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Network Centric Warfare as Complex Optimization: An Evolutionary Approach

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Military operations are very complex undertakings. However, complexity is not a feature unique to military operations. When biologists wanted to understand the properties of gene mutation they also faced complexity. Confronted by a large number of genes featuring different characteristics, a difficult-to-decode interaction among those genes, and an environment that could not be excluded as a factor, Sewell Wright introduced the shifting balance theory, also known as the theory of the fitness landscape. The theory allows complexity to be seen as a process that rests on adaptation and mutation. These two processes are also central to military operations as it is imperative to offset the changing conditions coming both from the environment and the interaction with the enemy. In the article the author uses Wright's theory to help see military operations as a complex optimization problem that includes approximations and estimations regarding optimal values.

Keywords: *network-centric warfare, complex optimization, biological evolution, fitness landscape, adaptation*

Military Operations and Networking the Force

Military operations are very complex undertakings, a fact which is also reflected in various official NATO documents. Allied Joint Publications are full of statements that the complex nature of military operations does not allow for simple definitions nor lends itself to simple analysis. Complexity of military operations means that relationships between causes and effects are very hard to detect and even harder to predict. This complexity very often precludes the definitive defining of desired effects. [3: 2–11] Due to the complexity of military operations many force employment concepts have been created over the years. [27: 6–16] A more enduring among them appears to be *network centric warfare,* which defines a new relationship among individuals, platforms, and organizations. Proponents of the concept assume that a networked force can result in processes that create more appropriate behaviors and modes of operation. Networking also promotes the effective linking of dispersed and distributed entities of a warfighting organization thus increasing combat power. In general, network-centric warfare for them stands for synergy, dynamically reallocated responsibility, and successful adaptation to the situation. Thinking in terms of networks shifts the focus on the interactions among entities as the emphasis is on information flows, nature and characteristics of the entities, and the way those entities interact. Network-centric warfare allows the entities to work in concert in which they act as nodes and process information by passing it from one to another. [1: 87–95]

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Proponents also assume that network centric warfare can help eliminate stove-pipe legacy systems, parochial organizational interests, redundant and non-interoperable military systems, and optimize investments for information technology systems. Due to its horizontal focus the concept stands for doing what needs to be done without traditional orders. It provides for an improved understanding of the higher command's intent, a better understanding of the operational situation at all levels, and an increased ability to tap into the collective knowledge, in order to reduce fog and friction normally associated with war. [29: 2] Network centric warfare thus offers many benefits such as enhanced combat power, better shared awareness, and increased speed of command, higher tempo of operations, greater lethality and better survivability. Central to it is a rapid decision making process and an increased speed of execution. All benefits of network centric warfare come from the shift from individual platforms to the network they can provide for, from independent actors to a continuously adapting *ecosystem* the actors are part of, and from making and executing strategic choices to adapting in those ecosystems should changes occur. [24: 3–6] [14: 245–256]

Military operations can indeed be seen as *warfighting ecosystem* in which the human organizations involved create a unique, highly complex and dynamic environment. In such complex situations, as one Allied Joint Publication states, pragmatism, experience and a good sense are required to achieve desired effects. [1: 83] [4: 1–7] Complex situations found in military operations require a proactive engagement and the careful coordination of sensitive responses. Complexity calls for sophisticated and non-linear models as military operations contain elements existing simultaneously, each coming to the surface at certain times. For a better understanding of complexity and the full realization of network-centric warfare an approach is needed that emphasizes decentralized command, freedom of action, tempo and initiative. Only this way can it be assumed to be possible to contend with the multitude of activities in dynamically changing situations as presented in military operations. [5: 1–9] [13: 659–671]

In order to better understand the complexity of military operations the author uses biological evolution as a basis. Exploring certain features of evolutionary biology by taking advantage of one of the central theories of population genetics can serve as a good vehicle to comprehend this complexity. Thus the author first explores the shifting balance theory according to which biological evolution is seen as a process that happens in networks. Then he details certain features of the internal dynamics of adaptation as it happens in such evolutionary networks. Following this the author examines how evolutionary adaptation can be fine-tuned in order to be successful. Then he goes over to detail evolutionary adaptation as a process that happens as a result of co-evolution. The article ends with the conclusion.

