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K POROZUMĚNÍ KRITICKÝM PŘECHODŮM VE VÁLČENÍ
Teoretický rámec a důkazy z rusko-ukrajinské války

TOWARDS UNDERSTANDING CRITICAL TRANSITIONS IN WARFARE
Theoretical Framework and Evidence from the Russo-Ukrainian War

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Abstrakt

V posledních desetiletích se systémový přístup stal dominantní myšlenkovou školou teoretického chápání válčení. V rámci systémové teorie se ukázaly jako zvláště důležité poznatky teorie komplexních (adaptivních) systémů, které nám umožňují prohloubit naše chápání válečnictví tím, že čerpají z poznatků, které byly uplatněny v mnoha jiných disciplínách. Tento článek se snaží zlepšit chápání válčení a inovovat ho pomocí konceptů atraktoru a kritického přechodu. Hlavní myšlenka spočívá v tom, že degradace klíčového subsystému vede k fázovému přechodu (výraznému poklesu bojové síly), a tím k přechodu z jednoho atraktoru do jiného, tj. do alternativního relativně stabilního stavu. Teoretický rámec je podpořen případovou studií první fáze ruské invaze na Ukrajinu v roce 2022.

Abstract

In recent decades, the systems approach has become the dominant school of thought to the theoretical understanding of warfare. Within systems theory, the insights of complex (adaptive) systems theory have proved particularly important, enabling us to deepen our understanding of warfare by drawing on knowledge that has been applied in many other disciplines. This paper seeks to improve the understanding of warfare and upgrade it with the concepts of attractor and critical transition. The main idea is that a degradation of a crucial subsystem leads to a phase transition (a significant decrease of combat power) and thus to a shift from one to another strange attractor, i.e., to an alternative relatively stable state. The theoretical framework has been supported by a case study of the first phase of the Russian invasion of Ukraine in 2022.

Klíčová slova

Válčení; kritický přechod; atraktor; teorie systémů; komplexnost; válka na Ukrajině.

Keywords

Warfare; Critical Transition; Attractor; Systems Theory; Complexity; War in Ukraine.

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INTRODUCTION

Armed conflicts have accompanied humanity at least since the Stone Age. Although it is reasonable to assume that the oldest concepts of warfare were already formed in prehistoric times, and that people were certainly able to integrate them into comprehensive theories in the BCE period, it was not until the 19th century that sufficient progress was made to speak of the institutionalisation of military science.[1] As Bousquet noted in this context, military science had forged and later evolved through the four distinct techno-scientific regimes.[2]

The foundations of the most recent warfare regime - characterized by chaos and complexity, or so-called chaoplexity - crystallized out in the 1980s. Although chaoplexity has not evolved into a coherent theory that could be formalized in a system of axioms and theorems,[3] its points of departure started to be used by researchers from a wide range of disciplines, including the military science.[4] Similar to the then-prevailing cybernetics, information remained the central concept of military thought, but with the impending regime, the focus has shifted to positive feedback loops. In turn, this led to the in-depth study of hitherto poorly understood characteristics, such as self-organisation, adaptability and high sensitivity to initial conditions.[5] However, despite the new theoretical baselines, the changed perception of warfare only slowly took hold. Thus, through the 1990s, the focus largely remained on systems thinking in general, while the impact of the narrower disciplines of (system) chaos and (system) complexity on the theoretical understanding of warfare has been less pronounced and manifests itself with a delay. In this way, there remains a lot of room for further examination of chaoplexity in warfare.

In an effort to fill the conceptual gap, we strive to answer the research question: "How can complexity theory further help us understand the warfare?" In this way, we aim to introduce two concepts from the field of complexity theory that have already been successfully applied in a number of disciplines (including medicine, epidemiology, transportation, climatology, electrical engineering, economics, ecology, and sociology), but have not yet received much attention in military science. These are the concepts of attractor and critical transition. Before discussing both concepts in more detail and applying them to the military field, we will highlight the methodological approach to (re-

[1] ŽABKAR, Anton. *Marsova dediščina: temelji vojaških ved* [The Mars Heritage: Foundations of Military Science]. Ljubljana: Faculty of Social Sciences, 2003-2004, at pp. 50-53. ISBN 961-235-142-2; 961-235-182-1.

[2] These regimes are: (1) mechanistic, (2) thermodynamic, (3) cybernetic, and (4) chaoplexic, intuitively best imagined through the metaphors of the (1) clockwork, (2) engine, (3) computer, and (4) network. See BOUSQUET, Antoine James Aimé. *The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity* [online]. London, 2007 [Cited 2021-12-22]. Available from: http://etheses.lse.ac.uk/2703/1/U615652.pdf. Doctoral thesis. London School of Economics and Political Science. Thesis supervisor Christopher Coker, Ph.D.

[3] BERTUGLIA, Cristoforo Sergio – VAIO, Franco. *Nonlinearity, Chaos, and Complexity: The Dynamics of Natural and Social Systems*. Oxford: Oxford University Press, 2005, at p. 275. ISBN: 0-19-856790-1; 0-19-856791-X.

[4] For a notable example, see e.g. NAVEH, Shimon. *In Pursuit of Military Excellence: The Evolution of Operational Theory*. London; New York: F. Cass, 1997. ISBN: 9780203044308.

[5] BOUSQUET, ref. 2.

)conceptualization and summarize the main features of systems approach. In the following, we will link the theory to empirical data. In doing so, we will conduct a case study of a contemporary armed conflict, analysing the initial phase of the Russian invasion of Ukraine. In conclusion, we will summarize the key supporting ideas, point to the limitations of the proposed reconceptualization and offer suggestions for further research on the topic.[6]

METHODOLOGICAL BACKGROUND

On (metaphorical) concepts

The theoretical examination of (armed) conflict is based on an abstract and generalized perception of reality or conceptualization. Only in this way it can convey universal knowledge, which is not limited by the context of an individual case. Although conceptualization begins with naming the object of our interest or research,[7] conceptualization is primarily about a complex connection of ideas with facts.[8] As many authors agree, concepts are the link between empirical facts and scientific theories. Concepts are thus the basic building blocks of scientific research, as they serve as tools for describing, classifying and explaining the phenomena under study.[9] According to Blumer, science could not exist without concepts.[10] Gerring takes a similar view, writing that "concept formation lies at the heart of all social science endeavor", that their use cannot be avoided, and that every significant work on a topic requires reconceptualization.[11]

[6] The article is conceived as an upgrade of the system-related findings from the author's doctoral research. Due to reliance on the doctoral research, the overall methodology of the doctoral dissertation (see Chap. 1.2), including multiple case study of five contemporary military operations, has contributed to the content of the article. See ŠLEBIR, Miha. *Applicability of the Centre of Gravity Concept in Contemporary Military Operations* [online]. Ljubljana, 2020 [Cited 2021-12-22]. Available from: https://repozitorij.uni-lj.si/IzpisGradiva.php?id=128667. Doctoral thesis. University of Ljubljana, Faculty of Social Sciences. Thesis supervisors Marjan Malešič, Ph.D, Uroš Svete, Ph.D.
The article also partly overlaps with the book chapter, which was published in Slovene. See ŠLEBIR, Miha. Prispevek teorije kompleksnosti k sistemskemu razumevanju vojskovanja [The Contribution of Complexity Theory to a Systemic Understanding of Warfare]. Malešič, Marjan (ed.). Kriza, varnost, vojska: preplet teoretičnih in empiričnih spoznanj. Ljubljana: FDV, 2021, pp. 185-205. ISBN 978-961-235-988-1.
[7] BECKER, Howard S. *Tricks of the Trade: How to Think about Your Research While You're Doing It*. Chicago; London: The University of Chicago Press, 1998, at p. 122. ISBN: 0-226-04124-7.
[8] ADCOCK, Robert – COLLIER, David. Measurement Validity: A Shared Standard for Qualitative and Quantitative Research. *The American Political Science Review*. Washington DC: American Political Science Association, 2001, Vol. 95, No. 3, pp. 529-546, at p. 529. ISSN 1537-5943 (web). Available from: https://www.jstor.org/stable/3118231?seq=1.
[9] MAGGETTI, Martino – GILARDI, Fabrizio – RADAELLI, Claudio M. *Designing Research in the Social Sciences*. Los Angeles; London; New Delhi; Singapore; Washington DC: Sage, 2013, at p. 36. ISBN 978-1-84920-500-9; 978-1-84920-501-6.
[10] Cited in: BECKER, ref. 7, at p. 110.
[11] GERRING, John. What Makes a Concept Good? A Critical Framework for Understanding Concept Formation in the Social Sciences. *Polity*. Chicago: The University of Chicago Press, 1999, Vol. 73, No. 3, pp. 357-393, at p. 359. ISSN 0032-3497. DOI: 10.2307/3235246.

