

CROSS-BORDER COOPERATION AS A FRACTAL SYSTEM: FROM LOCAL INTERACTIONS TO GLOBAL GEOPOLITICAL PROCESSES

ТРАНСКОРДОННЕ СПІВРОБІТНИЦТВО ЯК ФРАКТАЛЬНА СИСТЕМА: ВІД ЛОКАЛЬНИХ ВЗАЄМОДІЙ ДО ГЛОБАЛЬНИХ ГЕОПОЛІТИЧНИХ ПРОЦЕСІВ

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Abstract. *The purpose of this article is to examine cross-border cooperation as a fractal system in which local interactions among border communities, regions and states reproduce the structural and functional characteristics of the international system at higher levels of organization. The study substantiates the applicability of the fractal approach to the analysis of cross-border processes under conditions of globalization, regionalization and the transformation of the world order. Particular attention is devoted to the principles of self-similarity, nonlinearity, scalability and network interdependence that shape the evolution of contemporary cross-border relations. Using systemic, comparative and fractal analysis, the article explores the interconnection between local border practices and broader political, economic and security dynamics. It demonstrates that cross-border cooperation functions not only as an instrument of regional development but also as an important mechanism for the formation of a multi-level architecture of international relations. The study examines the influence of European integration, digitalization, migration processes, security challenges and the Russo-Ukrainian war on the transformation of cross-border interactions. The scientific novelty lies in introducing three key concepts: fractal cascades, geopolitical sensors, and fractal networks of cross-border cooperation. A fractal cascade explains the spread of local crises or innovations across levels of the international system. In this context, the Russia-Ukraine war is*

analyzed as a massive fractal cascade that shifted the security architecture of Europe. Border territories are conceptualized as geopolitical sensors that detect systemic changes at an early stage. The paper concludes that under multipolarity, cross-border cooperation operates as a system-forming rather than a peripheral element, organizing complex adaptive networks.

Keywords: *cross-border cooperation, fractal model, international relations, border regions, regional integration, geopolitical processes, international security, network interactions, complex adaptive systems, multipolarity.*

Анотація. Метою статті є дослідження транскордонного співробітництва як фрактальної системи, в якій локальні взаємодії між прикордонними громадами, регіонами та державами відтворюють структурні й функціональні закономірності міжнародної системи на вищих рівнях організації. У статті обґрунтовується можливість застосування фрактального підходу до аналізу транскордонних процесів в умовах глобалізації, регіоналізації та трансформації світового порядку. Особливу увагу приділено принципам самоподібності, нелінійності, масштабованості та мережевої взаємозалежності, які визначають розвиток сучасних транскордонних відносин. На основі системного, порівняльного та фрактального аналізу досліджено взаємозв'язок між локальними прикордонними практиками та ширшими політичними, економічними й безпековими процесами. Показано, що транскордонне співробітництво виступає не лише інструментом регіонального розвитку, але й важливим механізмом формування багаторівневої архітектури міжнародних відносин. Проаналізовано вплив європейської інтеграції, цифровізації, міграційних процесів, безпекових викликів та російсько-української війни на трансформацію транскордонних взаємодій. Наукова новизна дослідження полягає у розробці та впровадженні трьох взаємопов'язаних аналітичних концепцій: фрактального каскаду, геополітичного сенсора та фрактальної мережі транскордонного співробітництва. Поняття фрактального каскаду пояснює, як локальні кризи (наприклад, воєнні події в прикордонних зонах) або інновації поширюються на регіональний та глобальний рівні. Геополітичні сенсори відображають здатність прикордонних територій першими детектувати системні зрушення у світовому порядку. Зроблено висновок, що фрактальний підхід дозволяє пояснити механізми поширення локальних криз, конфліктів та інновацій на регіональний і глобальний рівень, а також виявити нові закономірності функціонування транскордонних мереж у багатополлярному світі. Запропоновано концептуальну модель аналізу транскордонного співробітництва як складної адаптивної фрактальної системи міжнародних відносин, яка демонструє високий потенціал самоорганізації та гнучкості в умовах кризової мобілізації.