Shifting Balance of Evolutionary Networks

Complexity and networks are not features unique only to military operations. When biologist Sewell Wright wanted to understand the properties of gene mutation he also faced a complexity comparable to what is found in military operations. He was confronted by a large number of genes featuring different characteristics, a difficult-to-decode interaction existing among those genes, and the environment that could not be excluded as factor. In order to handle this problem Wright showed, as demanded by one Allied Joint Publication, pragmatism, experience and good sense. He introduced the *shifting balance theory*, also known as the theory of the *fitness landscape* in which fitness describes the relative success of a species in relation to others in the environment. Similar to the unpredictable character of military operations also biological evolution happens in a constantly changing environment in which a species' suitability to the circumstances often alters in a subtle and dramatic way. [30: 3] [6: 66–75] [12: 40–41] [25: 268–279] His theory is a powerful aid to conceptualize a complex phenomenon such as biological evolution in a novel way. Wright's approach allows biological evolution to be seen as a process that rests on adaptation and mutation. These two processes are also central to network centric warfare as it is imperative in military operations to offset changing conditions coming both from the environment and the interaction with the enemy. Thus Wright's approach has much to say for network centric warfare too, as he proposed the evolutionary process to be a network composed of various genetic combinations. His theory can help understand military operations as a *complex optimization problem* that includes approximations and estimations regarding optimal values. In a similar way NATO publications also state that the way complex problems are framed in military operations has become more important than ever. Complexity demands principles aimed at gaining an understanding for better adaptation, rather than just simply executing orders. [26] [16: 389–396]

In order to solve his complexity problem Wright constructed a graphic representation, a short and non-mathematical approach to biological evolution that resembles a certain similarity with a topographical map. Although he emphasized that references to geography are of secondary importance, the result was a map containing multiple peaks surrounded by circular contours. The map was defined by two axes representing the dimensions along which possible combinations could be arranged. Every combination had a certain value and by connecting the points of equal value contours of peaks and valleys arose. (Figure 1) [6: 67–68] [31: 165–172] [32: 115–116]

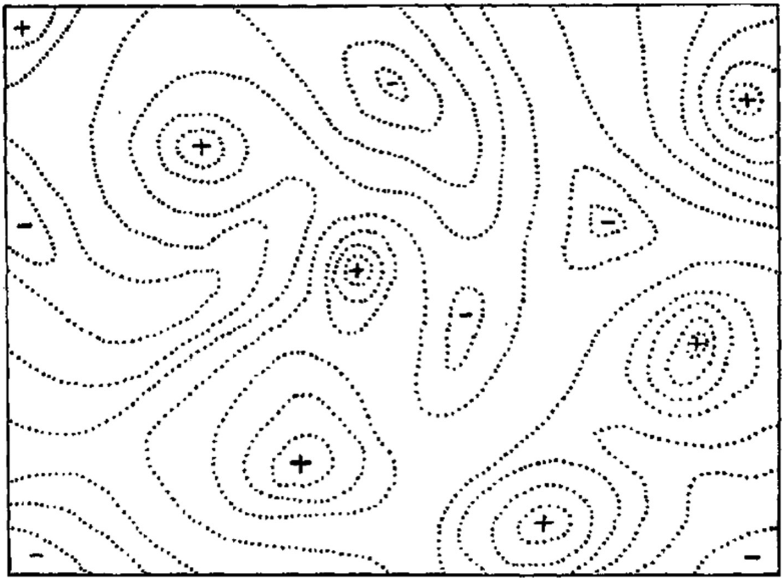


Figure 1. A diagrammatic representation of the field of gene combinations in two dimensions. Dotted lines represent contours with respect to adaptiveness. [30: 3]

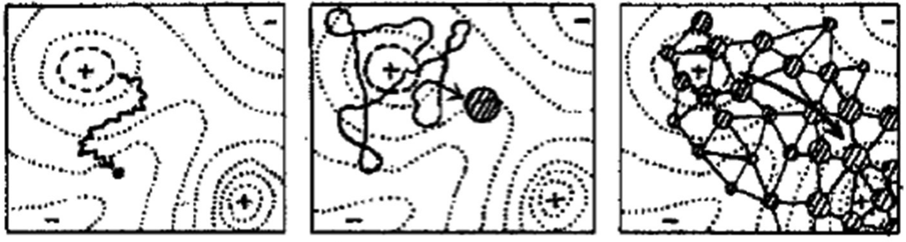
Wright assumed that evolutionary selection could carry the species to the top of the nearest peak, but could not cross valleys that separate the current peak from other, probably higher ones. However, should the species be able to cross valleys then it is not under the exclusive control of natural selection, but of a certain trial-and-error mechanism. An indefinitely large species that lives under constant environmental conditions and is exposed only to natural selection can reach equilibrium by occupying a certain peak. The population either grows through an increase in mutation rate or a decrease in mass selection, or it decreases through the opposite process. In both cases evolutionary selection alone does not seem to be sufficiently strong to push the species towards another and possibly higher peak. [30: 360–362] [32: 117]