Although one might assume that scientists typically form concepts in relative isolation, i.e., within the framework of each scientific discipline, this is far from being the case. As many studies have shown, scientists often 'borrow' concepts from other disciplines, investigate, adjust, and eventually introduce them into their own field of research. For example, Carl von Clausewitz, the founder of modern warfare theory, adopted some of the concepts from physics and mechanics, which are still in use by military theorists and practitioners to address the complex dynamics of war. Well-known examples of such nearly two-hundred-year-old concepts are friction (*Friktion*), fog (*Nebel*), character (*Charakter*), culmination point (*Kulminationspunkt*), and centre of gravity (*Schwerpunkt*).[12] This kind of transfer is a matter of metaphors, which project "a relatively clear and understandable set of ideas into an area that is problematic in terms of clarity and comprehensibility".[13]

Metaphors are an important promoter of scientific creativity,[14] help us think about the future,[15] and are a clever way of communicating findings.[16] Nevertheless, the metaphorical language is not unrestricted - metaphors are often criticized for their figurativeness, ambiguity and imprecision. Moreover, some metaphors are misleading, reinforce outdated scientific paradigms or unnecessarily combine facts with values. Although we cannot imagine science without their use, we must be aware that in practice, there are no perfect metaphors - each one is accompanied by implicit connotations that lead to a more or less pronounced gap between the original and the intended meaning.[17]

Systems approach to military science

As we have already pointed out in the introduction, a systemic view of warfare has been gaining ground in the recent decades. Although the origins of the military application of the systems approach go back much further than the institutionalisation of military science, it was not until the second half of the 20th century that the systems approach came to the fore, followed by its wider popularisation at the turn of the century.[18] This is also in line with the development of science in general, which was by no means non-systemic, yet it was only with Ludwig von Bertalanffy, a biologist, that awareness of the true meaning of systemicity began to expand.[19] Bertalanffy, one of the founders of

[12] CLAUSEWITZ, Carl von. *Vom Kriege* [e-edition]. Berlin: F. Dümmler, 1832. Available from: https://www.clausewitz.com/readings/VomKriege1832/_VKwholetext.htm.

[13] BRATOŽ, Silva. *Metafore našega časa* [The metaphors of our time]. Koper: Faculty of Management, 2010, at p. 20. ISBN: 978-961-266-077-2.

[14] MILLER, Arthur I. Metaphor and Scientific Creativity. HALLYN, Fernand (ed.). *Metaphor and Analogy in the Sciences*. Dordrecht: Springer, 2000, pp. 147-164. ISBN 0-7923-6560-7.

[15] WYATT, Sally. Danger! Metaphors at Work in Economics, Geophysiology, and the Internet. *Science, Technology, & Human Values*. London: Sage Publications, 2004, Vol. 29, No. 3, pp. 242-261, at p. 257. ISSN 1552-8251 (web). DOI: 10.1177/0162243903261947.

[16] PATTON, Michael Quinn. *Qualitative research & evaluation methods*. Thousand Oaks; London; New Delhi: Sage Publications, 2002, at p. 505. ISBN: 0-7619-1971-6; 978-0-7619-1971-1.

[17] See e.g. WYATT, ref. 15, and PATTON, ref. 16.

[18] ŽABKAR, ref. 1.

[19] RYAN, Alex J. *A Mulitdisciplinary Approach to Complex Systems Design*. Adelaide, 2007 [Cited 2021-12-22]. Available from: https://digital.library.adelaide.edu.au/dspace/bitstream/2440/47784/1/Ryan2007_PhD.pdf. Doctoral thesis. The University of Adelaide. Thesis supervisor Nigel Geoffrey Bean, Ph.D.

general systems theory, argued that in the mid-20th century, many scientific disciplines (including physics, biology and the social sciences, to which we can also add the military science) recognized that individual parts of the structure in question were not to be treated in isolation but only as part of a larger whole. This expressed the need for the systemic approach that Bertalanffy wrote about:

> *"A certain objective is given; to find ways and means for its realization requires the systems specialist (or team of specialists) to consider alternative solutions and to choose those promising optimization at the maximum efficiency and minimal cost in a tremendously complex network of interactions [...]. It is a change in basic categories of thought [...]. In one way or another, we are forced to deal with complexities, with 'wholes' or 'systems,' in all fields of knowledge. This implies a basic re-orientation in scientific thinking."*[20]

General systems theory is closely linked to complexity theory, which renews the principles of Bertalanffy's theory.[21] According to Ryan, at the end of the 20th century, complexity theory became the most active area of systems research and thus the dominant discourse that overcame older systems approaches such as cybernetics, systems analysis and systems engineering.[22] The effective dissemination of findings not only to the scientific community but also to the external public has made an important contribution to the popularization of the theory.[23]

Despite the apparent unity of systems theory, we can distinguish between two distinctly different research approaches - hard and soft.[24] The proponents of hard systems science focus on the development of mathematical, often computer-aided models, which are extremely successful in many scientific fields due to their exactitude, but not in the social (soft) sciences. Due to the preoccupation with problems that are difficult to quantify and where the human factor predominates, a different approach has become established there - less structured and more qualitatively oriented. In contrast to the hard approach, soft approach fosters a broad spectrum of systemic perspectives when examining a problem and thus promotes dialogue and the search for solutions. The use of the metaphors, which fundamentally (co-)shape the perception of a particular issue, is particularly common - these are the so-called root metaphors. As practice shows, the soft approach gives good results in solving real-life problems, but it is often not profound and has a weak theoretical basis and contribution. Ryan believes that we can overcome the dichotomy between hard and soft systems science and therefore proposes the use of multidisciplinary conceptual analysis, which he believes is an intermediate path between

[20] BERTALANFFY, Ludwig von. *General System Theory: Foundations, Development, Applications*. New York: George Braziller, 1969, at pp. 4-5. ISBN: unknown.
[21] MULEJ, Matjaž – POTOČAN, Vojko. Teorija kompleksnosti spada v več tokov teorije sistemov [Complexity theory belongs to several streams of systems theory]. *Organizacija*. Kranj: Moderna organizacija, 2006, Vol. 39, No. 1, pp. 44-53, at pp. 47-51. ISSN 1318-5454. Available from: https://tinyurl.com/mr25kzuh.
[22] RYAN, ref. 19, p. 67.
[23] See e.g. WALDROP, Mitchell M. *Complexity: The Emerging Science at the Edge of Order and Chaos*. New York: Simon & Schuster, 1993. ISBN: 0-671-87234-6; 0-671-76789-5.
[24] RYAN, ref. 19, Chap. 3 and 4.

mathematical modelling and metaphorical perception of systems.[25] The author advises using knowledge from different (especially natural) sciences as a solid theoretical starting point for creating low-resolution models that are not quantified and are still primarily aimed at solving practical problems.

