Active Inference in Modeling Conflict

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A B S T R A C T

In this paper, we integrate conflict studies with Active Inference, a developing framework which provides an integrative and systems-level perspective on cognition and behavior. This formalization, the Active Inference Conflict (AIC) model, situates conflict in terms of a multiscale process of communication, trust, and relationship management enacted by interacting entities. The AIC model helps capture and extend the insights of previous models applied to aspects of conflict and war, such as OODA loops (observe-orient-decide-act), the generations of warfare model, and the Rumsfeld Matrix. The AIC model aids in the analysis of pertinent aspects of modern conflict, such as cyber, psychological, biological, informational, financial, and ideological conflict, that are not amenable to coherent or consistent analysis using traditional models of human conflict. AIC is demonstrated to be of use in both monitoring and studying conflict, as well as in designing systems intended to facilitate controlled or managed conflict in scenarios characterized by business, operations, legal, technical, and social (BOLTS) components. Insights and implications from qualitative use are used as a foundation for offering recommendations for future research and social systems design.

Contents

Introduction

Human-scale conflict constituting "war" in its various incarnations has been studied from a variety of perspectives, including, but not limited to, statistical, ethnographic, logistical, sociological, legal, and philosophical frameworks. However, with the notable advances made in the capabilities of weapons systems and the introduction of global defense pacts made in the 20th Century, the risk calculus of triggering an official declaration of war has changed. The resulting dramatic increase in costs and displacements of kinetic war compels state and non-state actors to pursue their conflicting interests through alternative means. The resulting complex threat surfaces are not always well-described or modeled by existing frameworks for conflict (which usually have a military or domain-specific focus), which further amplifies risk even in tractable scenarios [1]. In this paper, we make use of Active Inference (ActInf), a framework which provides an integrative and systems-level perspective on cognition and behavior, to propose a new formalization of conflict in terms of a multiscale process of communication, trust, and relationship management enacted by interacting entities. This application of ActInf to questions of conflict, called the Active Inference Conflict (AIC) Model, extends recent work on Active Inference and human-robot trust system [2], cyberphysical systems [3], and societies as cognitive agents [4] to the domains of human conflict in expanding shared information environments.

The AIC model is grounded in several previous frameworks for action and conflict from military science, including the generations of warfare (GW) model, observe-orient-decide-act (OODA) loop, and the Rumsfeld Matrix. Additionally, the AIC extends these models to better describe, frame, and offer recommendations for the current and projected future nature of war and other forms of conflict, which is increasingly non-kinetic. The AIC model is intended to offer generalization beyond conflict itself, helping not just to describe nation-state conflicts, but also complex multi-scale conflicts involving individuals and communities in contexts characterized by their business, operations, legal, technical, and social (BOLTS) components. The essential historical insights gleaned from the GW model offer a useful foundation from which this paper's ActInf framing can be understood, and establishes a new chapter in the GW model's framing of the timeless yet ever-changing aspects of human conflict.

In this paper, we begin by offering a survey of past qualitative and quantitative models of conflict and the insights they provide. After this survey, we consider the essential features of the reviewed models, and highlight the need for models which offer more interoperability and generalization in order to stay relevant in the face of an ever-changing expression of conflict. We then offer a primer on the ActInf framework in terms of core terms and features. Following this description, we explore how the AIC model can extend previous models such as OODA and GW while still capturing their essential insights. In this exploration, special attention is given to how the AIC model relates to the Rumsfeld Matrix, and what this relationship may reveal about Rumsfeld's oft-neglected quadrant, the "unknown-knowns". We suggest that management of relationship and conflict with a prioritization of the often neglected "unknown-knowns" quadrant provides a pathway to multi-scale risk mitigation and leverage points for human interactions online. In summary, AIC is revealed to be more than just a powerful new model of war and conflict. AIC framing also invites consideration of how humans can harness the destructive energies of prior conflagrations of conflict at all levels into constructive systems that can perform useful "work" by converting the underlying information differentials of conflict into new forms of value the benefits of which can be distributed in managed ways to maintain the generative AIC apparatus (analogous to how an engine extracts useful work from heat gradients). The AIC model is an applied Active Inference approach for mitigating risk and enhancing value from the ever-increasing informational component of modern interactions. Finally, we conclude with a summary of insights and recommendations for future research and application.