Ключові слова: *транскордонне співробітництво, фрактальна модель, міжнародні відносини, прикордонні регіони, регіональна інтеграція, геополітичні процеси, міжнародна безпека, мережеві взаємодії, складні адаптивні системи, багатополлярність.*

Introduction. Cross-border cooperation is one of the most dynamic phenomena in contemporary international relations. It encompasses a wide range of interactions among border territories, regions, local communities, state institutions, businesses, and civil society actors. Under the conditions of globalization, digitalization, regional integration, and the transformation of the international order, cross-border cooperation extends beyond the traditional understanding of border interactions and increasingly functions as an important mechanism for shaping the multi-level architecture of international relations.

This issue has become particularly relevant in the context of the emergence of a multipolar world, where regions, cities, cross-border networks, and other non-state actors are gaining increasing importance alongside states. Under such conditions, traditional linear models of international process analysis are becoming insufficient for explaining the complex mechanisms linking local, regional, and global levels of politics. Local processes often generate far-reaching international consequences, while global trends are transformed into specific borderland practices, creating a complex system of interconnected processes.

One of the most promising approaches to studying such phenomena is the fractal approach to the analysis of international systems developed by O.A. Koppel and O.S. Parkhomchuk. According

to this approach, the international system is viewed as a complex adaptive structure characterized by self-similarity, nonlinearity, scalability, and polycentricity. The fractal model makes it possible to examine the recurrence of similar patterns at different levels of international interaction, ranging from local communities and border regions to the global international system. Within this framework, cross-border cooperation may be conceptualized as a specific “fractal” of international relations in which the fundamental mechanisms of cooperation, competition, conflict, integration, and adaptation characteristic of world politics as a whole are reproduced.

The Russia-Ukraine war, the intensification of geopolitical competition, migration crises, the rapid development of digital technologies, and emerging challenges to international security demonstrate that border regions are increasingly becoming spaces where processes with consequences extending far beyond the local level are formed. Therefore, the study of cross-border cooperation through the lens of the fractal approach not only contributes to a deeper understanding of the nature of contemporary international interactions but also enables the identification of new patterns in the functioning of the international system under conditions of ongoing transformation.

The **purpose** of this article is to examine cross-border cooperation as a fractal system of international relations and to identify the mechanisms linking local border interactions, regional integration processes, and global geopolitical transformations.

Research on cross-border cooperation occupies an important place in contemporary international relations theory, regional studies, and European integration research. Over recent decades, a substantial body of scholarly literature has emerged devoted to analyzing the role of borders, border regions, and mechanisms of interregional interaction in the context of globalization and regionalization.

One of the earliest directions in the study of cross-border cooperation focused on the transformation of state border functions in the contemporary world. In particular, A. Paasi (1996) conceptualized borders not merely as territorial boundaries of state sovereignty but also as social institutions that shape political, economic, and cultural interactions between neighboring territories. His approach laid the foundation for subsequent studies of deterritorialization processes and the emergence of new spatial forms of international interaction.

A significant contribution to the development of the concept of cross-border cooperation was made by M. Perkmann (2003), who examined cross-border regions as new forms of multi-level governance emerging at the intersection of national and supranational political structures. He argued that cross-border cooperation is gradually evolving into a distinct level of political organization functioning alongside traditional state institutions.

A similar position is advanced by J. Scott (2012), who emphasizes the role of border territories as spaces of innovation and experimentation in international cooperation. According to Scott, border regions frequently serve as laboratories for new models of governance, integration, and conflict resolution that subsequently diffuse into the broader international environment.

Contemporary research increasingly focuses on the relationship between cross-border cooperation and European integration processes. In this regard, E. Medeiros (2018) considers cross-border cooperation to be an important instrument for implementing the European Union’s territorial cohesion policy. The author argues that cross-border networks contribute to regional economic convergence, the development of shared infrastructure, and the formation of a common European identity.

In Ukrainian scholarship, cross-border cooperation has traditionally been studied within the framework of regional development, European integration, and border policy. Significant contributions to this field have been made by M. Mikula (2004), I. Studennikov (2005), A. Yurkiv (2024), M. Resler and T. Reis (2023), among other researchers.

In their works, particular attention is devoted to the institutional mechanisms governing the functioning of Euroregions, the role of local self-government, and the potential of cross-border cooperation as an instrument for the socio-economic development of border territories.