In the light of the above-presented baselines, we would like to enhance the theory of military science with the two concepts from mathematics and physics, namely the attractor and the critical transition. By doing so, we hope to elucidate some of the essential features of military (especially combat) operations. Since the (metaphorical) use can only be understood by reference to the basic meaning, we will first look at the initial, basic meaning of the concepts under consideration.

In the following, we will empirically back the proposed reconceptualization by conducting a case study research. We will analyse the empirical data from the first phase of the Russian invasion of Ukraine, which was launched on February 24, 2022. As the case study method allows for an in-depth empirical research of phenomena within a real-world context, especially when the boundaries between the phenomenon and the context are not clear,[26] the method can be assessed as appropriate for addressing the explanatory significance of concepts under consideration. However, we have to bear in mind that the question of external and internal validity always arises when using a case study method, as "case studies generally have a limited external validity due to a questionable generalization to other cases and situations. Since the unit of research is chosen by the researcher, a bias in the choice of units also exists that compromises internal validity."[27] The case study carried out should therefore not be considered as definitive proof, but rather as a first empirical step towards further research on the topic.

ADDRESSING THE COMPLEXITY OF WARFARE

From attractors and repellers…

Warfare (sub-)systems can be characterised as dynamical, as they are subject to a wide range of changes. The state in dynamical systems can be mathematically described by variables representing the components of the phase space. The phase space is an imaginary abstract space that allows us to describe and represent the dynamics of a system, whereby the number of the dimensions of the phase space depends on the number of variables used to define the system. The state of the system at a given time can be represented by a point in the phase space, and the change of the system over time by a trajectory connecting successive points.[28] Although multi-dimensional phase spaces are quite possible, it is difficult for humans to imagine their geometry.

[25] Ibid.

[26] YIN, Robert K. *Case Study Research and Applications: Design and Methods*. New York; London; New Delhi; Singapore; Washington DC; Melbourne: SAGE, 2018, at p. 50. ISBN: 9781506336169.

[27] FERLIGOJ, Anuška – LESKOŠEK, Karmen – KOGOVŠEK, Tina. *Zanesljivost in veljavnost merjenja* [Measurement reliability and validity]. Ljubljana: FDV, 1995, at pp. 100-101. ISSN 1318-1726.

[28] See e.g. GRABEC, Igor. Deterministični kaos [Deterministic Chaos]. *Strojniški vestnik*. Ljubljana: University of Ljubljana, Faculty of Mechanical Engineering, 1987, Vol. 33, No. 10-12, pp. 165-173, at p. 166. ISSN 0039-2480. Available from: https://tinyurl.com/3t6n77vb.

The concept of attractor plays a particularly important role in the description of dynamical systems. Landa defines attractor as "a point set in phase space attracting all neighbouring phase trajectories from some region named the attraction region",[29] and Vallacher as "a subset of a system's phase space to which the system evolves over time and which resists forces that would perturb this temporal trajectory".[30] Bertuglia and Vaio speak of a "particular region in the phase space (a subset of the phase space) that a dynamical system tends to reach during the course of its evolution".[31] Kiel and Elliott explain that the term attractor is used "because the system's temporal evolution appears to be consistently 'pulled' to identifiable mathematical points".[32] On the basis of the cited definitions, we can summarise that an attractor is therefore an abstract point or set of points used to describe a stability pattern in an evolution of a dynamical system.

The concept of attractor is often illustrated by the example of a ball rolling across a landscape.[33] Thus, when the ball is placed on the slope of the hill (basin of attraction), it always rolls towards the bottom (attractor), regardless of its exact starting position. The ball moves for a while but eventually settles at the lowest point (see Figure 1). All variants of system development therefore converge to the same result. Of course, in an imaginary case, it would be possible to have more than just one ditch near the ball. Likewise, it is generally possible that there are several attractors and that the evolution of the system depends on their basins of attraction and the (external) forces acting on the system. As illustrated by Young, the attractor acts similarly to "a magnet or center of gravity in mathematical space".[34] Thus, the attractor provides some stability to the system unless sufficient additional energy, information, perturbation, ideas, and the like re-accelerate the dynamics of change.

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[29] LANDA, Polina S. *Nonlinear Oscillations and Waves in Dynamical Systems*. Dordrecht: Springer, 1996, at p. 22. ISBN: 9780792339311.

[30] VALLACHER, Robin R. Social Psychology, Applications of Complexity to. MEYERS, Robert A. (Ed.). *Encyclopedia of Complexity and Systems Science*. New York: Springer, 2009, pp. 8420-8435, at pp. 8420. ISBN 978-0-387-69572-3; 0-387-69572-9; 978-0-387-75888-6; 0-387-75888-7.

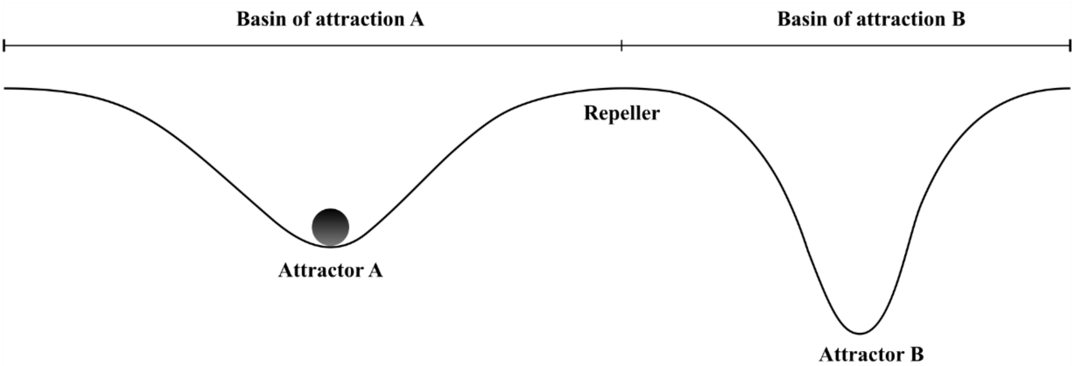
[31] BERTUGLIA – VAIO, ref. 3, p. 127.

[32] KIEL, L. Douglas – ELLIOTT, Euel. Exploring Nonlinear Dynamics with a Spreadsheet: A Graphical View of Chaos for Beginners. KIEL, L. Douglas, ELLIOTT, Euel (Eds.). *Chaos Theory in the Social Sciences: Foundations and Applications*. Ann Arbor: The University of Michigan Press, 1997, pp. 19-30, at pp. 26-27. ISBN 0-472-10638-4; 0-472-08472-0.

[33] See e.g. SCHEFFER, Marten. *Critical Transitions in Nature and Society*. Princeton: Princeton University Press, 2009, Chap. 2 and 6. ISBN: 978-0-691-12203-8; 978-0-691-12204-5; YOUNG, Gerald. *Development and Causality: Neo-Piagetian Perspectives*. New York; Dordrecht; Heidelberg; London: Springer, 2011, at p. 637-639. ISBN: 978-1-4419-9422-6; 1-4419-9422-X; VALLACHER, ref. 30, p. 8424.

[34] YOUNG, ref. 33, p. 638.

Figure 1: An illustration of the role of attractors and repellers in dynamical systems. The width of the ditch indicates the basin of attraction of the respective attractor, the depth its stabilizing power.