Previous Models of Military Conflict

Being of obvious, existential importance to state sovereigns, war and conflict has been a subject of interest to historians, scholars, and artists since the birth of civilization. As evidenced by the hundreds of thousands of books written about the American Civil War alone [5], and a history of scholarship which extends back to some of the earliest books ever written [6], the subject of war has an unfathomably large literary and oral corpus. The vastness of the body of literature on war suggests that even if only a small fraction of the corpus is dedicated to generalizing and modeling war (the rest being historical documentation and analysis of instances of war), it would still constitute a significant body of literature in itself. For purposes of this article, and in the interest of presenting a referenceable review of past models and generalizations of war (while acknowledging that it is an impossible task to describe them all), we present past models of war and conflict in the following categories:

- Narrative Models
- Quantitative Models
- Conflict Information Flows and Decision-Making Models

Narrative Models of Conflict

The term narrative model is used here to describe formal and semiformal models of conflict which were intended to provide guidance and actionable insight to strategic commanders through the use of qualitative, non-technical methods such as storytelling, aphorism, historical example, parables, and slogans.

Collections of Heuristics

The earliest attempts to create and compile informative representations of conflict and war do not offer integrated models in a modern sense, instead they offer collections of axioms, idioms, recipes, rules, principles, and patterns - rules of thumb, based on insights drawn from the experiences of the offeror. One of the oldest examples of these collections is Flavius Vegetius Renatus' *Epitome Rei Militaris*, or "Epitome of Military Science" [7]. It is one of the few surviving Roman-era works on military science and art from its time and was routinely used during the Middle Ages to augment and inform writings on warfare [7].

Though much of its content deals with specific questions about routine situations in which Roman commanders may have found themselves, such as in what kind of places camps should be built or how a suitable place might be chosen for battle, a section of the *Epitome* titled "General Rules of Warfare" also supplies "basic principles in an unspecific form which could be adapted to serve a great variety of military situations" [7]. These include:

- "It is difficult to beat someone who can form a true estimate of his own and the enemy's forces"
- "He who spends more time watching in outposts and puts more effort into training soldiers, will be less subject to danger"
- "Never lead forth a soldier to a general engagement except when you see that he expects victory"

[7]

Examples from other well-known collections of timeless heuristics relating to war throughout history and across cultures provide similar sorts of insights, such as the following:

From Sun Tzu's *Art of War*

- "A skillful soldier does not raise a second levy"
- "In order to kill the enemy, our men must be roused to anger"
- "If equally matched, we can offer battle; if slightly inferior in numbers, we can avoid the enemy; if quite unequal in every way, we can flee"
- "If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle."

[6]

From Moltke's *Art of War*

- "Excessive extension of the front brings danger of a breakthrough."
- "Engagements in forests last for a long time"
- "One must immediately prepare supporting points captured in an engagement for defense in order to thwart the enemy's efforts to recapture them"

[8]

Countless other works elaborating the art of war, provide detailed rules, patterns, and axioms of human armed conflict, such as those by Mao Tse-tung, Machiavelli, and Sun Bin [9–11]. When these collections are viewed as part of a common ensemble of axioms, bundled together, they may be argued to constitute nascent narrative models of warfare, helping generals, real or armchair, better understand the complex and challenging scenarios of conflict they are encountering, simulating, or studying.

Also included within these collections of heuristics are later works from the 1800's, such as Antoine-Henri Jomini's *Art of War* [12] and Carl von Clausewitz's *On War* [13]. While both these books provide their fair share of axioms and rules like earlier works, they also move beyond simple heuristics in an attempt to capture more generalizable models and frameworks for understanding and describing the underlying causes and motivations of warfare as an aid to formulating strategy and tactics for engagement. These developments signal an increasing awareness of the behaviors of war as part of the larger set of behaviors associated with human interactions and the conflict that they generate.

For example, Jomini provides the following frameworks for understanding the nature of conflict, moving beyond a mere description of the practices of war to its underlying contexts of conflict to encourage an enhancement of the understanding of how best to engage [12]. Several of Jomini's classification schemes are excerpted here:

Eight types of motivations for states to engage in warfare:

- "To reclaim rights or defend them...
- to protect and maintain the great interests of the state...
- To uphold neighboring states…
- To fulfill obligations…
- To propagate political or religious theories…
- To increase the influence and power of the state…
- To defend the threatened independence of the state…
- To avenge insulted honor…
- From a mania for conquest."