Wright assumed that the environment is never static, but changes continuously. The landscape constantly deforms by depressing high places and elevating low ones. According to him, if a species is not extremely specialized and occupies a wide field on the landscape, by moving constantly it can find higher general regions. Such a trial-and-error mechanism can shuffle the species about by means of change without advance in adaptation. As a solution he proposed a large species to be subdivided into many local races that shift continually in a non-adaptive fashion on the landscape. Although this exploratory process could result in a decrease of fitness as an immediate effect, this way it would become possible that at least one local race finds a higher peak and pulls the entire species towards this better position. Wright emphasized that a subdivision of a species into local races provides the most effective adaptation mechanism for trial and error in the field of gene combinations. In other words, he proposed adaptation to be most effective when being networked. (Figure 2) [30: 363]

A. Increased Mutation or reduced Selection 4NU, 4NS very large

B. Increased Selection or reduced Mutation 4NU, 4NS very large

C. Qualitative Change of Environment 4NU, 4NS very large



D. Close Inbreeding 4NU. 4NS very small

E. Slight Inbreeding 4NU. 4NS medium

F. Division into local Races 4nm medium

Figure 2. Field of gene combinations occupied by a population within the general field of possible combinations. [30: 6]

Wright's conclusion was that evolutionary adaptation involves differentiation in which the principal mechanism is essentially non-adaptive. Wright regarded evolution as a dynamic process in which adaptation comes as a result of a careful balance between natural selection and random genetic drift. In this process each has varying contributions to the survival and extinction of species over time and space. He proved that adaptation and chance events play an important role in biological evolution. [30: 362–366] [6: 68–72] [32: 118]

Evolutionary Networks and Adaptation

Backed by computer power Kaufmann and Levin picked-up Wright's idea and examined its internal dynamics in detail. They stated that evolutionary adaptation in the framework of genetic networks is composed of small changes. Its mechanism resembles and has similarities with a constrained local search process in the form of an *adaptive walk*. They also stated that evolutionary adaptation deals with conflicting requirements that always limit the end result. They assumed a landscape featuring many peaks and valleys in which adaptive walks proceed along a path leading to attainable local or global peaks. They regarded adaptation as the simplest form of optimization and also the simplest form of a trial-and-error mechanism. Similar to Wright they saw evolutionary change as a novel and creative process that may or may not be accompanied by adaptation to the constantly changing conditions of the environment. They proposed adaptation and fitness to come from the environmental context displaying an extended web of relationships in the form of conflicting constraints. [18: 12–15] [20: 163–166] [9: 222–230] [9: 245–254]

As a baseline case they first examined adaptation on uncorrelated fitness landscapes. In such landscapes they suggested drawing the fitness value of each entity randomly from a given, but fixed underlying distribution. Kaufmann and Levin used N genes where each gene could have only two values, 1 standing for gene activated and 0 for not activated. The number of possible combinations is 2^N with 1 being the lowest value and 2^N the highest. Connecting the 2^N points with lines results in landscape-like surface, which is very rich in peaks or local optima. According to them the number of such local optima increases almost exponentially to N resulting in an uncorrelated landscape of which the expected lengths of adaptive walks are generally very short. Each successive step on average moves halfway from the current point, towards the point with the maximum value. After each step the expected number of fitter points is halved on average. The result is that the stopping times are distributed very tightly. In such a setting the great majority of adaptive walks stop within one or two steps. The number of alternative pathways leading to higher optima decreases linearly with the rank order of the points. Consequently, with an adaptive walk from any single starting point only a small fraction of the true local optima is accessible. [18: 19–21] [20: 167–169]

Kaufmann and Levin argued that the success of an adaptive walk depends on the correlation structure of the landscape. A point with an initially low fitness has many fitter neighbors, a point with high fitness has just few and a point that is a local optimum has none. In such a landscape an adaptive walk can branch into many alternatives early in the process, but the number of alternatives slows down as fitness becomes higher. Their conclusion was that adaptation on an uncorrelated fitness landscape favors branching radiation that slows ultimately to stasis. (Figure 3) [18: 22–24]