Source: own illustration

The attractor is inextricably linked to the concept of the repeller (also written as repellor in some sources).[35] If we were able to identify the point of attraction (bottom of the ditch) when rolling the ball across a landscape, on the other hand, there is also a point that repels any stabilization of the system and leads to perturbation. In our case, these are the peaks between the ditches (see Figure 1). Similar to attractors, there may be more than one repeller in the system. The repeller is thus a point or part of the phase space where even the smallest perturbation disturbs the (apparent) stability and moves the system towards the attractor.

Scholars have identified several characteristic behaviours of dynamical systems and several related attractors:[36]

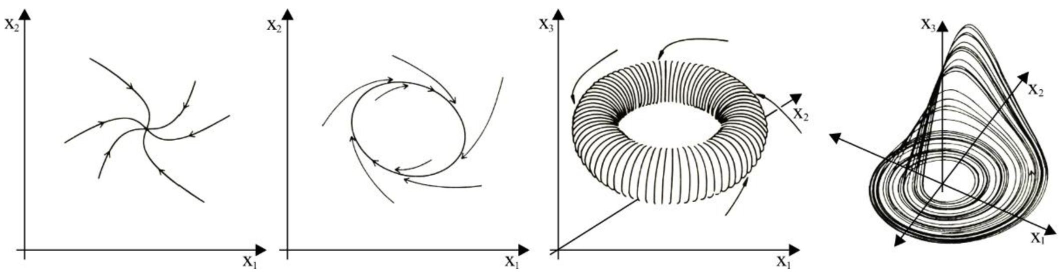
- The first group includes systems in which the trajectories always end at the same fixed point, also called a sink. A typical example of such an attractor is the equilibrium position of a damped pendulum - its trajectory in three-dimensional space converges, regardless of the initial state, to the lowest position of the pendulum.
- The second group includes systems where the trajectory eventually merges into a closed curve, called a limit cycle. A typical example of a cyclic attractor is the motion of a clock pendulum. For example, if the above-mentioned damped pendulum were frictionless and moving in a vacuum, its trajectory would endlessly trace out in three-dimensional space in the form of a closed curve.
- The third group includes systems that exhibit quasi-periodic cyclic motion, corresponding to an attractor called a torus. In three-dimensional space, we think of it as a kind of tire within which the evolution of the trajectory is quite complex yet deterministic. If, for example, the pendulum that drew the limit cycle was itself

[35] See e.g. VALLACHER, ref. 30, p. 8423-8424; YOUNG, ref. 33, p. 638.
[36] See e.g. GRABEC, ref. 28, pp. 167-168; LANDA, ref. 29, pp. 22-24; BOUSQUET, ref. 2, pp. 167-168; SCHEFFER, ref. 33, Chap. 2 and 3; YOUNG, ref. 33, pp. 640-641.

moving along a circular path, its trajectory in three-dimensional space would be drawn inside a kind of a doughnut.

- The last group includes systems characterized by a bounded but apparently random motion that does not end in a sink and does not merge into a limit cycle or torus. Such an attractor is usually called a strange attractor (see Figure 2).

Figure 2: Examples of trajectories of different attractors. From left to right: sink, limit cycle, torus and strange attractor.



Source: GRABEC, ref. 28, pp. 10-12

Until the 1960s, sinks, limit cycles, and tori were the only known examples of attractors. Then meteorologist Edward N. Lorenz discovered that even simple nonlinear systems in (at least) three-dimensional phase space can exhibit apparently random, yet clearly bounded, motion.[37] In doing so, Lorenz discovered a strange attractor that reflects structure in an apparently disordered data (see Figure 2). As the system changes over time, the values of the variables also change, but the evolution of the system never repeats exactly. Thus, the trajectories remain in a bounded space but never repeat themselves completely, nor do they intersect. This can be seen in the figure as a loop (or several of them) drawn infinitely around itself in phase space.[38]

As Young points out, strange attractors are usually chaotic, although by no means in the everyday sense of the word.[39] Indeed, they are a kind of combination of order and disorder and, globally, they bring stability to the system. At the local level alone, strange attractors are characterized by unpredictability and randomness. In this context, Bertuglia and Vaio write about "dynamic stability".[40] According to Gilstrap, strange attractor is characterized by "chaotic patterns of bounded instability" and is "the most common attractor in natural systems".[41]

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[37] LORENZ, Edward N. Deterministic Nonperiodic Flow. *Journal of the Atmospheric Sciences*. Boston, etc.: American Meteorological Society, 1963, Vol. 20, No. 2, pp. 130-141. ISSN 0022-4928. DOI: 10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2.
[38] GRABEC, ref. 28, pp. 168-169; GLEICK, James. *Chaos: Making a New Science*. New York; London; Ringwood; Markham; Auckland: Viking Penguin Inc., 1987, pp. 9-32. ISBN: 978-1-4532-1047-5.
[39] YOUNG, ref. 33, pp. 109 and 642.
[40] BERTUGLIA – VAIO, ref. 3, p. 155.
[41] GILSTRAP, Donald L. Strange Attractors and Human Interaction: Leading Complex Organizations through the Use of Metaphors. *Complicity: An International Journal of Complexity and Education*.

…to critical transitions and hysteresis

If a complex system loses its resilience, even a small perturbation can push it over the tipping point. This significantly changes the state of the system, so we speak of a critical transition. Because of their major consequences, critical transitions have attracted the attention of researchers in many fields; for example, they are studied in depth in limnology, climatology, and biology, as well as in the social sciences.[42] From a systemic perspective, during a critical transition the system shifts from one attractor to another, with positive feedback loops playing a key role and overriding negative ones. Keilis-Borok, Gabrielov, and Soloviev classify critical transitions in a category of extreme events, i.e., events that occur rarely but have a large impact on the system.[43] Critical transitions are commonly found under other names, such as breakage, fracture, collapse, crisis, catastrophe, or domino effect, which is also the case in military science.

As Scheffer points out, critical transitions are characterized by hysteresis.[44] Thus, at a certain point (called the bifurcation point), the state of the system can change drastically with even a small change in conditions, and a much larger change in conditions in the opposite direction is required for a reversal (see Figure 3). For example, a gradual increase in pollution in a lake may lead to a sudden decline in wildlife population, and a reduction to the last 'tolerable' level will not be sufficient to restore it, but conditions must be improved on a much larger scale. As Scheffer points out, the idea that a system can become vulnerable to gradual change is counterintuitive, but it explains well various dramatic changes in nature and society, from evolutionary leaps to the collapse of civilizations.[45]

As the conditions in the system approach a critical transition, the basin of attraction of a given attractor changes. In the example with a ball (see Figure 1), this could be illustrated by decreasing the depth and gradient of the ditch - the basin of attraction becomes shallower and shallower. As the system's resilience decreases, even a small perturbation can suddenly shift the state of the system (in the figure, illustrated by a ball) to an alternative basin of attraction (an adjacent ditch). The loss of resilience is key for the occurrence of a critical transition. Walker et al. define resilience as the "capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks".[46] In other words, resilience is the ability to absorb perturbations without the system switching from one attractor to another.

Alberta: The University of Alberta, 2005, Vol. 2, No. 1, pp. 55-69, at pp. 60-61. ISSN 1710-5668. DOI: 10.29173/cmplct8727.

[42] See e.g. SCHEFFER, ref. 33.

