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Knowledge Generation and Interdisciplinarity

Jüri Engelbrecht
Fellow, World Academy of Art and Science
Fellow, Estonian Academy of Sciences

Robert Kitt
Council Member, Tallinn University of Technology, Estonia

> *No man is an island entire of itself; every man is a piece of the continent, a part of the main; if a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as any manner of thy friends or of thine own were; any man's death diminishes me, because I am involved in mankind.*
>
> *And therefore never send to know for whom the bell tolls; it tolls for thee.*
>
> **– John Donne** (1572-1631)

Abstract

In this paper, it is argued how the present crises in the world are influenced by the breaking up of networks created by the communities worldwide. In addition to human-made networks, many networks in Nature also influence life in many aspects. In this context, the understandings of the behaviour of complex systems, especially in social spheres, can help us find better solutions in the future. The interdisciplinary studies uniting knowledge from science, humanities, and social sciences can proactively describe knowledge generation for understanding the complexity of processes in a coordinated and coherent way and applying it for problem-solving.

1. Introduction

Nature can be defined as a network of many phenomena that are binding the structure of our Globe, its flora and fauna into a whole. In addition, mankind has created many networks of its activities that certainly influence Nature and vice versa. The behaviour of ice masses in Antarctica and the health of rain forests in the Amazon basin influence the world's climate, acid rains, floods, and the melting of glaciers have more local influence if only few examples are to be listed. Man-made networks of spreading information, distribution of energy and goods are nowadays a part of our civilisation. We witness the acceleration of globalization despite the warnings to think before acting. Inequalities in welfare, and the threats from natural disasters, poverty, needs for food and water are growing and have been leading to migration flows. And threats from cyberattacks and terrorism have created additional problems influencing the relations between the countries and communities. We are proud of the scientific results, whether they concern the structure of matter, processes in the Universe, the functioning of life from the genetic viewpoint, or technological applications that make everyday life easier. Nevertheless, many activities were paralysed in 2020 due to the COVID-19 crisis. Mankind was simply not prepared for such an interruption of networks that were built up in good faith based on reciprocal contacts and agreements. The health threats were simply stronger than smooth ideas on globalization.

Even this brief analysis makes us ask why we face such a situation now where the networks are broken, the systems built after careful negotiations do not work, and even more importantly, what the impacts of this crisis are on social self-regulation, self-organisation and resilience. In other words, what is the impact of the crisis, and what must be done to prevent such a situation in future? We are far away from presenting a recipe for further actions, but this essay serves as an analysis of some possible ideas for further actions. Actually, it is obvious that mankind should use all existing knowledge and knowledge generation for analysing the situation and use consolidated management and communication for facing the world's challenges.

In Section 2 some ideas of networking are presented and in Section 3 some concepts that characterize the crises are analysed. Section 4 is devoted to the brief analysis of social systems, including risk analysis. Section 5 brings in interdisciplinarity in order to unite the knowledge from various scientific disciplines together with the philosophical viewpoint. The authors stress that only with joint efforts of all the fields of science, humanities, and social sciences it is possible to solve the current problems. Final remarks are briefly presented in Section 6.

2. Networking

Using the concepts of networking, society can be described by networks that are formed by nodes (individual agents, groups, communities, states, alliances) differing in space and time (Barabasi, 2016). Moreover, agents are also joined by certain links (families, communities, workplaces, faiths, etc.) and their behaviour influences strongly all the other networks. And the man-made networks of trade, transport, energy, capital, etc. present an important part of the contemporary globalized world. The behaviour of physical networks is pretty well studied and understood, but social networks due to their complex structures generate more questions than answers and explanations. The main problem is that the behaviour of complex systems depends strongly on interactions between their elements. In physical systems, the laws of physics are well studied, and the interactions are measurable. In social systems, the interactions depend on certain rules, traditions, governance systems economic conditions, environment, etc. and besides—values that are subjective. This makes the understanding of the behaviour of social systems difficult. Two important issues must be underlined. First, the interactions determine the behaviour of the system as a whole. As a result, new qualities may emerge in complex systems which cannot be deduced directly from the properties of constituents. Second, the predictability of a complex system is not possible anyway due to nonlinear links, and in social systems, it is shadowed also by insufficient knowledge about the links.