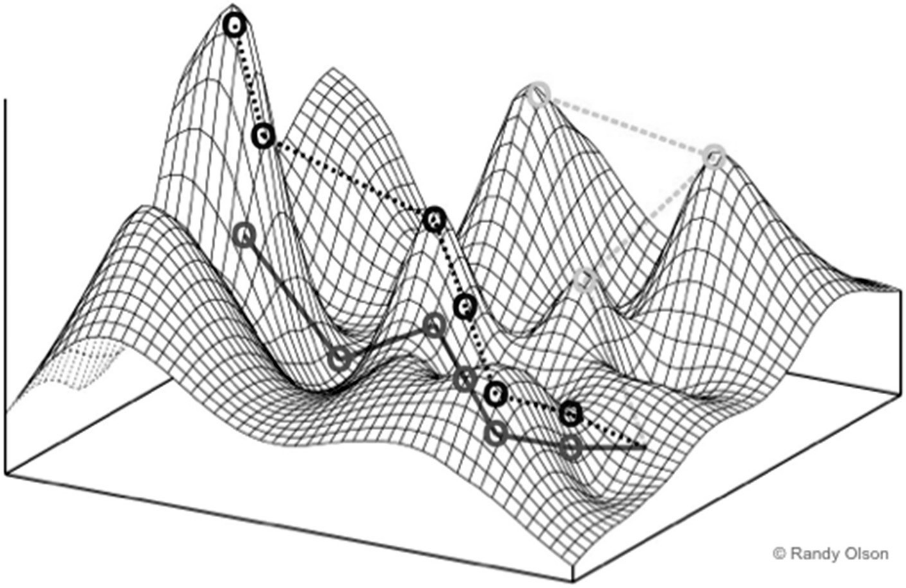


Figure 3. A three dimensional landscape featuring many peaks and valleys in which adaptive walks can lead to attainable local or global peaks. [28: s.p.]

According to Kaufmann and Levin most fitness landscapes are correlated in which points with similar values are closer to each other. The result is that neighboring points, which they called 1-mutant fitter variants, show similar properties. Correlated fitness landscapes can also be rugged and may require long-jump adaptation to distant points, also called J-mutant fitter variants. In this case the importance of a local optimum disappears since all points become accessible. As a result the correlation structure becomes weaker and weaker, and the number of local optima diminishes. On such landscapes the importance of the expected waiting time increases as jumps sufficiently far represent adaptation that experiences an uncorrelated landscape. Similar to an adaptive walk they assumed that if more than one J-mutant fitter variant is found the fittest is chosen. Thus on average, a single J-mutant fitter variant lies halfway between the least fit and the fittest; therefore the waiting time to find the next fitter variant doubles with each successive step almost independently of the population's size. Adaptation via J-mutant fitter variants is rapid at the beginning, then slows down and after a modest number of steps stasis sets in. Similarly to adaptation via 1-mutant fitter variants branching into alternatives is more common initially, but progressively harder later. Adaptation via J-mutant fitter variants also tends to prefer branching radiation that eventually quiets to stasis. [20: 619–622] [18: 26]

Later Kaufmann assumed that correlated landscapes might exhibit self-similar characteristics resulting in small hills nestling into the sides of larger hills, which again nestle into the sides of much larger hills. Consequently, landscapes can be correlated, but rugged. After a jump with a distance shorter than the maximum the species may land on an uncorrelated landscape when measured on a shorter length scale, but on a correlated landscape when measured on a longer length scale. [21: 572–577] [20: 171–175] Using the insights coming from the two baseline landscapes and the two sorts of adaptation, it became possible for them to derive some generalizations for adaptation on correlated landscapes. Kaufmann and Levin argued that it makes sense to marry the local and global search in adaptation depending on the time scale of the process. Most statistically rugged landscapes are correlated, and adaptation via J-mutant fitter variants may possibly escape the correlation structure, which is not possible with adaptation via 1-mutant fitter variants. Given a randomly chosen point on the landscape with an average fitness, in the beginning the population would sample both in the vicinity via 1-mutant fitter variants and further away via J-mutant fitter variants. Since the fitness is average, half of the points sampled will be fitter and half less so. Due to the correlation structure, points sampled nearby will only be slightly fitter, whereas points further away and not constrained by the power of correlation could reveal much higher fitness levels. Thus early in the process long jumps trying to find J-mutant fitter variants would become dominant and result in a branching radiation. However, as more J-mutant fitter variants are encountered, the chance of finding J-mutant fitter variants will be less than finding nearby and only slightly fitter 1-mutant variants. Consequently, in the mid-term adaptation via 1-mutant fitter variants in the form of an adaptive walk or local hill climbing will dominate the process. However, as the process goes towards the peak, the rate of finding 1-mutant fitter variants decreases and the danger of ending up in stasis grows. Therefore in the long term, adaptation via J-mutant fitter variants will again make sense, since only with long jumps is it possible to land in the vicinity of a fitter point that can again be climbed. [18: 33–35]