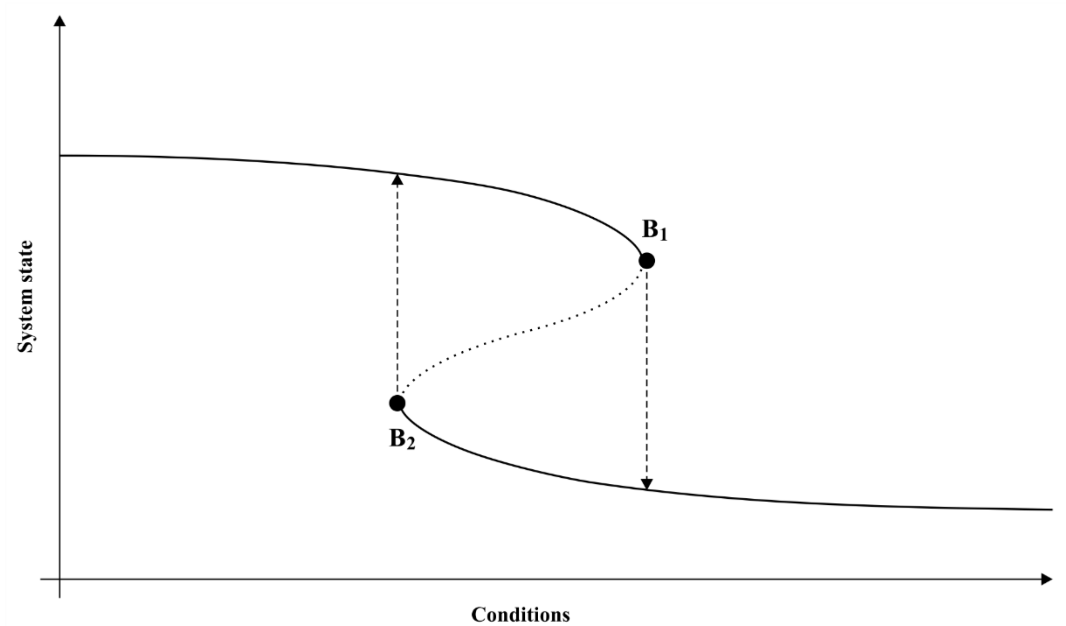
[43] KEILIS-BOROK, Vladimir – GABRIELOV, Andrei – SOLOVIEV, Alexandre. Geo-complexity and Earthquake Prediction. MEYERS, Robert A. (Ed.). *Encyclopedia of Complexity and Systems Science*. New York: Springer, 2009, pp. 4178-4194, at p. 4179. ISBN 978-0-387-69572-3; 0-387-69572-9; 978-0-387-75888-6; 0-387-75888-7.

[44] SCHEFFER, ref. 33, pp. 18-22.

[45] Ibid.

[46] WALKER, Brian – HOLLING, C. S. – CARPENTER, Stephen R. – KINZIG, Ann. Resilience, Adaptability and Transformability in Social–ecological Systems. *Ecology and Society*. Wolfville: Resilience Alliance, 2004, Vol. 9, No. 2, Article 5. ISSN 1708-3087. Available from: https://www.ecologyandsociety.org/vol9/iss2/art5/.

Figure 3: An illustration of a critical transition. As conditions change (e.g., an increase in pollution), the state of the system changes drastically (e.g., a decline in wildlife population) as resistance is lost at the bifurcation point (B_1). To achieve a critical transition in the opposite direction, it is necessary to change the conditions to the second bifurcation point (B_2).



Source: own illustration, inspired by SCHEFFER, ref. 33, p. 20.

As Scheffer et al. note on resilience, the key systemic features are (1) the heterogeneity of the elements and (2) their connectivity. The authors explain that homogeneous and highly interconnected systems are more resistant to change and 'repair' local losses more quickly, but only up to a critical threshold where even a small perturbation triggers a critical transition or collapse of the system. On the other hand, heterogeneous and modular systems respond to perturbations much more gradually, as individual, relatively isolated subsystems adapt to losses: critical transitions are therefore not typical of such systems. As the authors point out, highly connected and homogeneous systems often give a false sense of invariant stability, as they absorb perturbations well until they reach the threshold of the critical transition.[47]

Scheffer et al. conclude that critical transitions are a generic concept that reveals the fundamental properties of complex systems in general.[48] This gives the concept the potential to be used in a wide range of scientific fields. As we will illustrate in the

[47] SCHEFFER, Marten – CARPENTER, Stephen R. – LENTON, Timothy M. – BASCOMPTE, Jordi – BROCK, William – DAKOS, Vasilis – VAN DE KOPPEL, Johan – VAN DE LEEMPUT, Ingrid A. – LEVIN, Simon A. – VAN NES, Egbert H. – PASCUAL, Mercedes – VANDERMEER, John. Anticipating Critical Transitions. *Science*. Washington DC: American Association for the Advancement of Science, 2012, Vol. 338, No. 6105, 344-348, at. pp. 344-345. ISSN 0036-8075. DOI: 10.1126/science.1225244.
[48] Ibid., p. 347.

following, attractors and critical transitions are proving to be well suited for shedding light on military operations, and can also be linked to some well-established concepts in military science.

Warfare, attractors and critical transitions

Warfare can be seen as a system made up of many subsystems. For example, even a cursory glance at the capstone Doctrine for the Armed Forces of the United States reveals that we can distinguish between weapon systems, support systems, communications systems, command and control systems, intelligence systems, planning system, and so on.[49] It is clear from the naming itself that the individual (sub-)systems have different functions: some are directly aimed at killing people and destroying technical assets, others allow for information transfer, the third for material supply, the fourth provides for decision-making, the fifth for the care of the wounded and the like.

In order for a side in a conflict to develop maximum combat power, its subsystems must function as efficiently as possible, for which purpose the principles of warfare are incorporated into military doctrines. Usually, these are not given individually but in the form of a coherent set of principles (see, for example, page I-3 in the aforementioned doctrine), which are then employed by leaders or commanders in an effort to achieve victory. The composition of the system and the guidelines for its operation (principles of warfare) stabilize the development of the system even when it comes into contact with the enemy. Although combat may appear chaotic, unpredictability and randomness characterize events only at the local level, while globally the system remains relatively stable. Thus, an infantry brigade will never be particularly effective when used against targets in airspace, while it can unleash much of its combat potential when fighting against insurgents in an urban environment. One might say that the evolution of combat operations is characterized by a strange attractor - the infantry brigade will always operate within its general capabilities, while patterns of limited instability will quickly emerge in contact with the enemy in the face of casualties, stress, lack of information, and the like.

Because the armed forces are a complex system resistant to the degradation (reduction of functionality) of one element, a small number of elements, or the degradation of a small number of their connections, the system absorbs perturbations and reorganizes relatively quickly when losses are not significant. Thus, a commander who is killed can usually be replaced relatively easily by his deputy, the failure of a few weapon systems can be replaced by systems in reserve, and the failure of a network server can be replaced by other servers in the cluster. While the degradation of a small number of elements and/or connections slightly reduces the combat power, it remains close to the original level. From a systemic point of view, one could say that (conventional) armed forces are homogeneous and highly interconnected systems that are relatively resilient and 'fix' local failures quickly, but only up to a critical threshold.[50]

[49] The United States Armed Forces. *Doctrine for the Armed Forces of the United States*. 2013/2017 [Cited 2021-12-26]. Available from: https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp1_ch1.pdf

[50] On the other hand, some unconventional warfare actors, such as terrorist organizations, can be viewed as modular and heterogeneous systems that respond to perturbations gradually, as

