar izaten dute borroka beren lekua bilatzeko gero eta masifikatuago dauden inguruneetan. Batzuetan, horrek kolapsoa ekar dezake. Detroit da ohiko adibideetako bat, baina, esaterako, duela gutxi Birminghamen gertatutakoa bezalakoek (Udalak porrot egin du, eta gastu guztiak saihesten ari da, oinarrizko zerbitzuak bermatzekoak izan ezik[48]) gogorarazten digute zer gutxi behar den akats sistemikoak eragiteko. Aldiriak eraikitzea irtenbidetzat hartu da, baina, hasteko, presioa eragiten die garraio-zerbitzuei, eta epe luzera ez dirudi jasangarria. Zein tamainatatik aurrera eragiten du biztanleen «gaitzespenak» hiri baten kolapsoa? Oraingoz, etengabeko berrikuntzari esker saihesten dute hiriek kolapsoa. Biztanle-kopurua zenbat eta handiagoa izan, orduan eta laburragoa da hurrengo berrikuntzarako epea. Orain hasi gara eredu[49] gorabeheratsu ez-lineal horien mekanismoak ulertzeko oinarriak ezartzen. Hala ere, hain sentikorrak diren gai horiek aztertzen jarraitzea eta proposatutako planteamenduak baliozkotzea aurreikusi da.

11. Ikerketa eta teknologia

Hona hemen gizarte-zerbitzura bideratutako STHen adibide bat: mundu osoan barrena sakabanatuta dauden, sare-lana egiten duten eta lankidetzan aritzen diren hainbat laborategik eta enpresak azken produktu bat sortzeko abian jarritako ikerketa-, garapen- eta berrikuntza-ekimen globalak. Esate baterako, Ikerketa Nuklearrerako Europako Kontseilua (CERN), partikulen fisikako munduko laborategirik handiena. Eskuarki, CERNen hadroi talkagailu handiaren osagaiak laborategiaren Genevako (Suitza) egoitzatik oso urrun dauden lekuetan egiten eta, batzuetan, partzialki muntatzen dira. Beste adibide bat Nazioarteko Erreaktore Termonuklear Esperimentala (ITER) da. ITER proiektua ekimen teknosozial handia eta ezaguna da, eta 1985az geroztik, 35 naziotako milaka ingeniari eta zientzialari ari dira lanean bertan fusio magnetikorako gailu bat eraikitzeko, eta frogatzeko, gure Eguzkia eta izarrak bultzatzen dituen printzipio berean oinarrituta, fusio nuklearra eskala handiko eta karbonorik gabeko energia-iturri gisa bideragarria dela. Horrek STH sistema teknologikoen konplexutasun-maila jartzen du agerian.

Teknologia berri eta erabilgarri bat garatzea prozesu neketsua da eta izan da beti. Hura ezartzea are neketsuagoa da, zati batean edo osorik ordezkatu behar duelako zaharra izanagatik ondo aztertuta eta optimizatuta dagoen teknologia bat. Horrela, gizarte teknologiko efizienteak aldaketarekiko erresilienteak dira. Salbuespenak gertatzen dira kanpoko presazko estimuluek bultzatzen dituztenean. Nitrato sintetikoak garatzea, munizioaren ekoizpena edo bonba nuklearraren proiektua ziurtatzeko, estimulu militarrari emandako erantzunen adibide dira. Kautxu sintetikoa eta penizilinaren eta COVID-19ari aurre egiteko txertoen ekoizpen masiboa arrakastaz ezarri ziren denbora-tarte labur batean, pizgarri ekonomikoek eta, agian, altruismo pixka batek bultzatuta. Baina, oro har, garapen teknologikoa konplexua da, iragartzen zaila, eta bazter askotatik suertatzen diren ustekabez betea.

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[47] Castells, M. (2020). «Space of Flows, Space of Places: Materials for a Theory of Urbanism in the Information Age», in *The City Reader*, R. T. LeGates, F. Stout (Editorean), Routledge, Londres.

[48] https://www.bbc.com/news/uk-england-birmingham-66715441. Kontsulta-eguna: 2023ko irailaren 5a.

[49] Batty, M. (2008). «The size, scale, and shape of cities», *Science*, 319, 769-771.

