Soldiers assigned to Company B, 2nd Battalion, 70th Armor Regiment, 2nd Armored Brigade Combat Team, 1st Infantry Division, supporting the 4th Infantry Division, fire an M1A2 Abrams tank 15 May 2023 during a combined arms live-fire exercise as part of the Anakonda 23 Polish-led exercise at Nowa Deba, Poland. (Photo by Sgt. 1st Class Theresa Gualdarama, U.S. Army)

The Convergence Algorithm

Leveraging Artificial Intelligence to Enable Multidomain Operations

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Known as the "Opera Game," the 1858 chess match played during an opera between Paul Morphy (considered the greatest chess player of his generation) and two opponents—German nobleman Karl II, Duke of Brunswick, and French aristocrat Comte Isouard de Vauvenargues—is arguably the most famous match in history.[1] It is a prime example of attacking chess that conveys the importance of development, time, sacrifice, and tactical combinations. Although multidomain operations (MDO) are clearly more complex than chess, the stochastic nature of chess can provide a framework to consider and analyze this concept. The integration of artificial intelligence (AI) into the game of chess has revealed new strategies and evolved the game to new heights. The impact AI has had in games of strategy reveals possibilities for its integration into MDO, particularly to the concept of *convergence*. MDO requires commanders to combine arms through the employment of joint and Army capabilities across five domains and three dimensions—a challenge of the highest regard.

The Analogical Reasoning Framework: Chess and MDO

The modern rules of chess emerged in Italy and Spain by the dawn of the fifteenth century.[2] The game is divided in three distinct phases: the opening, middlegame, and endgame. In the opening, players develop their pieces, get their king to safety, and attempt to control the center. In the middlegame, players attack and defend, gaining advantages through tactical combinations. The endgame is when players seize positions of advantage and capture the king. MDO (particularly the concept of convergence), during a set period of conflict, can be analyzed in these phases. The challenge in executing MDO is not in the conceptual but rather the practical. Understanding the problem set is not difficult; however, operationalizing it in its fullest capacity is aspirational. Field Manual (FM) 3-0, *Operations*, defines convergence as "an outcome created by the concerted employment of capabilities from multiple domains and echelons against combinations of decisive points in any domain to create effects against a system, formation, decision maker, or in a specific geographic area."[3] The convergence "chess board" runs across five domains—space, cyberspace, maritime, air, and land—and three dimensions—physical, information, and human. As depicted in table 1, convergence can be described in phases like the phases of a chess match.

Commanders are challenged to combine joint and Army capabilities across multiple domains and dimensions to achieve desired effects. A commander must position capabilities across five domains and three dimensions, receive actionable real-time information, determine optimal synchronization and coordination combinations, and mass effects in time and space against a highly intelligent opponent. Conceptually, there are fifteen intersections, or spheres, among these domains and dimensions (see table 2).

Consider that there is one capability in each sphere. The mathematical formula for the number of combinations is shown in figure 1.

Conceptually, if a commander has fifteen capabilities ($n = 15$) available and wants to mass two of these capabilities ($r = 2$), there are 105 combinations one can consider. If a commander has one capability in each of these fifteen spheres ($n = 15$) and wants to mass three of these capabilities ($r = 3$), there are 455 combinations one can consider. If the commander desires to mass three capabilities and the order in which these are applied matters, we no longer consider combinations but permutations; in this case, there are 2,730 permutations for the commander to consider. This is only considering one capability present per sphere. The questions then present themselves: Does the commander have the tools available to process all these potential combinations and make the optimal choice in a time-constrained environment? Does the commander have the capacity to analyze anywhere near 2,730 permutations and select the best course of action?

FM 3-0 states that the degree to which a formation achieves convergence

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Table 1. Phases of Convergence

The Opening	Middlegame	Endgame
Convergence Integration Positioning assets across the five domains and three dimensions in time and space; this requires an understanding of positioning, projection, and geometry.	Convergence Synchronization Each capability has time implications; each capability will require different periods of time to achieve an effect; combinations of capabilities within the domains and dimensions can gain positions of relative advantage.	Convergence Closure Consolidating advantages; reaching the desired end state; completed objective.