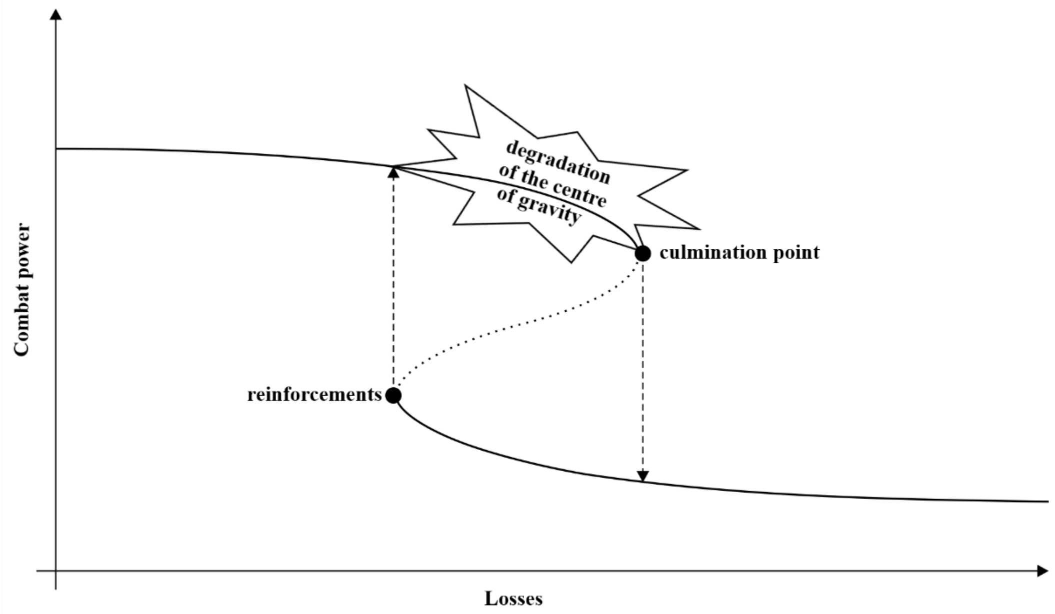
A much larger change occurs at this critical value when losses increase so much that the system loses its resilience. Then it reaches the bifurcation point and even a small perturbation can push the system past the tipping point - we call this a critical transition. Thus, once a crucial subsystem (often referred to as the centre of gravity by military experts)[51] is sufficiently degraded, any further loss can lead to a sharp decline in the combat power of the military system as a whole. In this respect, we can say that the evolution of combat operations is characterized by a change from one strange attractor to another - a new, relatively stable global state. In the established military vocabulary, such a development is often described as reaching a culmination point (see Figure 4).[52]

individual, isolated subsystems (such as terrorist cells) adapt to losses. In such systems, critical transitions are not to be expected, which could be the reason why it is relatively easy to weaken terrorist organizations but difficult to make them collapse.

[51] Centre of gravity - a warfighting concept, which aims to achieve disproportionate desired effects through the degradation of a limited but essential part of the enemy system. The concept favours an indirect approach and is used at all levels of warfare; however, it has special importance for strategy, and may be even more pivotal in the operational art. Although over the past few decades the centre of gravity has become the *modus operandi* of the planning and conduct of (major) military operations in a number of armed forces, questions arise about the true utility of the concept. As the author of these lines concluded in his doctoral research, the concept, despite many concerns, does have an analytical value, yet could be further refined and linked to the complexity theory.

[52] Vego defines a culmination point as "a 'point' in terms of time and space reached by the attacker or the defender, after which his stated objectives cannot be accomplished and continued effort to achieve them would considerably increase the chances of failure or even defeat; it is reached when relative combat power begins to decrease rapidly for one side in combat". Vego's definition of a rapid (!) decrease in combat power, and his additional explanation that it is an area of uncertainty which is dynamic and complex, both suggest that the author is in fact addressing critical transitions in combat. See VEGO, Milan N. *Joint Operational Warfare: Theory and Practice*. Newport: U.S. Naval War College, 2009, at p. GL-6. ISBN: 978-1-884733-62-8.

Figure 4: An illustration of a critical transition in combat. As casualties mount (especially in the case of a successful attack on a centre of gravity), the loss of resilience leads to a culmination. To achieve a critical transition in the reverse direction, extensive reinforcements are needed.



Source: own illustration

Based on observations in many other systems, we can presume that warfare is also characterized by hysteresis, whereby achieving a reversal transition (restoration of combat power) requires a much greater change in conditions in the opposite direction than just a return to the pre-critical transition. Therefore, after a critical transition, small reinforcements will not significantly improve combat power, but a more extensive reinforcement of the system will be required. However, this is often not feasible at a stage where the enemy already has superiority.

Take the example of the infantry brigade mentioned earlier: as it faces increasing degradation in one of the key subsystems (e.g., losses among the command and staff personnel due to enemy snipers), it will initially be able to absorb perturbations and reorganize. It is likely that some of the functions will also be taken by higher-level commands, adjacent or reserve units so that the decline in combat power will not yet be particularly obvious. However, at a certain point - the tipping point - a single additional loss (such as the death of another member of the staff) will cause the brigade to precipitously lose combat power. As the chain of command is degraded, subordinate units will self-organize, but the functionality of the overall system will be drastically reduced. More extensive reinforcement of the system will be required to make a reversal, so there will be no jump in functionality or increase in combat power if only the last loss is replaced. Let us look whether the proposed conceptualization could be supported by empirical data.

CASE STUDY: RUSSIAN INVASION OF UKRAINE

To this point, we have presented the proposed introduction of the attractor and critical transition concepts into the military field. In the following, we will try to relate the theory to empirical data. In doing so, we will analyse a recent case of an armed conflict, namely the initial phase of the Russian invasion of Ukraine.

The course of events

In the early morning hours of 24 February 2022, Russian President Vladimir Putin announced the start of the military invasion of Ukraine. He euphemistically named it a "special military operation" and defined its objectives "to protect the people [and to] demilitarize and denazify Ukraine and put to justice those that committed numerous bloody crimes against peaceful people, including Russian nationals".[53] Putin stressed that his intention was not to occupy Ukraine. In contrast, a number of analysts later assessed that the real Russian objective was a change of political power, which was to be achieved through the seizure of strategic Ukrainian locations. In this light, Kagan, Barros and Stepanenko evaluated that Russian forces intended to "seize Kyiv, Kharkiv, Odesa, and other major Ukrainian cities to force a change of government in Ukraine".[54] Similarly, Kofman estimated that the initial goal was a regime change, but that the invaders failed in all three military-strategic objectives - the encirclement/capture of Kyiv, the (deep) envelopment of Ukrainian forces tied to the Donbas, as well as the advance to Odessa.[55]

Shortly after Putin's speech, a missile strike on Ukraine's strategic infrastructure has commenced. Within hours, a ground offensive followed on three axes - northern (from Belarus along the Dnieper river towards Kyiv), northeastern (from Russia towards Kharkiv, Sumy and further to Kyiv) and southern (from Crimea towards Kherson and potentially Odessa). Operations on the northern axis constituted the Russian main effort, as the encirclement and potential fall of Kyiv would have meant a severe blow to Ukraine on the military, political and symbolic levels.

The Russian attack largely commenced in line with the analysts' projections.[56] In the first hours of the invasion, numerous missile detonations at Ukrainian airfields, air defence positions and other military facilities were reported. Initially, the ground troops advanced with relative ease: on the southern axis, Russian forces managed to penetrate as far as Kherson on the first day of invasion and secure a bridgehead over the Dnieper River there in the following days. On the northern axis, Russian forces reached the outskirts of Kyiv on the second day, and on the northeastern axis, attackers rapidly advanced to the suburbs of Kharkov, the second largest Ukrainian city. Yet, problems began to emerge.