Some examples demonstrate the present understanding. *First*, globalization is understood mostly in terms of international transactions (trade and financial flows). The International

Monetary Fund, for example, indicates four important aspects of globalization: multilateral trading system, capital investments, migration, and distribution (diffusion) of knowledge (IMF, 2008). The OECD (2015) stresses the importance of the environment for fostering long-term investment, financial stability, and business integrity. But all these aspects have created inequalities that support nationalism protecting individualities and identities. What is absent in these concepts is the social side of these processes. *Second,* the threats to the general ecological situation have forced the UN to accept the Sustainable Development Goals (SDGs) that are clearly a step forward to joint understanding (UN 2015). It has been shown by Nakicenovic (2019) that IIASA analysis demonstrates clearly that these 17 goals form a network, and one should deal with them not one by one but jointly. *Third*, one should pay attention to values in societies. Based on the World Values Survey, Inglehart and Welzel (2004) have designed the Cultural Map of the World where the countries are characterized by two dimensions: (i) traditional vs secular-rational and (ii) survival vs self-expression values. Their two-dimensional map shows clearly how the countries are grouped: protestant Europe, Catholic Europe, English-speaking, Confucian, orthodox, ex-Communist, South Asia, Latin America, Africa. The next step for understanding the differences between the countries (and language groups) is to include aspects of economic wealth (GNP), happiness and subjective well-being indices, etc. Changes in the Cultural Map over the years (1981-2007) have been especially informative reflecting the changes in societies (Inglehart et al., 2008). *Fourth,* Engelbrecht (2016) has conjectured that in physical systems the constraints are based on thermodynamics, in social systems the constraints are based on values.

It seems that in this context, the functioning of society and the role of values must be better understood than common knowledge. One should start from understanding and trust to avoid the conflict of cultures. Umberto Eco (1998) has indicated possible scenarios when two cultures meet. He distinguishes the following possibilities: conquest (European civilization subjugated Amerindian cultures); cultural pillage (Greeks transformed Egypt into a Hellenistic kingdom but admired Egyptian wisdom); exchange (reciprocal influence like contacts between Europe and China). All of them certainly have a variety of modifications. Whether such meetings produce stress, especially in the short run, is another question. Putnam (2007) has analysed the diversity in the community and based on the experience in the USA, shown that ethnic diversity tends in the short run to reduce social solidarity and social capital. The conflict of cultures may be a real threat to the connectivity of a tolerant society. Collier (2013) stresses that due to national barriers there might be an optimal degree of diversity in contemporary society.

Even this brief analysis demonstrates that the complexity of natural and man-made systems must be studied in detail to understand the influence of possible links and interactions for the sustainable development of the world. It means that basic knowledge about complex systems should be generalized from examples to general rules in order to change the mindset that is usually based on simple rules, additivity and predictability. In reality, one should understand the possible unpredictability of processes, non-additivity, influence of interactions and many more characteristics of complex systems (see Castellani, 2018).

3. Crises in the world

The well-known definition is that a crisis is an event that may lead to an unstable and dangerous situation. A crisis is unexpected, creates uncertainty and is seen as a threat to the goals of a person, a group or society in general (Seeger et al., 1998). Besides natural disasters (volcanic eruptions, floods, etc.), it is possible to distinguish man-made crises that occur in policy, economy or in the environment in general. Although the knowledge about the risks and mechanisms of crises is collected in the scientific community, the recent crisis related to the spread of COVID-19 in 2020 has demonstrated to the world how vulnerable man-made systems are and how the structures and relations built carefully over a long period collapsed rapidly.

Knowledge about the phenomenon of the instability of systems exists in physics and mathematics. In social systems, the situation is more complicated because it is related to consciousness, free will, traditions, and also to faith. Several concepts should be pointed out in this context: singularities, catastrophes, cascades.

The concept of singularity was introduced by J. von Neumann already in 1950. His definition of singularity was that, singularity is the moment beyond which "technological progress will become incomprehensively rapid and complicated." Kurzweil (2006) defined Technological Singularity as "…a future period during which the pace of technological change will be so rapid, its impact so deep, that human life will be irreversibly transformed."