(Table by author)

Table 2. Combination Spheres

Space/Physical	Air/Physical	Land/Physical	Maritime/Physical	Cyberspace/Physical
Space/Information	Air/Information	Land/Information	Maritime/Information	Cyberspace/Information
Space/Human	Air/Human	Land/Human	Maritime/Human	Cyberspace/Human

(Table by author)

in an operation depends on how well leaders can do the following:

- Develop an understanding of the enemy system, its capabilities, requirements, decision processes, and vulnerabilities through effective surveillance that provides mixed, redundant, and overlapping coverage.
- Determine the desired overall effect or opportunity and the individual effects and objectives that precipitate the opportunity.
- Integrate Army and joint capabilities at the echelons where they are most effective.
- Consider all domains and redundant methods of attack to increase the probability of success.
- Synchronize the employment of each capability and echelon to generate simultaneous, sequential, and enduring effects against the enemy system.
- Assess the individual effects and the probability that the desired overall effect has been achieved. Commanders prepare to re-attack or adapt a course of action if the desired effect is not achieved, or if other opportunities emerge.
- Assume risk and rapidly exploit the opportunities convergence provides.[4]

$$nCr = \frac{n!}{r!(n-r)!}$$

nCr = # of capability combinations
n = # of capabilities available to the CDR
r = # of capabilities the CDR desires to mass

(Figure by author)

Figure 1. Formula for Capability Combinations

4. Dxe5 Bxf3

5. Qxf3 dxe5

(Figure courtesy of Wikimedia Commons)

Figure 2. The Opening

Convergence should not be discovery learning for commanders. Commanders, based on their experience and warfighting framework, have concepts on how they like to approach operations. Like chess, they will have attack and defensive strategies they are inclined to favor, study, and implement. The advent of AI can assist both in the planning and execution phases by providing strategies at echelon and near-real-time analysis to increase the probabilities for success. In the planning phase, commanders can use AI to explore capability combinations against certain enemy parameters and discover new tactics and strategies or reaffirm their preferences. In the execution phase, AI can assist in processing/filtering information and providing recommendations for convergence.

Artificial Intelligence: Self-Learning Algorithms

AlphaGo, an AI program created by the Google DeepMind team, made headlines when it defeated then world champion (human) Lee So Dol in the game of Go.[5] The game of Go has 10170 moves, which is three hundred times more than chess. In 2018, AlphaZero defeated AlphaGo one hundred games to zero. The significance lies in the fact that AlphaZero trained itself to play Go from scratch in just three days and soundly defeated AlphaGo. The only input AlphaZero received was the basic rules of the game.[6] Given basic rules with clear parameters, AI algorithms can develop tactics and strategies without human input. In theory, one can develop an AI program to play a game that involves capabilities within the fifteen spheres. The AI program could discover optimal combinations or permutations to mass capabilities in the most effective ways. If one assumes that it takes ten thousand hours to become proficient in chess, do commanders have the repetitions needed to become MDO experts? The application of AI in MDO can provide these repetitions during planning and preparatory phases and provide recommendations during operations.

The Opening: Convergence Integration

According to FM 3-0, "Integration is the arrangement of military forces and their actions to create a force that operates by engaging as a whole."[7] This understanding of capability placement, timing, and condition setting is crucial for MDO. In the "Opera Game," Morphy, playing white, opened the game with pawn to e4. The subsequent opening sequence was as follows: (1) e4 e5, (2) Nf3 d6 (the opponents played the Philidor's Defense), (3) d4 Bg4, (4) dxe5 Bxf3, (5) Qxf3 dxe5, (6) Bc4 Nf6, and (7) Qb3 Qe7 (see figure 2).