Two kinds of international Intervention:

- "Intervention in the internal affairs of neighboring states…
- intervention in external relations"

And four kinds of war which result from such an intervention:

- "Where the intervention is merely auxiliary, and with a force specified by former treaties…
- where the intervention is to uphold a feeble neighbor by defending his territory, thus shifting the scene of war to other soil…
- A state interferes as a principal party when near the theater of war, - which supposes the case of a coalition of several powers against one…

- a state interferes either in a struggle already in progress, or interferes before declaration of war"

[12]

Clausewitz offers similar context-enhancing frameworks for war, but goes farther, arguing that even more generalizable analysis is needed and that those who "never rise above anecdote" will "never get down to the general factors that govern the matter… indeed they will consider a philosophy that encompasses the general run of cases as a mere dream" [13]. Clausewitz recognized that theory informs practice, and that awareness of context and causation of war as a form of human conflict provides valuable insights into the strategies and tactics for its effective engagement. Clausewitz was well aware of the limitations of prior descriptions of warfare, and made explicit the benefits of more comprehensive and multi-dimensional models that situated warfare among other forms of human conflict.

Trinity of War

Carl von Clausewitz, in pursuit of deeper generalizations, proposed what may be the earliest framework for describing warfare that is recognizable, on its face, as a generalizable model. He suggests that war is an extension of state policy, and as such, it is ruled by a "paradoxical trinity" of forces [13]. His description of this trinity is excerpted here:

> "The first of these three aspects mainly concerns the people; the second the commander and his army; the third the government. The passions that are to be kindled in war must already be inherent in the people; the scope which the play of courage and talent will enjoy in the realm of probability and chance depends on the particular character of the commander and the army; but the political aims are the business of government alone.
>
> These three tendencies are like three different codes of law, deep-rooted in their subject and yet variable in their relationship to one another. A theory that ignores any one of them or seeks to fix an arbitrary relationship between them would conflict with reality to such an extent that for this reason alone it would be totally useless…
>
> Our task therefore is to develop a theory that maintains a balance between these three tendencies, like an object suspended between three magnets."
>
> [13]

The trinity of war model captures the multi-node complexity that yields the nonlinear aspects of what motivates and channels the expression of those motivations in kinetic conflict. Further, it helps described certain non-combat oriented insights regarding conflict, such as war being conceptualized as an extension of political conflict [14], that it is motivated by state interest or *raison d'état*, and is moderated by a state's ability to channel the motivations of both civilians and military personnel toward conflict [15].

What may be the most important aspect of Clausewitz's model however, is that it was far ahead of its time in framing war as something akin to a complex system rather than a mechanistic process, in which a trinity of "chance, uncertainty, and friction… will make anticipation of even the first-order consequences of military action highly conjectural" [16,17].

Military Revolutions Model

Among the various categories of qualitative planning and descriptive models which have come into (and gone out of) fashion within the United States military was a collection of models centered on "revolutions in military affairs", which grew to "increasing prominence in Washington's Byzantine budgetary and procurement struggles'' in the 1990s [18], and served to rhetorically bind together technical and modeling advances. Initially just a reference by Western historians and Soviet military theorists to the notion of key historical inflection points in which there were unforeseeable, "fundamental [and] systemic" changes in the expression of war, the "military revolutions model" was picked up by the US defense community as a concept that was also considered valuable for doctrine and planning [18]. Since that time, numerous attempts have been made to model and chart these revolutions in order to help military leadership better understand their place both in history and in current affairs, and to help them plan for the future. Some examples of these models are surveyed below.

Krepinevich Model

The model presented by Krepinevich was one of the earlier attempts at formalization of the historical revolutions in military affairs. While the revolutions specifically noted by Krepinevich have been greatly modified or even abandoned in later models, his formalization of the elements underneath military revolutions has stayed relevant [18]. These elements were said to consist of technological change, systems development, operational innovation, and organizational adaptation [18,19]. The historical revolutions noted by Krepinevich, in chronological order, are as follows:

- Infantry Revolution
- Artillery Revolution
- Revolution of Sail and Shot
- Fortress Revolution
- Gunpowder Revolution
- Napoleonic Revolution
- Land warfare Revolution
- Naval Revolution
- Revolutions in Mechanization, Aviation, and Information
- Nuclear Revolution

[19]

Krepinevich's model is unique among the other historical revolution models for its focus on warfare alone. Notwithstanding the focus on war, he recognized that changes in technology, which are themselves generated by the larger social and historical context, affect the nature of engagement in war. In a sense, he saw technology as the vehicle through which large scale social and historical changes affect war. Among the more valuable insights he derives from this model is that technological innovation does not guarantee a revolution in military affairs - instead, these revolutions occur when states change their process, systems, and organization in order to incorporate those innovations [19].