In mathematics, singularity means discontinuous change. Such problems are dealt with by the so-called catastrophe theory derived by the French mathematician René Thom (1968) and British mathematician Eric Christopher Zeeman (1976). A 'catastrophe' means that in a nonlinear system the equilibria can appear or disappear due to small changes in some leading parameter. Geometrically such catastrophes are classified according to Thom as a fold, a cusp, a swallowtail, a butterfly, etc. depending on the shape of the potential function called control surface which describes the process. In physics, catastrophe theory can be used for describing the phase transitions and gravitational lensing (detecting black holes). In physiology, the human behavioural patterns including nervous disorders can be described by using the concept of a control surface. The catastrophe theory has been used for describing the behaviour of stock markets: jumping from the bull market (index rising) to the bear market (index falling) which causes a crash. The geometry of control surfaces, however, shows that besides jumps there exist also smooth paths from one equilibrium to another. Such processes need careful changes in control parameters or in other words, a deep understanding of the processes. For example, it has been shown that large-scale social processes like war-peace, can also be described using the catastrophe theory. In this case, when public opinion is divided between 'hawks' and 'doves', the negotiation may move the process of the war threat to peaceful solutions. A similar description could be used in the analysis of riots. It seems that the catastrophe theory can be used as a metaphor explaining how jumps (discontinuities) can be avoided by changing the control parameters differently.

Next, one should understand the consecutive effects in man-made or natural systems. The domino effect is a chain reaction—one event sets off a chain of similar effects like the toppling of dominos. This metaphor has been used widely, even for describing the political events like how Dwight D. Eisenhower in 1954 described the spread of the influence of communism. Another important effect is related to propagating failures. Pescaroli and Alexander (2015) have defined "cascading effects... in disasters, in which the impact of a physical event or the development of an initial technological or human failure generates a sequence of events in human subsystems that result in physical, social or economic disruption. Thus, an initial impact can trigger other phenomena that lead to consequences with significant magnitudes. Cascading effects are complex and multidimensional and evolve constantly over time."

To avoid the failures of systems, one should understand the reasons why such effects will take place. Helbing (2013) has argued that disasters should not be seen as 'bad luck' but "Systemic failures" and that extreme events are consequences of the highly interconnected systems and networked risks humans have created. According to his analysis, the drivers of systemic instabilities are: "increasing system sizes; reduced redundancies due to attempts to save resources; denser networks (increasing interdependencies between critical parts of the network); a high pace of innovation (producing uncertainties)". It means that actually globalization and increasing network densities may push systems towards systemic instabilities or in other words, "hyper-connected world leads to hyper-risks" (Helbing, 2013).

One should also note the Seneca effect (Bardi, 2018): increases are of sluggish growth but the way to ruin is very rapid.

Is it possible to foresee the risks? One of the most prominent analyses of global risks is presented by the World Economic Forum (WEF). The 15th annual WEF Global Risk Report was made public in 2020 (WEF Global Risk Report 2020). The reports present the top 10 risks ranked by their likelihood and impact over the next 10 years. It is quite natural that attention is paid to biodiversity, cyberattacks, natural disasters, food crisis, state-on-state conflicts, etc. Was the report able to forecast correctly? Not really. During the five years of 2016-2020, the likelihood of the extreme weather problem was forecasted four times and the weapons of mass destruction problem was forecasted three times as top risks by likelihood and impact respectively. These risks have luckily not been realised. However, infectious diseases were listed four times among the last of the list, i.e., they have not been estimated as a real threat, although the WEF 2020 Report indicates that the health systems are weak and cannot meet the challenges of well-being. One could ask whether the sentence in the Report (p 9) "When health systems fail to mitigate vulnerabilities and adapt to changing contexts, they increase the likelihood of economic crises, political instability, social rupture and state-on-state conflict" has been taken seriously by policymakers. There is an important character in the WEF Risk Reports. Namely, the Global Risks Interconnections Map depicts the interconnections between the impacts of events. The impact of infectious diseases is, for example, related to global governance problems and possible social instability. However, not all links are indicated. It is, for example, surprising that infectious diseases are not related to the possible collapse of infrastructures and unemployment, as we witnessed in 2020.