Here are the lessons we can draw from the opening. First, Morphy immediately threatens with move no. 5, Qxf3, presenting a checkmate scenario with a

6. Bc4 Nf6

7. Qb3 Qe7

(Figure courtesy of Wikimedia Commons)

Figure 3. The Opening (continued)

next move of Bc4. Even prior to move no. 5, Morphy places his pieces in positions of advantage that threaten unguarded pawns. The concept of "danger levels" is a common theme in chess as the player places attacking pressure to every opponent's weakness with an understanding that even a pawn advantage tilts the odds to their favor down the road.[8] The key takeaway for convergence is understanding one's ability to place immediate pressure on the enemy through capability placement. Second, Morphy's unorthodox move of moving the queen a second time during the opening (move no. 7, Qb3) immediately presents another checkmate scenario (see figure 3). Although most likely not played in the modern game, he decided (based on his opponent's chess acumen) that immediate mate pressure was the best course of action. This move forced the opponents to respond with Qe7 that blocked in the black f8 bishop, making it ineffective. Applying this to MDO, are there capability placements in the opening that immediately make the enemy's application of a certain capability combat ineffective or provide enough friction where significant time, resources, and energy must be spent to deploy the capability?

MDO concept of convergence challenges commanders to orient integrating parts of the force to achieve unity of purpose and unity of effort. According to FM 3-0, the commander has multiple intellectual tools to facilitate this integration: targeting processes, mission analysis, nesting task and purpose by echelon, and engagement area development.[9]

AI recommendation #1. *Create an AI-supported intellectual tool that allows commanders to explore, learn, and understand capability employment*. The commander can then decide which conditions they prefer to set based on their personality, experience, and AI-enhanced wargaming. The utilization of AI to study capability emplacement and initial condition setting can greatly enhance the initial moves commanders make during operations to increase their chances for success. Chess professionals all have openings that they favor and have strategies to answer or combat opponent responses. Commanders can have capabilities within the MDO construct that they favor, and they can become experts in the application of these effects. Based on the lessons learned from the opening of the "Opera Game," the initial AI study can be focused on the following questions:

- Which capabilities, by sphere, place immediate pressure on enemy assets? Which capabilities can target initial enemy weaknesses in their structure?
- Which capabilities, by sphere, block key enemy capabilities through its initial positioning? Does a capability in one sphere, automatically negate or mitigate and enemy capability in another sphere?
- Which initial capability emplacements provides the greatest threat to the enemy? Are there any

8. Nc3 c6

9. Bg5 b5

10. Nxb5! cxb5

(Figure courtesy of Wikimedia Commons)

Figure 4. The Middlegame

that automatically threaten the enemy's ability to win (checkmate)?

The Middlegame: Convergence Synchronization

Once leaders have integrated the right capabilities, they must synchronize their employment and effects. FM 3-0 defines synchronization as "the arrangement of military actions in time, space and purpose to produce maximum relative combat power at a decisive place and time."[10] Factors that enable commanders to determine when to initiate employment of a capability and how to adapt to changes in the operational environment during execution include the following:

- How the individual effects complement each other over time.
- The time it takes each capability or formation to generate its individual effects from the start of employment.
- Whether each individual effect is enduring, simultaneous or sequential.[11]

Furthermore, FM 3-0 states that convergence is most effective when its effects accrue and create a cycle of expanding opportunity. Employing multiple and redundant methods of attack increases the probability of success by avoiding dependence on a single method. Success causes enemy forces to react and activate more of their capabilities, creating another opportunity in one or more domains.[12]

The middlegame is where commanders can gain positions of advantage through a series of wins at decisive points. There are many applicable concepts from the "Opera Game" that can be applied to the convergence middlegame. The game continues with (8) Nc3 c6, (9) Bg5 b5, (10) Nxb5! cxb5, (11) Bxb5+ Nbd7, and (12) 0-0-0 Rd8 (see figures 4 and 5).

The ability to maintain flexibility with Bg5 on move no. 9 proves to be critical. It develops all of white's capabilities, showing tactical patience, while maintaining the ability to castle on either side. It also pins the black night on f6, which now makes both the opponent's bishop on f8 and knight on f6 ineffective. Furthermore, understanding it's in a position of weakness, it forces the enemy to initiate an attack early (seen by black's pawn move to b5). The combination of the pins on the knights and the open file for white's rook will lead to black's defeat.