Atzean geratu dira ikerketa-zentroek, unibertsitateek eta enpresek ikerketa- eta garapen-eragiketak (I+G) beren laborategietan egiten zituzten egunak. Gaur egun, I+Ga mundu mailan egiten da. Teknologia kanpoko hornitzaileetatik, startupetatik, munduko beste ikerketa-zentroetatik eta abarretatik lortzen da maiz. Berez, ezagutzaren zatirik handiena kanpotik sortzen da, STH sistema teknologiko globalen (mundu-mailakoen) sarearen barruan. Horrela, beste leku batzuetan egindako I+Ga kapitalizatzeko ekimenak sistemaren parte dira gaur egun, eta berrikuntzaren puntu kritiko bihurtu dira nazio askorentzat. Gobernuaren eskema zaharrak akats asko ditu. Haren bitartez, oinarrizko ikerketa finantzatzen da, tokiko sektore publiko/pribatuko I+Gko zentroetan balio ekonomikoa sortuko duten berrikuntzak sortzeko, baina, horren ordez, produktuak modu korapilatsuan lotutako urrats askoko prozesu luze baten ondoren sortzen dira. Produktu horietako gehienek ez dute aldaketa sakonik eragiten gizartean, baina batzuek bai. Eta hori gertatzen denean, erabateko berrikuspena eragiten du: Schumpeterren olatu deiturikoak[50]. Horrek sistema kritiko autoantolatuetako fase-trantsizioak imitatzen ditu. Olatu horiek errepikakorrak[51] izaten dira. Haien eboluzioa ulertzeko, STH sistema teknologikoaren konplexutasun orokorrari heldu behar zaio.

12. STH sistemen akatsak

Dena den, gauzak gaizki joan daitezke STH sistemen akatsen ondorioz. Horrek hainbat ondorio izan ditzake, akatsa izan du(t)en STH sistem(ar)en izaeraren eta hark edo haiek eskainitako zerbitzuaren arabera. Bi akats-mota aurreikus daitezke: konbentzionalak eta sistemikoak. Akats konbentzionalak espazioan eta denboran mugatu daitezke, kausa-efektu erlazio linealei jarraitzen diete, eta kausa-efektu katean esku-hartze eraginkorrak eta zorrotzak eginez zuzendu daitezke, eta askotan gizarte-eremu bakar batean soilik gertatzen dira. Akats sistemikoek[52], berriz, ezaugarri hauek izaten dituzte: konplexutasun handia, irismen handiko ondorioak, harreman estokastikoak, inflexio-puntuak dituzten kausa-efektu eredu ez-linealak. Horrez gain, behar baino arreta publiko gutxiago jasotzen dute sarri. Akats horiek zailak dira behar bezala kudeatzen; neurri batean, haien izaera ez delako ulertzen, eta horrek eragotzi egiten du akats sistemikoen arriskuaz ondo jabetzea.

Jakina da akats sistemikoen arriskuaren garrantzia behar bezala ebaluatzeko tresna praktikoak ezartzen hasi direla duela gutxi, baina badirudi akats horien arriskuak irrazionalki arinagoak direla publikoaren pertzepzioan[53]. Horri «arrisku sistemikoaren pertzepzioaren paradoxa» deitu izan zaio; hau da, gizarteak akats sistemikoen arriskuei buruz duen pertzepzioa ez dator bat publikoki eskuragarri dauden datuek islatzen duten errealitate enpirikoarekin[54].

Akats sistemikoak fenomeno konplexuak dira, eremu jakin batetik harago doaz, ez dira linealak, itzulerarik gabeko puntuetara eramaten gaituzte maiz, eta, aldi berean, gizartearen hainbat eremuri kalte egiten dieten gertakari-zaparradak eragiten dituzte. Oro har, STH sistemak eta, zehazki, ekonomian eta finantzetan jarduten dutenak aldez aurretik detektatzeko zailak diren akats sistemikoak izateko joera duten sistemen taldekoak dira. Schumpeterrek argudiatu zuen[55] arazoaren zati bat gizarte-dinamikaren

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[50] Kleinknecht, A. (1990). «Are there Schumpeterian waves of innovations?». *Cambridge Journal of Economics*, 14, 81-92.

[51] Devezas, T. C.; Corredine, J. T. (2002). «The nonlinear dynamics of technoeconomic systems- An informational interpretation», *Technological Forecasting and Social Change*, 69, 317-358.

[52] Tanzi, V (2020). «The Economics of Government: Complexity and the Practice of Public Finance». Ikus 8. kapitulua: «Systemic Failure, Complexity, and Public Policies», Oxford University Press. Londres.