The Global Risks Interconnections Map represents according to Helbing (2013) the hyper-connected world that leads to hyper-risks. He lists the drivers of systemic instabilities in this world (system size, saving resources, the density of networks, high pace of innovation, etc.) and demonstrates how vulnerable networks of networks are. Unfortunately, the theoretical knowledge of systems, instabilities cascades, etc. (briefly described also above) has not found its way to policymakers.

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4. Some Ideas on Social Systems

It is not only about the COVID-19 crisis in 2020. This crisis has actually opened a Pandora's box of global financial, economic and societal crises. One cannot say that the scientists have not thought about that. The predictions about the future of the World (Meadows et al., 1972; Randers, 2013, etc.) warned mankind that the resources for constant growth are limited. The problems are mixed, but much attention is paid to the economy because this is actually the blood circuit of contemporary life and welfare. The human face of the economy is questioned by many think tanks of the world. Although already the French Revolution called for "liberty, equality, and fraternity", the situation in the World is far from it. The main obstacle for changes in the economy is in the following assumptions (Helbing, Kirman, 2013) which have a paradigmatic value: (i) an economy is an equilibrium system; (ii) selfish behaviour of individuals yields a result that is beneficial for society; (iii) individuals and companies decide rationally; (iv) the behaviour of all the agents together can be treated as the average; (v) financial markets are efficient, all the relevant information concerning an asset is reflected in the price of that asset; (vi) the financial markets function better if their liquidity is greater; (vii) the more connected the networks of individuals and institutions are, the more is the reduction of risks and the more stable is the system. The analysis of the economy as a complex system leads to the conclusion that these assumptions are erroneous (Helbing, 2015) and cannot work in the long run (see examples in Section 3). That is why a fundamentally new kind of economics is needed for 'networked minds' as Helbing (2015) states. This leads to the need that global networks must be redesigned by using the knowledge from complex systems and the digital revolution. The leading principle in all these actions is the transfer from a technology-driven society to a socially oriented technology.

It is important that in future discussions, the economy is not singled out as a special field of knowledge but analysed and modelled as the socio-economic system.

The ecological footprint is a well-known indicator to measure human impact on the environment. This indicator was introduced only about 30 years ago for defining the amount of the environment necessary to produce goods and services for supporting lifestyle in a particular country or the whole world. According to Lin et al. (2018), humanity's estimated ecological footprint was 1.7 times as fast as planet Earth can renew it. We should also account for the social footprint which is the impact of human decisions and actions on the social fabric of society, let it be a community, a country, or the whole world (McElroy, 2008). Leaving aside the technical details, one can intuitively understand the social footprint of the recent US President. In all the societal actions, the social footprint whether we like it or not, is a factor that could influence life and welfare considerably.

Socio-economic systems possess many properties (Helbing, 2010): (i) the number of variables is very large; (ii) the relevant parameters and variables are often unknown; (iii) time scales are not often separated; (iv) there is just one realization, i.e. human history; (v) it is difficult to subdivide the system into simple, non-interacting subsystems; (vi) observers participate in the system; (vii) factors such as emotions, creativity, memory consciousness, communication, individual interpretation, etc. create complications in the analysis; (viii) social systems are influenced by normative and moral issues, etc. All this creates a lot of difficulties in modelling the socio-economic phenomena and none of the possible approaches (physical, economic, sociological, psychological) can reflect the complexity of interactions between the main actors of social systems—the people. During crises, the emotions, defence mechanisms, irrational thinking, and a disorganized approach to problems create more problems than rational actions.

5. On Interdisciplinarity

Interdisciplinarity means the combination of two or more research disciplines into one activity by drawing knowledge from several fields with one goal. Dealing with complex systems like socio-economic systems or even more widely—techno-socio-economic-environmental systems, the interdisciplinary approach is the best way to understand problems and analyse them. This means integrating information, data, techniques, tools, concepts, and perspectives of various disciplines. Dialogue is the main condition for success. Note that transdisciplinarity usually refers to what is found simultaneously between the disciplines and beyond any discipline.