Although evolution can be understood as a process composed of long jumps and adaptive walks uphill, after each long jump and hill climbing the time requirement for finding the J-mutant fitter variant is typically more than double. Consequently, radiation and stasis are inherent features of evolution. Early in the process many different pathways branch upward. As time passes fewer alternatives can emerge until single lineages get trapped on local optima. As local optima are approached the number of ways leading uphill decreases. On rugged landscapes radiation and stasis are utterly generic as adaptation stands for branching lineages that surf on a turbulent fitness sea with both divergence and convergence occurring at wavetops. [21: 577–580]

Fine-tuning Evolutionary Adaptation

Although in reality the contours of fitness landscapes remain unknown, they can be reconstructed in order to make them knowable. Based on the general insights gained above, Kaufmann developed a model, which is defined both by the variable N and another variable K. Variable N stand for the number of genes, whereas K stands for the average number of epistatic interactions or conflicting constraints within N that profoundly influences the fitness of any combination. Since K can be tuned from zero to a maximum value (N – 1), it basically defines the ruggedness of the landscape. As K increases, the landscape changes from smooth to very rugged, or from statistically correlated to statistically uncorrelated. [21: 540–543] [20: 169–171] [23: 301–302] In the case of K = 0 there are no epistatic interactions, no conflicting constraints and no cross-connections. The structure of the landscape contains only one global optimum, which makes an adaptive walk via 1-mutant fitter variants possible. This landscape is the simplest possible in which all points are on a connected pathway leading to the top. The surface is smooth with neighboring points having nearly the same fitness value. Thus knowing the fitness value of one point provides significant information about the fitness value of neighboring points. On such landscapes for very large N the fitness values of 1-mutant fitter variants are very similar. In that case, walk lengths to the global optimum increase linearly with N resulting in the pace of such a walk being very slow. This smooth landscape perfectly reflects the ideal gradualism of evolution as outlined by Darwin. [20: 544–545] In the case of K = N – 1 the amount of conflicting constraints is maximum and each point is affected by all other points. The result is an entirely uncorrelated and extremely rugged fitness landscape. The fitness value of any given point does not give information about the fitness value of neighboring points. On such landscapes, the number of local optima is very large and the rate of finding better optima via 1-mutant fitter variants decreases at every step. Thus the lengths of adaptive walks to local optima are generally very short and the expected time to find a local optimum is proportional to N. Only a small fraction of the local optima is accessible from any given point. As the number of points increases, the fitness value of local optima falls towards the average fitness of the space, which limits the force of selection and the success of an adaptive walk. The fitness values of accessible optima become poorer as the peaks themselves decrease. [20: 173–175]

NK landscapes can thus have two baseline cases. Whereas the first equals K = 0 and indicates an entirely smooth surface, the other equals K = N – 1 and stands for an entirely rugged surface. [20: 546–547] However, there is an infinite variety of potential landscape surfaces between the two end-poles. Should K and N increase proportionately, the fitness of accessible optima becomes an ever poorer compromise. Such landscapes resemble isotropic features as high peaks move apart from each other in the landscape. Consequently, any one area looks roughly as any other area. Good peaks do not exist since it is not possible to climb higher peaks than afforded by the landscape itself. However, if K is small and fixed whilst N increases the landscapes display non-isotropic features and contain special regions in which high peaks cluster. The location of one high optimum gives information about the location of other good local optima. In this case it is reasonable to search for peaks that lie between two higher peaks that contain mutual information about possible good regions of the landscape. [22: 180–183] [20: 180–183] Originally the concept of NK landscapes was developed to understand evolutionary migration of *haploid gene combinations* that do not involve recombination, but happen if advantageous point mutations accumulate. However, recombination of *diploid gene combinations* helps improve the mostly myopic search process of an adaptive walk guided only by the local features of the landscape. Through recombination it becomes possible to get a bird’s-eye view on the landscape, but also in this case success depends on the correlation structure. Consequently, on random landscapes recombination is useless and does not make any sense since it suffers the problems of long-jump adaptation. However, on correlated landscapes in which the highest optima are close to each other and peaks are largest, the location of any given high optimum carries information about other optima. Peaks contain mutual information about the good regions in which recombination can be compared with the effect of repeated long jumps. Thus recombination is a very powerful form of adaptation on very rugged, but correlated fitness landscapes. The only critical requirement is that local optima must carry mutual information about the location of other good or better optima. [21: 583–592] [21: 569] [21: 611] [10: 227–228]