[53] Schweizer, P. -J.; Goble, R.; Renn, O. (2022). «Social perception of systemic risks», *Risk Analysis*, 42, 1455-1471.

[54] Renn, O. (2014). «Das Risikoparadox. Warun wir uns von dem Falschen fürchten», Frankfurt/Main, Alemania: Fisher. [Alemanez].

[55] Schumpeter J. P. (2002). «Kapitalismoa, sozialismoa eta demokrazia», *Klasikoak*, Bilbo, 75-76 or. [Euskaraz].

izaeratik bertatik datorrela, errore-iturri eta aldagai asko dituen «prozesu» bat baita. Errore eta aldagai horietako gehienak ezin dira behar bezain zehatz neurtu, eta, beraz, egoera jakin batzuen diagnostiko zuzena egitea kasualitate-kontua bihurtzen da.

Ildo horretatik, gizarte-dinamiketarako konplexutasun-zientzien hurbilketa berriak akats sistemikoen eta horien gizarte-eraginaren ikuspegi berri bat eman diezaguke, sistema konplexuen eta oreka gabeko fisika estatistikoaren (*non-equilibrium statistical physics*, ingelesez)[56] azterketetatik datozen metodoetan oinarritutako ikuspegi desberdin batetik. Askoren iritziz, hori etorri berrien —fisikariak— eskatu gabeko mutur-sartze bat da beren ezagutzatik kanpo dagoen eremu batean —gizarte-zientziak—. Nolabaiteko berritasunak ekar baditzake ere, aldi berean, aitortu beharra dago beren buruarekiko gehiegizko konfiantzarekin eta xalotasunarekin iristen direla, uste baitute aurreiritzi zaharrak gainditu eta ikuspegi erabat berria eman dezaketela. Normalean, egoera horretan, ezagutza-esparru horretan urte asko daramatzatenek ez dute «errebelazio» handirik espero. Eta, hala ere, ikuspegi freskoak ongietorriak dira, aukera ematen baitigute zalantzan jartzeko orain arte tradizio luzeko esparruetan ikuskera errotuak finkatu eta jardunbide profesionala gidatu duten doktrina nagusi ohoragarriak.

13. Ekonomia eta finantzak

Aurrekoa aintzat hartuta, demagun merkatu orekaren eredu ekonomikoak, eragile arrazionalen merkatal elkarrekintzak deskribatzen dituen doktrina ohoragarria. Hemen, jalgitako orekak prezioak, kostua, eskaria eta hornikuntza berdintzen ditu, eta orekoi, betirako iraungo duela eta inoiz inolako krisirik gabe jasan mantenduko dela suposatzen baita[57]. Dena den, hipotesi hori ez dator bat prezioek finantza-merkatuetan izaten dituzten gorabeherei buruzko estatistikaren errealitatearekin; izan ere, tamaina guztietako bat-bateko aldaketak gertatzen dira, eta merkatuen bilakaeran ez dago batere orekarik.

1987ko eta 2008ko krisiek hori berresten dute, modu sinesgarrian berretsi ere. Beraz, badirudi «orekaren hipotesia», erabilgarria izan daitekeen arren, *stricto sensu* faltsua dela. Krisiak gertatu gertatzen dira. Zergatik gertatzen dira? Hiru faktore nabarmentzen dira krisien agerraldiekin lotuta: (i) gai garrantzitsuei buruzko informazio-zati txiki ezezagunak daude, (ii) eragiketetan aldibereko portaera irrazionala dago, eta (iii) merkatarien jokabidea ekonomiaren etorkizuneko bilakaerari buruz dituzten itxaropenen ondorio da, eta, ondorioz, itxaropen horiek bultzatzen dute ekonomiaren bilakaera. Hau da, ekonomiak pertsonek hari buruz dituzten itxaropenekin batera eboluzionatzen du[58]. Horren ondorioz, gure ustez, egungo ekonomia osatu gabeko informazioan, ezagutza-faltan eta itxaropen zalantzagarrietan oinarritutako ariketa arrazionala da. Baieztapen horren oinarrian zera dago: gorabeherei, burbuilei eta talkei aurre egiteko itxaropen bakarra merkatarien jokabide arrazional gaituan datzala, sistema teknosozial finantzario handi, konplexu eta hiperkonektatuaren azpiko orekarik gabeko mekanismoen ezagutza sakonagoan oinarrituta.