AI recommendation #2. *Create an AI algorithm that provides recommendations for capability effects to the commander*. Whether the data is pulled from sensors (ideal, although there is inherent risk of data hacks) or manual input, AI can help filter information and provide recommendations on how to provide multiple dilemmas to the enemy. If there are 2,730 permutations a commander must consider when converging capabilities, AI can provide recommendations for "best moves." Based on positioning of capabilities and enemy assessments, AI can help facilitate commander decisions during an operation; in essence, the AI program becomes an additional staff member that assists the commander with decision-making. It can assist in the targeting process, but more importantly, it

11. Bxb5+ Nbd7

12. 0-0-0 Rd8

(Figure courtesy of Wikimedia Commons)

Figure 5. The Middlegame (continued)

13. Rxd7 Rxd7

14. Rd1 Qe6

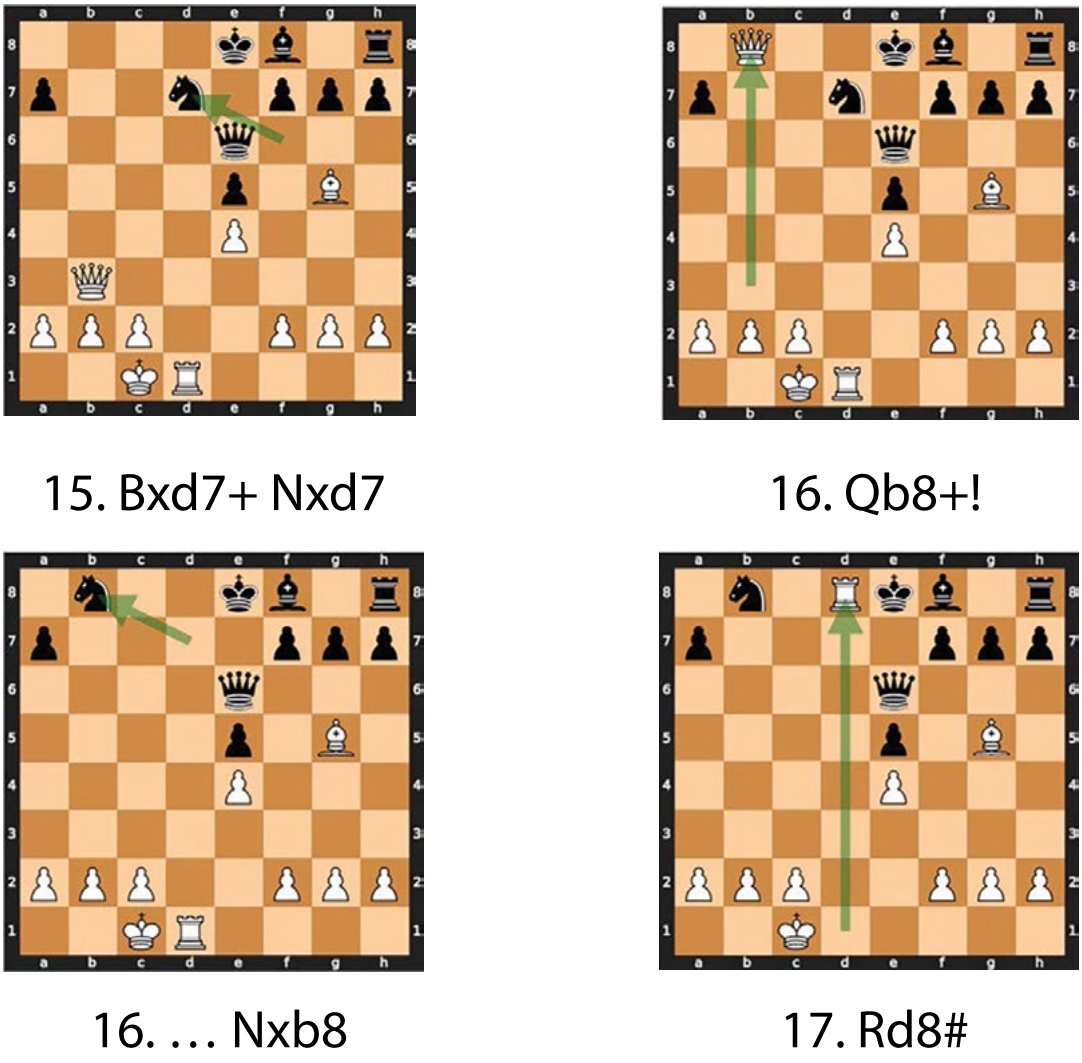
(Figure cour tesy of Wikimedia Commons)

Figure 6. The Middlegame (continued)

can provide real-time recommendations for the execution of the kill chain.