It must also be mentioned that by approaching one of the two end-poles evolution suffers from two limits of complexity in the form of catastrophes. The first extreme refers to K = 0 in which the gradient leading to the single optimum is shallow. In this case selection is not always able to hold the population at the peak and can become too weak compared with mutation. The adapting population cannot stay at the top of the peak, but flows down mostly in the form of quasi-species into the lower regions of the landscape. This phenomenon stands for large mutation rates that lead to a sudden breakdown of stability. Such a case is called the *error catastrophe*. The other extreme refers to $K = N - 1$, which indicates a very rugged landscape containing a huge number of peaks. Here, local optima fall towards the mean of the space. Consequently, walks are locked into typical local regions that have an average fitness value. In this case selection affords only poor peaks to be climbed. A shift towards this extreme results in a *complexity catastrophe*. [17: 068104-1-4] [11: 4481–4487] [21: 552–558] [21: 580–583] [21: 587–592] Given these two limitations, Kaufmann assumed that early in the evolutionary process adaptation occurs on a highly uncorrelated fitness landscape with a subsequent adaptation happening on a rather well-correlated landscape. Adaptation on a correlated landscape means that the rate of finding fitter variants can either stay constant as the fitness increases or decreases slower than on uncorrelated landscapes. In other words, history does matter since early development always locks in. [20: 177]

Evolutionary Adaptation as Co-evolution

In real life species live in niches afforded by other species, with the result that fitness landscapes are not fixed, but evolve due to interactions with other species. As Kaufmann argued, real evolution is a co-evolutionary process that happens on coupled landscapes in which the adaptive moves of one species deform the landscapes of other species. This implies epistatic interactions between the landscapes themselves, since in reality the fitness of each species depends both on the environment and other species. Consequently, landscapes of co-evolving species show a very dynamic surface that trembles, waves and heaves. In such a situation all bets are off since attempts of one species to improve its own fitness may deform the landscape of the other species to which it is coupled. Although the fitness landscape of any given species is a function of the adaptive moves of other species since they correspond to the changes, it cannot be excluded that certain aspects of fitness might be independent from interactions. In order to catch the essence of the co-evolutionary process Kaufmann introduced two new variables, C and S. Variable C describes the epistatic interactions between the landscapes and represents those external constraints that influence a species' fitness. Increased C shows how the adaptive moves of species deform the landscapes of their partners. Variable S stands for the number of interacting species, hence the number of different fitness landscapes. Thus the variables tune the landscape's ruggedness and also model the richness of external conflicting constraints. [21: 675–688] [20: 215–222] [19: 325–369]

Similar to fixed NK landscapes, there are also two end-poles on co-evolutionary landscapes. Whereas one end-pole is called *evolutionary stable strategy*, the other is called *evolutionary unstable strategy* also dubbed the Red Queen. In an evolutionary stable strategy each species climbs to a peak that is consistent with the peaks on the other species' fitness landscape. Under this condition the species stop co-evolving because each is better off not changing as long as the others do not change. [8] At the other extreme the species never settle down, but keep chasing peaks forever. Their effort to deform and lower the peaks on the other species' landscape also alters indirectly their own. Consequently, the behavior lies in the chaotic domain in which the species run ever faster in order to stay in the same place. For cases in between Kaufmann found that species can co-evolve well. The speed at which species move depends on their current fitness and the ruggedness of the respective landscapes. If species are on landscapes of different ruggedness the rate at which they move uphill depends on their joint fitness and landscape ruggedness. When the amount of coupling between the landscapes is high, by increasing the number of conflicting constraints internally, a species can reach equilibrium faster and gain higher fitness. [21: 689–702] [20: 223–225] Kaufmann concluded that for K > C equilibrium is encountered more rapidly than for K < C where the waiting time can become very long. For co-evolving species K = C is a crude dividing line for the time requirement to encounter equilibrium. In the case K > C×S the co-evolving partners all get to equilibrium rapidly; in the case K < C×S equilibrium can only set in after a long period of time. Thus the fitness in co-evolving systems increases when a species can adjust its K to C with K = C×S being a rough guide. [19: 334–343] [15]