Datu-kopuru masiboek berekin dakarten ikuspegi freskoa, batetik, eta, bestetik, datu-gordailu handiak «ohikoak ez diren» moduetan erabiltzeko baliabide berriak diziplina[59] ezberdinetako adituen artean

[56] Lazer, D.; Pentland, A.; Adamic, L.; Aral, L.; Barbási, A. L.; Brewer, D.; Christakis, N.; Contractor, N.; Fowler, J.; Gutmann, M.; Jebara, T.; King, G.; Macy, M.; Roy, D.; van Alstyne, M. (2009). «Computational social science», *Science*, 323, 721-723.

[57] Doyne Farmer J.; Geanakoplos, J. (2009). «The virtues and vices of equilibrium and the future of financial economics», *Complexity*, 14, 11-38.

[58] I. Palacios-Huerta, komunikazio pertsonala.

[59] (a) Anderson, P. W.; Arrow, K.; Pines, D. (1988). «The economy as an evolving complex system», CRC Press. (b) Darlauf, S. N.; Arthur, W. B.; Lane, D. (Eds.) (1997). «The economy as an evolving complex system II», Addison-Wesley. (c) Blume, L.; Darlauf, S. N. (Eds.) (2006). «The economy as an evolving complex system III», Oxford University Press.

lankidetza-bide berriak irekitzen ari dira. Bereziki, giza portaerari buruz ditugun datu-kantitate ikaragarriak kontuan hartuta, ekonometristek konpromiso aktiboa hartu dute beren datuak prozesatzerakoan faktore ez-linealak eta orekarik gabekoak kontuan hartzeko. Ondorio horiek funtsezkoak dira merkatuaren portaera —itxuraz «irrazionala»— ulertzeko eta iragartzeko, hein batean behintzat, eta horrek aldi berean aukera ematen digu merkatuek egonkortasunari nola eusten dioten edo nola bat-batean aldatzen diren aztertzeko. L. Hansen-ek esan zuenez, «sisteman gaur gertaturiko astindu txikiek eragin handia izan dezakete etorkizunean»[60]. Horrek bide eman dezake gorabehera basatiak leuntzeko eta, hala, etorkizuneko krisiak menderatzeko, ziurgabetasunaren eragina behar bezala kuantifikatuta[61].

14. Osasuna

Gizarte modernoek gaur egun dituzten erronkarik larrienen artean, herrialde askotako gai-zerrenda politikoaren lehenengo postuetan, biztanleriari osasun-sistema unibertsal bat eskaintzea dago. Gizarte garatuetan, horrek esan nahi du, herritarrak bizirik mantentzeaz gain, medikuntzan aurrerapen teknologikoak egin behar direla, pertsonek nahikoa osasun ona izan dezaten, bizitza luzeagoa izateko eta bizi-maila onari eusteko. Herrialde garatuek beren barne-produktu gordinaren % 10 bideratzen dute osasun-sistemetara; izan ere, ohiko borroka politiko alderdikoietatik harago, Europako demokrazia gehienetan, behintzat, adostasun handia dago «Europako gizarte-eredua»[62] delakoaren oinarrietako baten inguruan, eta harro daude beren osasun-sistemekin. Izan ere, baliabide publikoen zati handi bat bideratzen da sistema horiek finantzatzera, eta horrek agerian uzten du osasun-sistemen arloko STHen tamaina eta konplexutasun izugarria. Gogoratu, gainera, osasun-sistemen arloko STHak erakunde publikoen eta fundazio eta/edo enpresa pribatuen nahasketa baten bidez eratuta daudela, eta horrek aldi berean funtzionatzen duten lege- eta erregelamendu-egituren aniztasun handia sortzen duela. Hona hemen ikasi beharreko lehen ikasgaia: testuinguru horretan, antolaketa-gaiak gailendu egingo dira eztabaidagai gisa; izan ere, gero eta medikuntza-teknologia sofistikatuagoak hedatuko dira, gero eta «sofistikatuagoa» eta dibertsifikatuagoa den gizarte batentzat.

Portaera sozial kolektiboaren azken modelizazioak erakusten du fenomeno berriak sor daitezkeela egoera berezietan. Barne-tentsioko egoeren ertzetan gizarte-baldintzetan gertatutako aldaketa txikiak nahikoa dira sistema osoa krisi sistemiko batera eramateko, eta krisi hori, izan ere, sare sozialaren bidez zabaltzen da pertsonei larriki eraginda[63]. Egoera horiek kudeatzeko politika publikoak ingeniaritza sozialeko gai bat direnez, fenomeno horien agerraldiaren eta ondorengo hedapenaren mekanismo eragileak ondo ulertzeak berebiziko garrantzia du.