The most powerful concept in Morphy's middlegame is the concept of sacrifice. Instead of retreating the bishop to d3 after the opponent's move of pawn to b5 (move no. 9), Morphy takes the pawn with Nxb5! (move no. 10), sacrificing his knight but giving him a position of advantage. Instead of retreating, Morphy decides to sacrifice to maintain tempo and attack pressure. At this point in the game, although is down in material, Morphy is winning on the utility of his pieces. Morphy has four pieces (2xbishops, 1xrook, and 1xqueen) that he can utilize to attack, while black is cocooned around its king. There are plenty of options after black rook to d8. A common chess concept is the idea of forcing moves that makes the opponent react in a disadvantageous way. Primary forcing moves include checks and captures.

The middlegame continued with (13) Rxd7 Rxd7 and (14) Rd1 Qe6 (see figure 6). It is interesting to note that on move no. 13, takes with Rxd7 instead of his g5 bishop taking knight f6. After the black takes with Rxd7, the lesser powerful white bishop has made the



(Figure courtesy of Wikimedia Commons)

Figure 7. The Endgame

black rook ineffective as it is pinned in place to protect the king.

The closest concept in MDO to sacrifice is deception. Joint Publication 3-13.4, *Military Deception*, defines military deception as "actions executed to deliberately mislead adversary military, paramilitary, or violent extremist organization decision makers, thereby causing the adversary to take specific actions (or inactions) that will contribute to the accomplishment of the friendly mission."[13] FM 3-0 states that deception "contributes to creating multiple dilemmas," uncertainty, and slow enemy decisions.[14] The word "sacrifice" is not found in FM 3-0. In chess, a sacrifice is a move that gives up a piece with the objective of gaining tactical or positional compensation in other forms. A sacrifice could also be a deliberate exchange of a chess piece of higher value for an opponent's piece of lower value. This was clearly demonstrated by Morphy in move no 10 (Nxb5!). There are subtle differences in the concepts of military deception and sacrifice. Joint Publication 3-13.4 clearly states that the point of deception is to mislead decision-makers. This is primarily done through informational advantage by giving the enemy decision-maker multiple dilemmas or focusing its attention on one plan of attack while executing another. Sacrifice, on the other hand, is the deliberate destruction of a capability for the sake of advantage. Both parties know that the capability is important. As war is

a human endeavor, the idea of sacrificing human lives for positional advantage is difficult to fathom. Additionally, the idea of purposefully destroying equipment, platforms, or other resources for positional advantage is not advised. However, with the advent of unmanned systems and the increased difficulty of achieving surprise, the idea of sacrifice must be explored in MDO.

AI recommendation #3. *Create an AI-enabled intellectual tool that explores the concept of sacrifice during convergence operations.* What is the capability equivalent on the battlefield to a queen chess piece? Bishop or knight? The concept of sacrifice must be explored in MDO. With the advent of increased sensors, surprise and deception will become increasingly difficult. In order to provide multiple dilemmas to enemy decision-makers and inflict uncertainty, the concept of sacrifice must be introduced. Are there capability combinations or permutations based on the concept of sacrifice with concrete follow-up lines of attack that can produce positions of advantage?

The Endgame: Convergence Closure

For the sake of discussion, this article defines victory as the closure of an objective. After black's move of queen to e6, one of the most iconic combinations in chess history ensues: (15) Bxd7+ Nxd7, (16) Qb8+! Nxb8, and (17) Rd8# (see figure 7). Morphy's move Qb8, a queen sacrifice, forces his opponent to take with Nxb8, creating a checkmate with Rd8.

The "Opera Game" has stood the test of time because of this amazing sequence. Morphy's application of the basic principles of chess is now taught in every chess club. Uncertainty and changing conditions will be prevalent in future warfare. However, the use of AI in MDO can assist in analytics, filtering data, and providing recommendations. MDO presents an incredible challenge for commanders to apply capabilities across domains and dimensions. The integration of AI can streamline operations and assist in executing convergence operations. ■

Notes

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