Conclusion

The shifting balance/fitness landscape theory indicates that biological evolution is full of results that feature potential outcomes rather than planned ones. Moreover, as the distribution of these potentialities overlap approaches attempting to *optimize* make more sense than those attempting to *maximize*. Thus success and victory in the form of life and death, survival and extinction, can be seen as emerged positive and not as realized maximum outcomes. The greater the uncertainty the greater the possibility, that factors such as relative superiority and fortuitous circumstances become decisive. Chance events often demand from species to work in a trial-and-error modus. In biological evolution there is no guarantee that a particular outcome is really the best one. Once chance forces the selection of a particular path a species often locks in regardless of the quality of other possibilities. Complexity indicates that there are many possible solutions to the same problem and often small, fortuitous, and trivial events determine the one event that becomes dominant. [2: 211–221] [7: 92–99]

The evolutionary analogy, however, has many benefits for the concept of network centric warfare as well, as it:

- highlights the dynamic processes of military operations as options that can help create more appropriate behaviors and modes of operation;
- promotes the effective linking of dispersed and distributed entities of a warfighting organization into an organic whole;
- helps better understand the relationship between those entities on various scale (individuals, platforms, organization);
- shifts the focus toward the interactions of the entities by delivering means to better understand the underlying dynamics;
- promotes the collective knowledge of the entities to reduce fog and friction traditionally associated with war;
- enhances the combat power of those entities on various scale and increases their common operating picture;
- emphasizes the importance of information flows, clarifies the nature and characteristics of the entities, and the way those entities interact;
- underlines the importance of synergy, dynamically reallocated responsibility, and successful adaptation;

- allows the entities to work in concert to help them act as nodes that process information by passing it to another;
- contrasts legacy systems that reflect bureaucratic stove-pipe thinking and parochial organizational interests;
- replaces redundant and non-interoperable military systems by fostering investments for new information technology;
- provides for an improved understanding of the internal dynamics of military operations to gain a better understanding of the situation at all levels;
- increases speed of command, contributes to higher operational tempo, greater lethality and better survivability;
- emphasizes a horizontal focus that fosters decentralized command, freedom of action, and bottom-up initiative;
- displays adaptation in military operations as a process that is composed of small changes and features conflicting requirements;
- regards adaptation as a simple form of optimization and a simple form of a trial-and-error mechanism;
- emphasizes military operations as a novel and creative process that cannot be isolated from the environment’s constantly changing conditions;
- proposes operational adaptation to be influenced also by the environment that displays an extended web of conflicting constraints;
- sets with the two baseline cases (NK landscape with $K = 0$ and $K = N - 1$) clear limitations for the power adaptation;
- displays adaptation as a search process that features both local and global characteristics and points to the necessity for information and innovation;
- suggests that adaptation in military operations is most successful when it correlates with the characteristics of the environment;
- emphasizes military operations as a co-evolutionary process in which increasing the number of conflicting constraints internally can result in better adaptation;
- makes clear that despite their strive for order and equilibrium military organizations need to tolerate messiness and disorder in operations;
- emphasize the need to make the shift from the traditional plan-and-execute approach toward learning and adaptation;
- makes clear that interaction with the enemy (NKC landscapes) produces feedback effects that have emergent characteristics;
- highlights that feedback effects produced in the co-evolutionary process with the enemy has clear limitations in terms of planning and execution.

References

[1] ALBERTS, D. S., GARTSKA, J. J., STEIN, F. P.: *Network Centric Warfare: Developing and Leveraging Information Superiority.* 2nd Ed. Washington, D.C.: CCRP Publication Series, 2000.

[2] ALCHIAN, A. A.: Uncertainty, Evolution, and Economic Theory. *The Journal of Political Economy*, 3 (1950), 211–221. DOI: https://doi.org/10.1086/256940

[3] *Allied Joint Doctrine AJP-01(D).* December 2010.

[4] *Allied Joint Doctrine for Land Operations AJP-3.2.* October 2009.

[5] *Allied Joint Doctrine for the Conduct of Operations, AJP-3(B).* March 2011.

[6] AMITABH, A.: The Shifting Balance Theory of Evolution. *Resonance*, 12 (1999), 66–75.

[7] ARTHUR, B. W.: Positive Feedbacks in the Economy. *Scientific American*, 2 (1990), 92–99.

[8] BECKERMAN, L. P.: *The Non-Linear Dynamics of War, Science and Application Corporation.* www.belisarius.com/modern_business_strategy/beckerman/non_linear.htm (Downloaded: 04 07 2003)

[9] CAPRA, F.: *The Web of Life. A New Scientific Understanding of Living Systems.* New York: A Division of Random House, Inc., 1997.