Horrela, SARS-CoV-2ak gizakien osasun fisikoan[64] dituen ustekabeko ondorioez gain —eta epe luzera oraindik erabat ulertzen ez direnak—, ustez COVID-19aren pandemian ezarritako gizarte-baldintzekin lotuta dauden gaixotasun mentalen agerraldiak harridura eragin du askoren[65] artean, eta alarmak piztu ditu estres-egoera luzeen mende egoteak biztanleriari eragindako osasun mentaleko arazoak tratatzeko

[60] https://larspeterhansen.org/meet-lars/. Kontsulta-eguna: 2023ko urriaren 20a.

[61] Hansen, L. P.; Sargent, T. (2023). «Risk, ambiguity and misspecification: Decision theory, robust control, and statistics», *J. Applied Econometrics*, 1-31.

[62] Piketty, T. (2014). «EL capital en el siglo XXI», Fondo de Cultura Económica, Madril, 531-534 or. [Gaztelaniaz].

[63] Sousa, J.; Barata, J.; Woerden, H. C. V.; Kee, F. (2022). «COVID-19 Symptoms app analysis to foresee healthcare impacts: Evidence from Northern Ireland», *Applied Soft Computing*, 116, 108324.

[64] Davis, H. E.; McCorkell, L.; Moore Vogel, J.; Topol, E. J. (2023). «Long COVID: major findings, mechanisms and recommendations», *Nature Reviews Microbiology*, 21, 133-146.

[65] Harrison,P. J.; Taquet, M. (2023). «Neuropsychiatric disorders following SARS-CoV-2 infection», *Brain*, 146, 2241-2247.

metodo zaharrak aldatzeko beharraren inguruan, gaur egungo agertoki infodemikoek[66] eragindako presio gehigarriaren pean. Egoera horretan, duela gutxi ohartu gara akats sistemikoak gerta daitezkeela, baldin eta osasun-sistemen arloko STHek ez badute ematen beren gizarte-inguruneetan gertatzen diren bat-bateko aldaketetara egokitzeko behar bezalako erantzun azkar bat. Gaur egun gai horren inguruan dagoen adostasunaren arabera, COVID-19aren pandemiaren agerraldiak sortutako ingurunean osasun mental ahula zabaltzeko baldintzak areagotu egin ziren, eta, horren ondorioz, agerian geratu zen, munduko ia herrialde guztietan, zalantzan jarri behar zirela osasun-sistemen arloko STH gehienetan osasun fisikoa eta mentala eskaintzeko protokoloen arteko orekaren oinarrian egon diren funtsezko hipotesiak. Horrenbestez, ingurune aldakor eta, kasu honetan, disruptibo batera egokitzen den sistema (tekno) sozial handi bat sortzen da. Sistema horrek hau eskatzen du beste ekintza batzuen artean: inoiz baino hurbilagotik kontrolatzeko biztanleen osasun mentalaren narriadura-zantzu goiztiarrak, hartara osasun fisikoko arazoei ez ezik osasun mentaleko arazoei ere behar bezala aurre egite aldera.

Zenbaki honetan, STH konbentzional batzuk hain konbentzionalak ez diren beste batzuekin batera aztertu eta sakonki berrikusiko dira. Haien egituren berezko konplexutasuna nabarmenduko da, agerian jartzeko alderdi anitzeko ikuspegi bat behar dela sistema horiek jarduten duten gizarte-ingurunearekiko loturak argi eta garbi ikusi ahal izateko. Azpimarratzekoa da ahaleginak egingo direla STH gehienen oinarrizko ezaugarrien azpian dauden mekanismo konplexu komunak (antzekotasun harrigarriak dituztenak) nabarmentzeko.

Esker onak

Egileek eskerrak ematen dizkiote Palacios-Huerta irakasleari, idazki hau hobetu duten iruzkin estimulatzaileak eta iradokizun lagungarriak egiteko eskainitako denbora eta energiagatik.

Echeverría, Javier[67]
Ugalde, Jesus M.[68]
Editors in Chief

Jatorrizko artikulua ingelesez. Itzulpena: Belaxe Koop. E.

[66] «Infodemiko» hitzak esan nahi du ingurune digitaletan eta fisikoetan informazio gehiegi ematen dela, informazio faltsua edo engainagarria barne, gaixotasun-agerraldi batean.

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