At the same time, most existing approaches are primarily based on linear models of analysis that conceptualize cross-border cooperation either as a separate area of international activity or as a component of regional policy. Such approaches do not always adequately explain the complex mechanisms linking local processes with global transformations.

In this context, the authors' fractal approach to the analysis of international systems acquires particular significance. This approach is grounded in the understanding of the international system as a complex adaptive structure characterized by self-similarity, nonlinearity, scalability, and process recursiveness. Unlike traditional hierarchical models, the fractal model makes it possible to examine international relations as a set of interconnected levels, each reproducing similar patterns of interaction among actors.

The fractal approach opens new opportunities for the study of cross-border cooperation. If a border region is viewed as an element of the international system, then the processes of cooperation, competition, conflict, adaptation, and integration occurring at the local level may be interpreted as reflections of analogous processes operating within regional subsystems and the global international system. In this perspective, cross-border cooperation functions not merely as an instrument of regional policy but also as a model of the functioning of the international system as a whole.

Despite the substantial body of research devoted to cross-border cooperation, its analysis as a fractal system of international relations remains largely unexplored. This gap determines the scientific novelty of the present study and highlights the relevance of applying the fractal approach to investigating the relationship between local border interactions and global geopolitical processes.

The methodological foundation of this study is the fractal approach to the analysis of international systems, which enables cross-border cooperation to be examined as a complex adaptive system operating simultaneously at local, regional, national, and global levels. In contrast to traditional linear models, the fractal approach provides a framework for exploring interactions among different levels of the international system through the principles of self-similarity, nonlinearity, scalability, and recursiveness. Within this framework, a border community, a cross-border region, an interstate association, and the global international system can be conceptualized as interconnected levels of a single fractal space of international relations.

One of the key methodological principles of this study is the principle of self-similarity. This principle assumes that the fundamental forms of interaction among actors—cooperation, competition, conflict, coordination, and adaptation—are reproduced at different levels of the international system. For example, coordination processes among border communities may reflect the logic of interaction between states or international organizations. Similarly, local disputes over resources, infrastructure, or security may mirror the mechanisms of geopolitical competition operating at regional and global levels.

The second important principle is the nonlinearity of development. In fractal systems, there is no direct proportionality between causes and consequences. Minor local events may generate large-scale political, economic, or security effects at the international level. Such processes are particularly characteristic of contemporary cross-border spaces, where local migration crises, environmental disasters, or border conflicts can rapidly evolve into international challenges.

Particular importance is attached to the principle of scalability. This principle implies the possibility of analyzing the same patterns at different levels of the international system. Within the framework of this study, cross-border cooperation is examined simultaneously as a local mechanism of interaction among border territories and as a component of broader processes of regionalization, integration, and transformation of the global order. Such an approach makes it possible to trace how local initiatives shape wider international processes and, conversely, how global trends influence the development of border regions.

An important analytical tool employed in this research is the concept of fractal cascades. A fractal cascade is understood as a process through which local changes spread across different levels of the international system. In the context of cross-border cooperation, such cascades may include the diffusion of innovative governance practices, migration processes, economic crises, security challenges, or conflicts. The Russia-Ukraine war provides an illustrative example of such a cascade, where developments within specific border areas gradually evolved into a large-scale regional and global crisis that affected both the security architecture of Europe and the international system as a whole.

To achieve the objectives of the study, a combination of general scientific and specialized research methods has been employed. The systems approach is used to analyze cross-border cooperation as an integrated multi-level system. The comparative method is applied to examine and

contrast different models of cross-border interaction in Europe and other regions of the world. The case study method enables the investigation of specific examples of cross-border cooperation and their impact on broader international processes. Fractal analysis is utilized to identify self-similar structures and recurring patterns at different levels of international interaction.

Thus, the application of fractal methodology makes it possible to develop a comprehensive understanding of cross-border cooperation as a complex adaptive system that integrates local, regional, and global processes within a unified space of international relations. At the same time, it opens new opportunities for analyzing contemporary geopolitical transformations and the evolving architecture of the international system.