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[53] Decision taken on denazification, demilitarization of Ukraine - Putin. TASS – Russian News Agency [Cited 2022-03-11]. Available from: https://tass.com/politics/1409189

[54] KAGAN, Frederick W. – BARROS, George – STEPANENKO, Kateryna. Russian Offensive Campaign Assessment, March 19. Institute for the Study of War [Cited 2022-04-04]. Available from: https://tinyurl.com/bbvv24px

[55] Quoted from: In the Fourth Week, is Russia Revising its War Aims Amidst Attrition? The War on the Rocks [Cited 2022-04-04]. Available from: https://tinyurl.com/ysd7xbfe

[56] KAGAN, Frederick W. – BUGAYOVA, Nataliya - BARROS, George – STEPANENKO, Kateryna – CLARK, Mason. Putin's Military Options. Institute for the Study of War [Cited 2022-04-04]. Available from: https://tinyurl.com/4k9sxyjb

The initial air and missile strikes on Ukrainian positions were relatively limited and, perhaps deliberately, did not significantly degrade the Ukrainian command and control. Russia also largely failed to neutralise the Ukrainian air force and air defence, and failed to secure the critical airfield at Hostomel. Military analysts soon recognised indications that Russian operations were characterized by poor planning, coordination, and execution, that the attackers were facing growing morale and logistics issues and that units, especially on the northern axis, were relying on *ad hoc* combat formations. By the third day of the invasion, the Ukrainian defenders largely halted the advance on the northern and northeastern axes. Russian progress was somehow more successful in the south, where the point of effort was shifted towards the port city of Mariupol, which became the scene of fierce urban combat.[57]

In the first days of March, reports started coming in that Russian forces were increasingly resorting to artillery shelling (often targeting civilian infrastructure), while manoeuvre units were holding positions or only slowly advancing on divergent lines. Despite significant military and paramilitary reinforcements, the attackers failed to develop manoeuvre into the enemy depth, nor were they able to envelop, encircle or destroy any major Ukrainian ground unit. Moreover, Ukrainian counter-attacks and ambushes continued to significantly degrade the combat power of the attackers. In this light, analysts assessed that after only a few days of fighting, Russian forces were forced to a series of operational pauses, eventually leading up to the culmination of the attack.[58] By that, Ukrainians halted the enemy's advance on the most dangerous northern and northeastern axes, thus bringing the war into the next phase. Let us look at more detail.

Unravelling the critical transition

As we have already written, combat may seem chaotic at the local level, while globally systems remain relatively stable. In this light, initial Russian operation could be thought of as a rather stable attractor of continuous advance. Indeed, in the first few days of the war, Russian units faced rather sporadic resistance, advanced several dozens of kilometres per day and eventually penetrated up to 200 km into the depth of the enemy territory. Yet this phase was relatively short-lived. Indeed, patterns of instability quickly emerged in the face of significant Russian casualties,[59] command and control issues,[60] insufficient logistics,[61] and the like.

As the armed forces are a complex system, resistant to the degradation of one or small number of elements and/or its connections, advancing Russian forces were initially able

[57] Ukraine Conflict Updates. Institute for the study of War [Cited 2022-04-15]. Available from: https://www.understandingwar.org/backgrounder/ukraine-conflict-updates
[58] Ibid.
[59] After the first month of fighting, death toll on the Russian side estimated to be between 7,000 and 15,000 service members, while Ukrainian military casualties were believed to be somewhat lower. See, e.g.: Up to 15,000 Russian soldiers dead in Ukraine, NATO says. The Brussels Times [Cited 2022-04-11]. Available from: https://tinyurl.com/39e49s9y
[60] Russia suffering 'command-and-control' difficulties in Ukraine, Pentagon says. The Brussels Times [Cited 2022-04-11]. Available from: https://tinyurl.com/5a4d7j4a
[61] For an intriguing view on Russia's logistics problems, see VERSHININ, Alex. Feeding the Bear: A Closer Look at Russian Army Logistics and the Fait Accompli. War on the Rocks [Cited 2022-04-04]. Available from: https://tinyurl.com/ysrxdcwe

to absorb minor perturbations and reorganize their operations accordingly. Yet, losses among critical systems started to mount with such intensity that even a series of operational pauses could not restore the Russian combat power. In conventional military vocabulary, we could say that Ukrainian defenders exploited Russian critical vulnerabilities (especially logistics and command and control), neutralized the enemy's centre of gravity (*ad hoc* combat group advancing on the northern axis) and culminated the Russian attack. From a systemic point of view, we could explain that fierce Ukrainian defence initially diminished resilience of the attackers. Next, continuous perturbations lead to a relatively sudden shift in the state of the Russian system, which switched to an alternative attractor, thus achieving a critical transition. Military operations were therefore characterized by a change from one strange attractor to another - a new, relatively stable global state of predominantly positional and attritional warfare. Bounded by hysteresis, Russian command was not able to deploy sufficient reinforcements to achieve a reversal transition and significantly regenerate combat power on the northern axis. Therefore, Russia eventually decided to completely retreat the forces from the area of Kyiv.

Culmination of the initial Russian attack might conventionally be best illustrated in spatial sense, e.g., on a map by the halt of the Russian advance.[62] Yet, we can address a change between attractors from another perspective. If Russian forces truly experienced a critical transition, we expect that the Russian side was affected by a significant drop in its combat power (in contrast to the Ukrainian, where it is assumed to remain relatively stable or it may even increase). Even though combat power might be difficult to assess,[63] we expect that higher combat power resulted in higher losses on the opposing side. In other words, we expect that the side generating higher combat power generally inflicted higher casualties in terms of killing, injuring or capturing enemy personnel, destroying, damaging or capturing enemy equipment, and the like. In that manner, we can compare the dynamics of casualties and losses.

As publicly available reports on combat deaths vary widely and were not regularly updated (thus having a poor resolution), we illustrated the critical transition using data on losses of major military equipment.[64] In this manner, we have extracted data from the Oryx portal,[65] which daily tracks destroyed, damaged and captured vehicles, aircraft, vessels and other significant equipment of which open-source photo or videographic evidence is available. As the authors of the website point out, the total amount of equipment

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[62] For continuously updated mapping of the conflict, see, e.g.: Ukraine Conflict Updates. Institute for the study of War [Cited 2022-04-15]. Available from: https://www.understandingwar.org/backgrounder/ukraine-conflict-updates

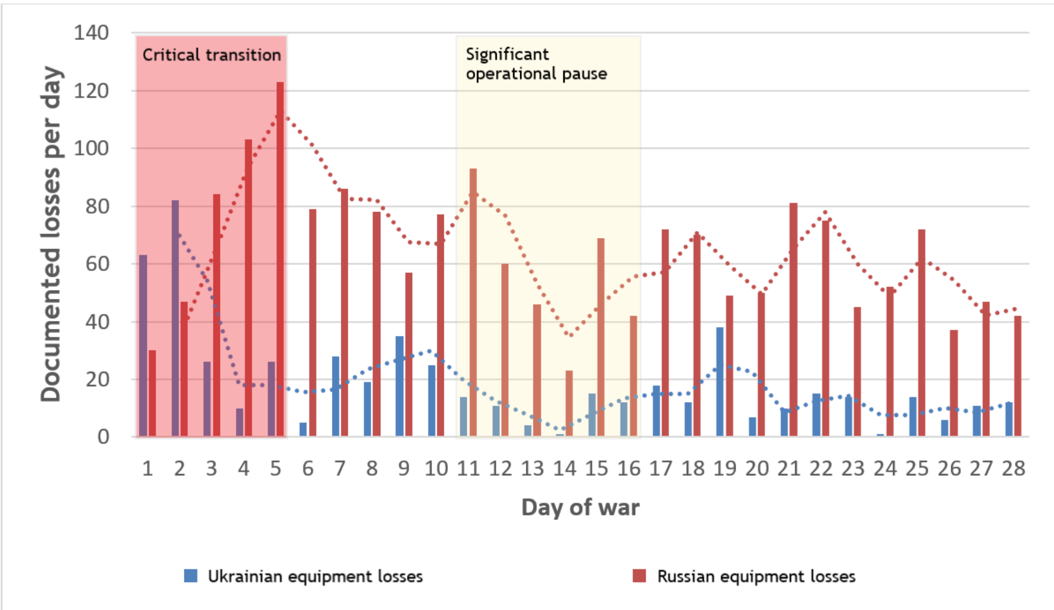
[63] As Vego points out, combat power encompasses a number of elements that are unquantifiable or difficult to quantify, such as leadership, surprise and deception. See VEGO, ref. 52, at p. III-34.