Contemporary knowledge generation is divided between various disciplines, but the challenges mankind faces need mobilizing not only all the existing knowledge but the generation of knowledge between traditionally separated disciplines. What has been described above is a brief description of such complex systems and the phenomena occurring in them that call for knowledge from various fields. Some interdisciplinary fields are well-established, like biophysics, molecular biology, geophysics, etc. Some are gaining importance during recent years like econophysics (cf. Roehner, 2002; Stanley et al., 2008; and references therein). Let us use econophysics to illustrate interdisciplinarity. Classical school of finance and economics has described phenomena in economic activities by using the normal distribution of events. Although being correct in short time scales, and having an advantage of finite mean and variance, it fails to describe long term processes in economics. Namely, normal distribution severely underestimates the probability of large-scale changes in studied social phenomena. Furthermore, the classical school relies on independent, identically distributed variables in financial time series. This assumption has also been proven to be inaccurate, as financial time series possesses autocorrelation in various time scales as well as self-similar behaviour patterns governed by multi-fractal processes (c.f. Kitt and Kalda 2005). Borrowing from natural sciences, econophysics replaced normal distributions with power laws, i.e., distributions with infinite variance. Thus, the methods and tools from physics were transferred to finance and economics that has led to the coining of the term ‘econophysics’.

“The problems related to climate change cannot be solved without involving knowledge from physics, chemistry, ecology, biology, economics, and human values.”

It seems that physics has much to contribute to other disciplines of research. Some cases are described above but one must stress the role of thermodynamics and nonlinear dynamics in developing more general knowledge. The concept of dissipative structures introduced by Prigogine (1945) has a fundamental importance in many areas of knowledge. Dissipative structures operate out of thermodynamic equilibrium and exchange energy, matter, and information with the external environment. This concept is extremely useful in biology, chemistry, social sciences, etc. and has also a paradigmatic value recognized in many branches of science and can be considered as a ‘driving force’ of organization. The concepts of network analysis (Barabási, 2016) are used in neural networks, biology, virus spreading, banking systems, power grids, etc. These concepts help to understand the signal (information) propagation speed, self-organization, synchronizability, etc. The concepts of physics (conservation laws, internal variables) are used for describing physiological processes (Engelbrecht et al., 2020). The concepts of chaos and unpredictability are derived within the framework of nonlinear dynamics and are nowadays widely accepted in many fields of knowledge (see, for example, Scott, 2005).

Interdisciplinary elements are also being developed in computational social science. Following these studies in the ETH (Zürich), it is remarkable how the focus of research has moved from studying pedestrian crowds and vehicle traffic to studying social coordination, cooperation, norms, and conflict as well as collective opinion formation and wisdom of crowds. And the problems related to climate change cannot be solved without involving knowledge from physics, chemistry, ecology, biology, economics, and human values.

The general information on interdisciplinarity has been collected by Frodeman et al. (2017) and a specified analysis—by the National Academy of Science et al. (2005). The latter analysis lists the needs for interdisciplinary research: (i) the inherent complexity of nature and society; (ii) problems that are not confined to a single discipline; (iii) the need to solve societal problems; (iv) the power of new technologies. Such research can be problem-oriented, concept-oriented, or method-oriented (Hübenthal,1994). In addition, she distinguishes intermeshing and complementing, related to agreements in respect either to the analyzed topic or the phenomena, respectively.

The interdisciplinarity of ideas is fruitful in many fields of research. Presently it seems that one of the strong drivers for interdisciplinary studies is a social science (Helbing, Balletti, 2011). The list of problems is long: how to avoid crises and contagious cascade-spreading processes, how to cope with the increasing flow of information, how to improve social, economic, and political participation, how to avoid 'pathological' collective behaviour (panic, extremism, breakdown of trust), how to avoid conflicts and minimize their destructive effects, how to cope with migration. The solving of these problems needs a lot of data mining, knowledge about psychology, economy, mathematics, etc. One cannot forget the ethical problems too.

> *"The social problems that are in focus now are strongly influenced by human behaviour and values spiced by ethical issues related to socio-economic processes."*

An excellent analysis of how the concepts of nonlinear dynamics have a deeper meaning in epistemology and ontology is given by DeLanda (2002). He actually reconstructs the philosophy of Deleuze and Guattari (1987) that distinguishes intensive and extensive spaces together with actual and virtual space. The notions like attractors, bifurcations, phase portraits, fluctuations, self-organization, limit cycles, singularities, trajectories, vector fields, manifolds, etc. are used for explaining dynamical processes that are analysed by Deleuze and Guattari (1987). In this way, the notions of difference, intensity and multiplicity obtain the philosophical meaning and without any doubt justify using the methods of nonlinear dynamics for modelling the social sciences.