Main results of the research. In the twenty-first century, cross-border cooperation has increasingly moved beyond the classical understanding of interaction between neighboring border territories. While it was previously associated primarily with the development of local infrastructure, economic contacts, and cultural exchanges, contemporary cross-border spaces are becoming complex nodes of global interaction where economic, security, political, technological, and humanitarian processes intersect. For this reason, cross-border cooperation should be viewed not merely as a distinct area of international activity but as a fractal system that reflects the fundamental patterns governing international relations as a whole.

Within the fractal model, each border region functions as a micro-level representation of the international system. Nearly all the basic elements of world politics are present within such regions: competition for resources, struggles for influence, cooperation, integration processes, security challenges, information interaction, and cultural diplomacy. Consequently, border territories may be regarded as “geopolitical laboratories” in which the processes characteristic of the international system are reproduced on a smaller scale.

The principle of self-similarity is particularly evident in the functioning of Euroregions. For example, the activities of the Carpathian Euroregion effectively reproduce the principal mechanisms underlying the operation of the European Union itself, including multi-level governance, policy coordination, interinstitutional cooperation, resource allocation mechanisms, and joint decision-making processes. In this way, a local system of cross-border interaction becomes a model of broader integration processes taking place at the European level.

At the same time, the fractal nature of cross-border cooperation is manifested not only through cooperation but also through conflict. Border territories frequently become the first areas where global contradictions emerge. Local conflicts may gradually evolve into large-scale international crises, creating the effect of what may be termed a fractal cascade. In such cases, a relatively small local event generates a chain of interconnected processes that spread to regional and global levels.

A striking example of such a fractal cascade is the Russia-Ukraine war. Events that initially appeared as a localized conflict centered on specific border territories gradually evolved into the most significant security crisis in Europe since the end of the Cold War. The war has affected not only the regional security architecture but also global energy markets, food security, migration dynamics, international logistics, and systems of international alliances. In this case, a local border space became the point of origin for a large-scale geopolitical cascade whose consequences are felt across virtually all regions of the world.

Fractal logic is also evident in the diffusion of innovation. Contemporary cross-border regions increasingly serve as platforms for testing new models of governance, digitalization, and economic integration. Innovative practices that emerge at the local level can gradually scale up and spread across broader international spaces. Many mechanisms of European integration developed in precisely this way: initially tested within individual border regions and later incorporated into wider European policies and institutional frameworks.

Particular importance in the contemporary era is attached to the digital dimension of cross-border cooperation. While traditional borders were shaped by geographical space, modern digital networks create new forms of cross-border interaction that are increasingly independent of territorial proximity. As a result, the phenomenon of “digital fractals” emerges, whereby similar patterns of communication, mobilization, and interaction are reproduced across different levels, ranging from local online communities to global digital platforms.

Interestingly, contemporary cross-border networks increasingly resemble the structure of neural

networks. Within such systems, individual nodes may possess relatively limited significance on their own, yet collectively they form a complex web of interdependencies. Similar to neurons in the human brain, border communities, cities, regions, and institutions create networks through which information, resources, and political influence spread in nonlinear and uneven ways. This helps explain why even relatively small border regions can sometimes play a disproportionately important role in international processes.

The fractal approach also offers a new perspective on the issue of international security. Traditional security concepts often view security primarily as a product of the actions of states and international organizations. Contemporary challenges, however, demonstrate that sources of instability increasingly emerge at the local level. Migration crises, transnational crime, cyber threats, terrorist networks, and information campaigns frequently originate within specific border spaces but rapidly spread through global networks of interaction. Consequently, border territories increasingly function as sensors of the international system, often serving as the first areas to register emerging transformations within the international environment.

Particular attention should be devoted to the phenomenon of fractal adaptation. Unlike rigid hierarchical structures, cross-border networks demonstrate a high capacity for self-regulation and adaptation to changing conditions. During the COVID-19 pandemic, migration crises, and the Russia-Ukraine war, many border communities proved capable of responding to new challenges more rapidly than certain state institutions. This suggests that contemporary cross-border cooperation increasingly operates as a complex adaptive system characterized by a high degree of internal self-organization.

In the context of the emerging multipolar world order, the role of cross-border spaces continues to grow. While states were the principal actors of the international system throughout most of the twentieth century, regions, cities, networked communities, and cross-border associations are increasingly gaining prominence today. In this sense, border territories are no longer peripheral to the international system; rather, they function as active nodes through which key flows of resources, information, technologies, and political influence pass.