[10] COVENEY, P., HIGHFIELD, R.: *Frontiers of Complexity. The Search for Order in a Chaotic World.* New York: Ballantine Books, 1995. DOI: https://doi.org/10.1177/027046769701700418

[11] FRANZ, S., PELITI, L.: Error threshold in simple landscapes. *Journal of Physics A: Mathematical and General*, 30 13 (1996), 4481–4487. DOI: https://doi.org/10.1088/0305-4470/30/13/006

[12] GLENN, K.: *"Complex" Targeting: A Complexity-Based Theory of Targeting and its Application to Radical Islamic Terrorism.* Montgomery: School of Advanced Airpower Studies, Air University Maxwell AFB, 2002.

[13] HAIG Zs., KOVÁCS L.: New way of terrorism: Internet and cyberterrorism. *AARMS*, 6 4 (2007), 659–671.

[14] HAIG Zs.: Network-Centric Warfare and Sensor Fusion. *AARMS*, 2 2 (2003), 245–256.

[15] HORDIJK, W., KAUFFMAN, S. A.: *Correlation Analysis of Coupled Fitness Landscapes.* www.lirmm.fr/mab/IMG/pdf/HK-COMPLEX-05.pdf (Downloaded: 12 12 2006)

[16] JOBBÁGY Z.: On Adaptation in Military Operations: Tinkering and Bottom-Up Perspectives. *AARMS*, 13 3 (2014), 389–396.

[17] KAMP, C., BORNHOLDT, S.: Coevolution of Quasispecies: B-Cell Mutation Rates Maximize Viral Error Catastrophes. *Physical Review Letters*, 88 6 (2001), 068104-1-4.

[18] KAUFMANN, S. A., LEVIN, S.: Towards a General Theory of Adaptive Walks on Rugged Landscapes. *Journal of Theoretical Biology*, 128 (1987), 12–15.

[19] KAUFMANN, S. A., JOHNSEN, S.: Co-Evolution to the Edge of Chaos: Coupled Fitness Landscapes, Poised States, and Co-Evolutionary Avalanches. In. LANGTON, C. G., TAYLOR, C., FARMER, J. D., RASMUSSEN, S.: *Artificial Life II, SFI Studies in the Sciences of Complexity*, 325–369. Boston: Addison-Wesley Publishing Company, 1991.

[20] KAUFMANN, S. A.: *At Home in the Universe. The Search for Laws of Self-Organisation and Complexity.* Oxford: Oxford University Press, 1995.

[21] KAUFMANN, S. A.: Principles of Adaptation in Complex Systems. In. STEIN, D. L. (Ed.): *Lectures in the Sciences of Complexity.* Boston: Addison-Wesley Publishing Company, 1989.

[22] KAUFMANN, S. A.: *The Origins of Order: Self-Organization and Selection in Evolution.* Oxford: Oxford University Press, 1992.

[23] McKELVEY, B.: Avoiding Complexity Catastrophe in Coevolutionary Pockets: Strategies for Rugged Landscapes. *Organization Science*, 10 3 (1999), 301–302.

[24] Office of Force Transformation: *The Implementation of Network-Centric Warfare.* Washington, D.C.: OFT, 2005.

[25] OSINGA, F.: *Science, Strategy and War. The Strategic Theory of John Boyd.* Delft: Eburon Academic Publishers, 2005.

[26] ROSÉ, H.: Complexity of Fitness Landscapes. In. *International Conference on Complex Systems*, 21–26. Noshua, 09 1997. (Proceeding) www.first.fraunhofer.de/publikationen?prID=1167&von=mitarbeiter (Downloaded: 11 08 2005)

[27] UJHÁZY L.: Some Thoughts on the Command Structure of EUFOR Operation ALTHEA. *Műszaki Katonai Közlöny (Online)*, 22 Special Issue (2013), 6–16.

[28] WHITTAKER, D.: *Evolution 101: Fitness Landscapes.* http://beacon-center.org/blog/2012/10/08/evolution-101-fitness-landscapes/ (Downloaded: 05 04 2016)

[29] WILSON, C.: *Network Centric Warfare: Background and Oversight Issues for Congress.* Washington, D.C.: Library of Congress, 2004.

[30] WRIGHT, S.: *The Roles of Mutation, Inbreeding, Crossbreeding and Selection in Evolution.* Proceedings of the Sixth International Congress of Genetics, 1932.

[31] WRIGHT, S.: *"Surfaces" of Selective Value.* Proceedings of the National Academy of Sciences USA, 1967. DOI: https://doi.org/10.1073/pnas.58.1.165

[32] WRIGHT, S.: Surfaces of Selective Value Revisited. *The American Naturalist*, 131 1 (1988), 115–116. DOI: https://doi.org/10.1086/284777