What should be stressed in fostering interdisciplinary ideas is the communication problem. This concerns not the mother tongue of researchers but the different terminologies. The differences between the disciplines are often due to different communities of researchers. Kagan (2009) has pointed out that even such a basic notion like the concept of truth is understood differently by different researchers. In principle, the concept of truth can be understood as correct, valid, coherent, and right. Kagan (2009) states that "most natural scientists trust only the first two; social scientists trust the first and third, humanists rely on the last two". As a consequence, one should pay serious attention to communication because interdisciplinarity is most of all about a widening of mindsets.

The crucial problems are always related to the future, that is from 2020 on, shadowed by the crises in many societal structures and activities. Many more traditional activities have been stopped. What will happen next? The world is complex and the mathematical models for the forecast should take into account the properties of complex systems, let them be of physical or of social character. A recent overview of ideas of such modelling is presented by Engelbrecht (2019). The models of Meadows et al. (1972), Randers (2013), for example, are based on the analysis of dynamics of rather general variables like resources, population, industrial output, productivity, consumption, etc. These models have served as a warning for society because the growth of consumption has limits and the systems may collapse. Some remarks are needed to specify the situation. **First**, the GDP alone does not characterize the reality well, but the values related to the GDP give more information about the welfare of countries (Caldarelli et al., 2012) which is a sign of economic complexity. **Second**, Daly (1987) has distinguished two general classes of limits to growth: biophysical limits on the Earth and socioethical limits. The first class of limits involves resources, ecological connections, etc. resulting in changes in economic subsystems, explicitly shown in "The Limits of Growth" (Meadows et al., 1972). The second class involves (i) cost imposed on future generations; (ii) extinction in the number of sub-human species; (iii) effects of welfare; (iv) corrosive effects on moral standards. And besides GDP and material goods, there are intermediate goods (Hirsch, 1977) and public goods (Puu, 2006). Among the intermediate goods is also education which facilitates professional and social advance (Hirsch, 1977). All this is a clear call for interdisciplinary studies to understand the possible trends and threats of development. This is stressed by Helbing (2010) calling for (i) cooperation of social scientists and natural scientists, (ii) modelling of socio-economic systems; (iii) managing of complexity and corresponding systems design; (iv) applications of social coordination to the creation of self-organizing technical systems; (v) development of technical systems combined with social competence and human knowledge.

In the Summary "A Planetary Momentum" (Šlaus et al., 2020) these ideas are formulated as follows: "Attention should be paid to decision theory, rational choice and values in framing solutions taking into account the complex relations, interactions and reciprocal immediate and long-term influences involved. … Lessons concerning the weaknesses of social systems must be studied in-depth and analysed to understand why and how conventional thinking has led to global crises, the vulnerabilities generated by globalisation and networking, and the ideas needed to foster effective social innovation."

6. Final Remarks

The future is something we build with our actions. Academia understands this challenge and there are many examples of targeted research and activities (Engelbrecht et al., 2020). It is clear that the main problem is how to manage jointly with 'hard' (like in physics or chemistry) and 'soft' (related to values or behaviour) concepts. Whatever the problems or models concerning nature and material processes, the laws of physics and thermodynamics must be satisfied. It is well known that Erwin Schrödinger (1944) has explained the concept of living systems from the viewpoint of thermodynamics. Furthermore, Philip Anderson (1972) warned about reductionist thinking in science in his famous essay "More is different". He claimed that the properties of the systems could be different from the properties of their constituents. Nowadays we know much more about complex systems (Castellani, 2018) and the role of physics like explaining the behaviour of all ecosystems related to nonequilibrium dissipative structures and processes like Prigogine (1945) has proposed. The social problems that are in focus now are strongly influenced by human behaviour and values spiced by ethical issues related to socio-economic processes. One cannot forget that these processes are also strongly influenced by technological developments. In all cases, interdisciplinary research is the best tool to proceed in this complex world. In this context, the words by John Donne (see the beginning of the article) have a special meaning.

Authors Contact Information
Jüri Engelbrecht – *Email: je@ioc.ee*
Robert Kitt – *Email: Robert.Kitt@icloud.com*

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