Consequently, cross-border cooperation may be conceptualized as a fractal model of international relations in which local interactions reflect the broader patterns governing global political development. Through the analysis of cross-border processes, it becomes possible to identify the underlying mechanisms driving transformations within the international system. This is particularly important in an era characterized by increasing instability, multipolarity, and the nonlinear nature of contemporary geopolitical dynamics.

One of the key characteristics of complex adaptive systems is the capacity of local processes to generate large-scale consequences at higher levels of organization. In contemporary complexity theory, such phenomena are examined through the concepts of nonlinearity, network interdependence, and cascading effects (Mitchell, 2009; Holland, 2014). Within the framework of the fractal approach to international relations, these processes can be conceptualized as fractal cascades—sequences of interconnected changes that spread from local to regional and global levels, thereby transforming the structure of the international system (Koppel & Parkhomchuk, 2024).

Ukraine represents one of the most illustrative examples of the functioning of such cascades within the contemporary international system. Its geopolitical position at the intersection of the European, Black Sea, and Eurasian spaces creates a distinctive pattern of cross-border interactions in which local developments frequently acquire international significance (Medeiros, 2018). From a fractal perspective, Ukraine's border regions can be viewed as nodes within the international system through which flows of security, energy, migration, trade, and information are transmitted.

The Russia-Ukraine war has become the most significant example of a fractal cascade in Europe since the end of the Cold War. Events that initially unfolded within specific border regions gradually evolved into a systemic crisis affecting the entire European security architecture. As Buzan (2018) argues, contemporary regional security complexes are characterized by a high degree of interdependence, enabling local conflicts to spread rapidly beyond their original environment. In the Ukrainian case, the consequences of such diffusion included the reassessment of NATO's strategic approaches, the strengthening of the Alliance's eastern flank, and the emergence of new formats of security cooperation across Europe.

A particularly illustrative example is the Black Sea Grain Corridor. The blockade of Ukrainian

seaports was initially perceived as a regional security issue; however, within a matter of months, its consequences extended to countries in Africa, the Middle East, and South Asia. According to assessments by the Food and Agriculture Organization of the United Nations (FAO, 2023), disruptions in Ukrainian grain exports affected global food markets and intensified the risks of food insecurity in numerous countries. In this case, a localized logistical challenge evolved into a factor of global food security, demonstrating how cross-border processes can trigger cascading effects across multiple levels of the international system.

An equally important example is the migration cascade. According to the United Nations High Commissioner for Refugees (UNHCR, 2024), millions of Ukrainian citizens left the country following the outbreak of the full-scale invasion, with the majority crossing the borders of Poland, Slovakia, Romania, and Hungary. Initially, this represented a humanitarian phenomenon concentrated in border regions; however, it subsequently evolved into a major factor shaping the demographic, social, and economic policies of the European Union. As Castles (2020) argues, contemporary migration flows increasingly function as mechanisms of structural change within international systems, influencing labor markets, social institutions, and political processes in receiving states.

Another example of a fractal cascade can be observed in the transformation of Europe's energy architecture. For decades, energy relations between Russia and the European Union were based on principles of economic interdependence. Following 2022, however, a large-scale restructuring of cross-border energy networks took place, including the diversification of supply sources, the expansion of LNG infrastructure, and increased investment in renewable energy projects (European Commission, 2024). As a result, a localized military conflict became a catalyst for the transformation of the entire European energy system.

A particularly illustrative example of the fractal diffusion of influence is the shift in the security policies of Northern Europe. The accession of Finland and Sweden to NATO after decades of military neutrality demonstrates how developments in one segment of the international system can trigger transformations within other regional subsystems. In this case, the Ukrainian security environment became a source of change that significantly altered the geopolitical configuration of the Baltic region and Northern Europe as a whole (NATO, 2024).