[64] Including, but not limited to: main battle tanks, infantry fighting vehicles, armoured personnel carriers, infantry mobility vehicles, C4I systems, engineering vehicles, tube and rocket artillery, surface-to-air missile systems, logistic vehicles, fixed and rotary aircraft, and ships.

[65] MITZER, Stijn – OLIEMANS, Joost – KEMAL, Dan - JANOVSKY, Jakub. Attack On Europe: Documenting Ukrainian Equipment Losses During The 2022 Russian Invasion of Ukraine. Oryx [Cited 2022-04-29]. Available from: https://tinyurl.com/yvknt3br; MITZER, Stijn – OLIEMANS, Joost – KEMAL, Dan - JANOVSKY, Jakub. Attack On Europe: Documenting Russian Equipment Losses During The 2022 Russian Invasion of Ukraine. Oryx [Cited 2022-04-29]. Available from: https://tinyurl.com/yvz6m3ux

destroyed, damaged or captured is probably significantly higher than recorded on the portal, as information on all and every losses is not made public.[66] Yet, the available data clearly indicates the ratio (rather than the absolute number) of the losses and the prevailing trend (significant increase or decrease). In this respect, the data can be considered of sufficient quality to be used to illustrate the critical transition (see Figure 5). To illustrate the critical transition, we have tallied all known losses of major military equipment during the first month of the war for each side in the conflict. We have summed up all pieces of major military equipment that has been assessed as destroyed, damaged, captured or abandoned.[67]

Figure 5: An illustration of a critical transition during the first phase of Russian invasion of Ukraine. Solid columns indicate documented major equipment losses, dashed lines a 2-day moving average.



Source: own illustration

As can be seen from the Figure 5, Russian forces were initially able to destroy, damage or capture a significant amount of Ukrainian weapons and equipment. For example, on 25 February 2022 (the second day of the invasion), loss of 82 items of Ukrainian weapons and equipment has been visually confirmed, including a larger number of unarmoured trucks. Yet, this figure quickly began to drop and only after a couple of days stabilized at around 20 confirmed losses per day. This was also in line with the halt of the Russian invasion in the spatial term, especially on the northern axis, which constituted the Russian main

[66] Ibid.
[67] Detailed data (in the tabulated form) that support the findings are available from the author upon request.

effort. On the other hand, losses among Russian troops began to rapidly increase during the initial advance, topping at the 123 visually documented weapon and equipment losses on the fifth day of the war, including a large number of armoured vehicles. The number remained high in the following weeks, regularly exceeding the number of 50. As illustrated by the prevailing trend of increased Russian and decreased Ukrainian losses, the Russian forces experienced (a rather early) critical transition. Even after an operational pause (indicated by a notable drop of documented losses on both sides, which is also marked on the figure), the Russian forces were not able to overcome the hysteresis and did not achieve much additional progress. Eventually, after around a month of hostilities, Russia withdrew its forces from the Kyiv area and shifted the main effort to eastern Ukraine. In this light, forcing Russian forces into the critical transition enabled the Ukrainian forces to successfully defend Kyiv, which could be considered a victory for the Ukrainian side.

CONCLUSION

Like many other fields, military science has also been shaped by the introduction of a systems approach. Although inextricably linked to subjectivity, the systems approach promotes a holistic, dynamic, and long-term view of reality. According to systems theory, warfare in general as well as its individual hierarchical components - duels, engagements, battles, operations, campaigns, and wars - can be seen as a violent interaction between (at least two) complex adaptive (sub-)systems. Based on the recommendation that insights from different (especially natural) sciences can be used as a starting point for a systemic approach that lies between a strictly mathematical and a purely metaphorical conception, we have tried to link the theory of warfare with the concept of attractor and, by extension, with the concept of critical transition. Although attractors primarily concern mathematicians and physicists, the importance of the concept has also been recognized by authors in many other sciences. Similarly, critical transitions are the subject of investigation in many disciplines. In this respect, the attempt to introduce new concepts merely follows an example that has already proved its worth in quite different scientific fields.

The basic idea is that unpredictability and randomness characterize warfare only at the local level, while – globally - (sub-)systems remain relatively stable most of the time. In this respect, it can be said that the evolution of combat operations is characterized by a strange attractor, as (sub-)systems reorganize themselves relatively quickly in the face of minor perturbations. While the degradation of a small number of system elements and/or connections slightly reduces the combat power, it remains close to the original level. However, a much larger change occurs when losses in key subsystems increase so much that the system loses its resilience.[68] The system then reaches the bifurcation point, and even a small perturbation can push the system past the tipping point - we call this a critical transition. In this respect, we can say that the evolution of combat is characterized by a change from one strange attractor to another - a new, relatively stable

[68] For a recent discussion on the armed forces' resilience, see, e.g., DIVIŠOVÁ, Vendula – FRANK, Libor – HANZELKA, Jan – NOVOTNÝ, Antonín – BŘEŇ, Jan. The Whole is Greater than the Sum of the Parts: Towards Developing a Multidimensional Concept of Armed Forces' Resilience Towards Hybrid Interference. *Defence and Strategy*. Brno: University of Defence, 2021, Vol. 21, No. 2, pp. 003-020. ISSN 1802-7199 (online). DOI: 10.3849/1802-7199.21.2021.02.003-020.

global state. Based on observations in many other systems, we can presume that warfare is also characterized by hysteresis. Such a conception is also supported by the empirical data on the Russian invasion of Ukraine, in which the Russian side experienced a critical transition after only a few days of combat operations.

Although the presented linkage of warfare to the phase space, attractors, critical transitions, hysteresis, centre of gravity, and culmination point seems plausible, it does not yet provide a comprehensive explanation. In this light, a more detailed analysis of critical transition in combat or warfare in general would be fruitful. In doing so, we could use the already established indicators that there are indeed multiple attractors in the system or that the system is approaching a critical transition.[69] When examining critical transitions, it would also be useful to address the question of what is the most appropriate balance between homogeneity and heterogeneity, or interconnectedness and modularity, in warfare systems.

Lessons from complex (adaptive) systems theory allow us to gain a deeper understanding of warfare, using insights that have already been proven in many other sciences. Thus, we could also look to additional concepts/metaphors from the field of complex systems, such as equilibrium, criticality, black box, turbulence, autopoiesis, coevolution, and fractal. However, it should be kept in mind that no metaphor can serve all purposes and that military science should eventually include only those building blocks that allow a better understanding of the real world. We should not be afraid of creative thinking, yet, we should strive for a thorough reflection on the proposed reconceptualization.

[69] See, e.g., SCHEFFER, ref. 33, Chap. 14 and 15; SCHEFFER et al., ref. 47.