Contemporary logistical transformations also exhibit a fractal character. The closure of traditional transport routes through Russian territory and the partial disruption of Black Sea shipping corridors stimulated the development of alternative transportation networks through Poland, Romania, the Baltic states, and the South Caucasus. Particular importance has been attached to the Trans-Caspian International Transport Route, which is increasingly viewed as an alternative link between Europe and Asia (World Bank, 2023). Consequently, changes occurring in specific Ukrainian border areas have contributed to the restructuring of logistical flows across the Eurasian continent.

At the same time, fractal cascades are capable of transmitting not only crises but also innovations. Ukraine has emerged as one of the most notable examples of rapid digital transformation in public administration under wartime conditions. The introduction of digital public services, electronic identification systems, and mobile governance solutions has attracted considerable attention from governments and international organizations worldwide (OECD, 2024). In this case, locally developed innovative practices are gradually evolving into internationally recognized experiences that are being adapted and implemented in other countries.

Therefore, Ukraine should be viewed not only as an object of global processes but also as an active node within the international system through which numerous fractal cascades are transmitted. The analysis of the Ukrainian experience demonstrates that contemporary cross-border cooperation can no longer be understood solely as an instrument for the development of border territories. Instead, it is increasingly becoming one of the mechanisms shaping new configurations of the international order, where local processes play an ever more significant role in determining the direction of global transformations.

Traditional approaches to the study of international relations have generally viewed border territories as peripheral zones of state space, influenced by political and economic decisions adopted at the national or international level (Paasi, 1996; Scott, 2012). However, contemporary processes of globalization, digitalization, and increasing network interdependence indicate a gradual

transformation in the role of cross-border regions within the international system. These regions increasingly function not as passive recipients of external influence but as active nodes within international networks through which flows of information, capital, migration, technology, and security interactions are transmitted (Castells, 2010).

Within the framework of the fractal model of international relations, border territories may be conceptualized as geopolitical sensors of the international system. Just as peripheral elements of a complex adaptive system are often the first to respond to changes in the external environment (Holland, 2014), border regions frequently become the spaces where emerging political, economic, or security transformations first become visible. This perspective allows cross-border regions to be viewed as important indicators of change within the international environment (Koppel & Parkhomchuk, 2024).

A particularly illustrative example is the migration crisis of 2015–2016. The first consequences of large-scale population movements were experienced by the border regions of Greece, Italy, and the countries of the Western Balkans. It was within these segments of the international system that processes became visible which later reshaped the political agenda of the European Union, contributed to the revision of migration policies, and strengthened the position of right-wing populist political forces in several European states (Medeiros, 2018; European Commission, 2022). In this sense, local cross-border processes effectively functioned as early indicators of broader political transformations across Europe.

A similar pattern can be observed in the security sphere. According to the Regional Security Complex Theory developed by B. Buzan and O. Wæver (2003), security threats most frequently spread through geographically contiguous spaces. Consequently, border regions are often the first areas to register changes in the security environment. The developments preceding Russia's full-scale invasion of Ukraine in 2022 were reflected in the concentration of military activity, shifts in transportation flows, and transformations of border regimes. As a result, Ukraine's border territories became a significant indicator of the impending crisis affecting the entire European security architecture (NATO, 2024).

In the context of the digital transformation of international relations, the informational dimension of cross-border regions has acquired particular significance. As M. Castells (2010) argues, the contemporary network society generates new forms of spatial organization in which information flows increasingly shape political and economic dynamics. Border territories, simultaneously embedded within multiple information spaces, frequently become the first targets of information operations, cyberattacks, and influence campaigns. For this reason, they may be viewed as zones for the early detection of emerging forms of hybrid threats.

Fractal analysis also helps explain why certain cross-border regions occasionally play a disproportionately significant role in international affairs. From the perspective of complexity theory, the importance of an element within a system is determined not primarily by its size but by its position within networks of interdependence (Mitchell, 2009). Consequently, relatively small border territories may function as nodes through which political decisions, economic innovations, or security challenges spread across much broader geographical areas. Examples include the Poland-Ukraine borderland during the humanitarian crisis of 2022 and the Finnish-Russian border following Finland's accession to NATO.

Within this context, it is useful to formulate the principle of fractal sensitivity of cross-border regions. The essence of this principle lies in the assumption that the influence of a border territory on the international system is determined less by its geographical or demographic characteristics than by the degree of its integration into networks of international interaction. The higher the level of such integration, the more rapidly a region responds to changes in the international environment and the greater its capacity to influence broader geopolitical processes.

Accordingly, cross-border regions should not be viewed as peripheral components of the international system but rather as its active nodes and geopolitical sensors. It is through these regions that the earliest signs of transformations in the international order frequently become visible, making the analysis of border spaces an important instrument for anticipating future developments in international relations.

The contemporary transformation of the international system is driven not only by shifts in the

balance of power among major states but also by the increasing complexity of the architecture of international interactions. Multipolarity in the twenty-first century cannot be reduced merely to the emergence of several centers of power. Its deeper essence lies in the formation of a complex networked system in which states, regions, cities, corporations, international organizations, cross-border associations, and local communities increasingly operate as interconnected elements of a single international space (Acharya, 2014; Castells, 2010; Khanna, 2016).

In this context, cross-border cooperation acquires a new significance. It ceases to be merely a technical instrument of regional development or a mechanism for overcoming the peripheral status of border territories. In a multipolar world, cross-border cooperation increasingly functions as a mechanism for the formation of new fractal networks of international interaction. Such networks may be understood as multi-level systems in which similar patterns of coordination, competition, adaptation, and integration are reproduced across different levels, ranging from local communities to regional subsystems and the global international order (Koppel & Parkhomchuk, 2024).

The analytical value of the concept of a fractal network lies in its ability to explain why local cross-border processes can acquire disproportionately significant geopolitical importance. Within the traditional hierarchical model, a border region is viewed primarily as a state's periphery. Within the fractal model, however, it appears as a network node capable of accumulating, transforming, and transmitting impulses across different levels of the international system. Consequently, the importance of a cross-border region is determined not only by its territorial size or economic potential but, above all, by the degree of its integration into international flows of security, trade, energy, migration, information, and technology.

The European experience of cross-border cooperation illustrates this logic particularly clearly. The Interreg programs, originally established as instruments to support cooperation among neighboring regions, have gradually evolved into a complex system of multi-level governance linking local, regional, national, and supranational levels. During the 2021–2027 programming period, the European Commission identified 73 cross-border cooperation programmes with a total budget of €6.7 billion, demonstrating the institutionalization of cross-border networks as an integral component of the EU's territorial cohesion policy (European Commission, 2024). In this sense, Interreg represents not merely a financial instrument but an example of a fractal institutional architecture in which similar principles of coordination are reproduced across different levels of governance.

Importantly, fractal networks emerge not only under conditions of stable integration but also during periods of crisis. Following the outbreak of the full-scale Russia-Ukraine war, the Ukraine-Poland, Ukraine-Slovakia, Ukraine-Romania, and Ukraine-Moldova borderlands became spaces of intensive humanitarian, logistical, security, and economic interaction. These processes extended far beyond interstate channels. They involved local communities, volunteer networks, universities, charitable organizations, transportation companies, border services, local authorities, and international institutions. Such multi-level mobilization demonstrates that, under crisis conditions, cross-border networks are often capable of operating more rapidly and flexibly than traditional bureaucratic structures.

The migration dimension of this transformation is particularly illustrative. According to UNHCR data, in 2024 the number of refugees from Ukraine reached 6.9 million, while the number of internally displaced persons amounted to 7.1 million (UNHCR, 2025). This means that Ukraine's border regions became not merely crossing points but key nodes in the redistribution of human mobility flows across Europe as a whole.

From a fractal perspective, migration should not be understood as a linear process of movement from point A to point B. Rather, it constitutes a networked cascade that reshapes the social, demographic, and political structures of receiving states.

A similar logic can be observed in the field of logistics. The closure or disruption of traditional transport routes as a consequence of the war has increased the importance of alternative corridors connecting Europe and Asia. The World Bank considers the Middle Corridor, or the Trans-Caspian International Transport Route, to be an important link connecting Chinese and European markets through Central Asia and the South Caucasus (World Bank, 2023). This demonstrates that changes occurring in one segment of the Eurasian transport system can generate new network configurations across a much wider geographical space.

In the security sphere, the formation of fractal networks is manifested through the growing interconnection between the local level of defense resilience and the broader architecture of European security. Finland's accession to NATO on 4 April 2023 and Sweden's accession on 7 March 2024 demonstrated that the Russia-Ukraine war generated not only a regional crisis but also a structural transformation of the entire Northern European security configuration (NATO, 2024). In fractal logic, this means that a localized conflict can alter the behavior of actors in other geographical subsystems when they are connected by shared perceptions of threat.

Therefore, under conditions of multipolarity, cross-border cooperation functions not as a peripheral but as a system-forming element of the international system. Through cross-border networks, not only are resources exchanged and local projects implemented, but new models of political coordination, security interdependence, and geoeconomic adaptation are also created. For this reason, fractal networks of cross-border cooperation may be regarded as one of the fundamental forms of organization of international relations in the twenty-first century.

Conclusions. The conducted research makes it possible to conclude that cross-border cooperation in the twenty-first century can no longer be viewed solely as an instrument of regional development or a technical mechanism of interaction between border territories. Under contemporary conditions, it acquires systemic significance and becomes one of the forms of organization of international relations through which the deeper processes of transformation of the world order are manifested.

The fractal approach makes it possible to conceptualize cross-border cooperation as a complex adaptive system in which local interactions reproduce patterns characteristic of regional and global processes. Border communities, Euroregions, cross-border networks, states, and the international system emerge not as isolated levels of analysis but as interconnected fragments of a single multi-level structure. This constitutes the principal heuristic value of the fractal model of international relations: it enables an explanation of why local processes may produce global consequences and why global trends frequently manifest themselves through specific border practices.

The article demonstrates that cross-border cooperation operates according to the principles of self-similarity, nonlinearity, scalability, and network interdependence. Self-similarity is reflected in the recurrence of patterns of cooperation, competition, adaptation, and conflict across different levels of the international system. Nonlinearity implies that minor local changes may generate large-scale regional or global consequences. Scalability makes it possible to trace how local practices spread to broader international spaces. Network interdependence explains why the significance of a border region is determined not only by its geographical location but also by its degree of integration into flows of people, resources, information, energy, and security.

The scientific novelty of the study lies in the introduction and substantiation of three interrelated analytical concepts: the fractal cascade, the geopolitical sensor, and the fractal network of cross-border cooperation. The concept of the fractal cascade explains the mechanism through which local events spread to regional and global levels. The concept of the geopolitical sensor highlights the capacity of border territories to detect emerging changes in the international environment at an early stage. The concept of the fractal network describes a multi-level structure of cross-border interaction in which local, regional, national, and supranational actors operate as elements of a single system.

The Ukrainian experience confirms the analytical value of this approach. The Russia-Ukraine war, migration processes, the transformation of logistical routes, the restructuring of Europe's energy system, the digitalization of public administration, and changes in NATO's security architecture demonstrate that developments related to Ukraine's cross-border space possess not only local or regional significance but also global importance. Ukraine functions not as a periphery of the international system but as one of its key nodes through which the major flows of contemporary geopolitics pass and are transformed.

Particular significance should be attached to the conclusion regarding the changing role of border territories within the international system. Whereas borders were previously viewed primarily as lines of separation, they increasingly function today as spaces of interaction, adaptation, and strategic forecasting. Border regions are becoming zones for the early detection of crises, spaces for testing new governance models, and platforms for the development of cross-border resilience. This makes it possible to regard them not as peripheral elements of state policy but as important resources

for geopolitical positioning.

From a practical perspective, the findings of this study are relevant to the formulation of Ukraine's policy on cross-border cooperation with the European Union, the countries of the Black Sea region, Central Europe, and the Caucasus. The strengthening of cross-border networks may become one of the factors contributing to Ukraine's post-war reconstruction, European integration, and enhancement of regional security. At the same time, an effective cross-border policy should consider not only economic and infrastructural aspects but also security, digital, humanitarian, and informational dimensions.

Thus, cross-border cooperation as a fractal system represents an important analytical tool for explaining contemporary international dynamics. It makes it possible to understand how the local becomes global, how the periphery is transformed into a center, and how border spaces become sources of new forms of international interaction. For this reason, future research on cross-border cooperation should develop not only within the fields of regional studies or European studies but also as part of a broader theory of international relations capable of explaining the nonlinear, networked, and fractal nature of the contemporary world order.

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