Knox and Murray Model

Knox and Murray's take on the revolutions in military affairs model [20] was built from its predecessors, incorporating key elements from Krepinevich, which they considered "typical" and fundamental to models of this kind [18]. What sets Knox and Murray's model apart from its predecessors however, is three-fold. First, they explicitly included non-military systemic changes within the scope of revolutions in military affairs, such as those related to economies beyond the ability to supply armament. Second, they see each of the revolutions as reflecting, not just the innovations of its time, but also the novel combination and integration of the innovations and resulting changes of its predecessors. Third, they include two separate tracks of revolutions, seemingly inspired by Krepinevich's suggestion that the inflection points in expression of warfare were separable from the implementations and incorporations of technological innovations. One was termed "military revolutions", the other, "revolutions in military affairs", referring to abstract inflection points and revolutionary implementations, respectively [18]. A summary of their charting of revolutions is included here:

- Precursory, or "anticipatory" Revolutions in Military Affairs
    - The introduction of the longbow, gunpowder, and fortress architecture
- Military Revolution I: The Modernization of the State and its Military Institutions
    - Associated revolutions of military affairs:
        - Dutch, Swedish, and French tactical and organizational reforms
        - Britain's financial revolution
- Military Revolutions II and III: The French and Industrial Revolutions
    - Associated revolutions of military affairs:
        - Napoleonic warfare and the complete battlefield annihilation of the enemy's armed forces)
        - Transportation: railroads, steamships
        - Armament: combination of quick-firing small arms and artillery
        - Communications: telegraph

- The Fisher Revolution
    - The introduction of “all-big-gun” battleships
- Military Revolution IV: The First World War and its Irrevocable Combination of Preceding Revolutions
    - Associated revolutions of military affairs:
        - Combined Arms Tactics
        - Blitzkrieg Operations
        - Carrier, Submarine, and Amphibious Warfare
        - Radar and Signals Intelligence
- Military Revolution V: Nuclear Weapons and Ballistic Delivery Systems
    - Associated revolutions of military affairs:
        - Precision Reconnaissance and Strike
        - Stealth Systems
        - Increased Lethality of Conventional Munitions

[20]

Hoffman Model

Hoffman, a former US Marine Corps infantry Officer with 4 decades of experience as a national security analyst, offers one of the most recent models of military revolutions which expands on and challenges aspects of the Knox and Murray model [21]. Hoffman focuses on what comes after the five revolutions within the Knox and Murray model through the lens of the Clausewitz trinity, considering how human-machine teaming, the end of the “heroic age” of the military, and automated systems might affect various aspects of war, social stability, and public sentiment toward policy [21]. He expands the Knox and Murray model to seven revolutions, with a more explicit emphasis on non-violent phenomena, such as ideological extremism [21]. A summary of the Hoffman model of military revolutions (and their key features) is included here:

- Westphalian System
  - Revenue generation, banking and taxes, and the introduction of professional militaries
- French Revolution
  - National mobilization and levy en masse
- Industrial Revolution
  - Mass production, standardization, and large-scale economic exploitation
- World Wars
  - Combined arms, armored blitzkrieg, carriers, bombers, and jets
- Nuclear Revolution
  - Nuclear weapons and intercontinental ballistic missiles
- Information Revolution
  - Command and control, connectivity and global reach, imagery, and ideological levy en masse
- Autonomous Revolution
  - Autonomous weapons, swarms of robotic vehicles, self-organizing defense systems, big data analytics, and deep-learning systems.

[21]

Generations of Warfare Framework

In the late 1980s, William Lind and a collection of US Military officers from the US Army and Marine Corps presented what is now known as the "Generations of Warfare" (GW) framework in an article published in the Marine Corps *Gazette* [22]. It is notably similar to the military revolutions model both in terms of its intentions and structure. The GW framework is built on the notion of linear sequential development over time, marked by key inflection points driven by technology and ideas. The GW framework has arguably achieved broad use and has received a great deal of commentary and adaptation, for example the projection of a fifth generation of war (5GW) beyond the four initially described [23]. A summary of the initial conception of the four generations of warfare is provided here:

- First generation: Line and Column Tactics
    - Driven by technological changes
    - Operational Art practiced by individual commanders (e.g., Napoleon)
    - Reliance on indirect fire (e.g., artillery)
- Second generation: Fire and Movement
    - Driven primarily by technological changes, but also by ideological changes
    - Operational art practiced by high-ranking officers
    - Reliance on massed firepower, and manpower
- Third generation: Nonlinear Tactics
    - Driven primarily by ideological changes, but also technological changes
    - Operational art practiced by low-ranking officers (e.g., tank commanders)
    - Reliance on maneuvers and non-linear tactics
- Fourth generation: Whole of Society
    - Driven primarily by ideological changes
    - Operational art practiced in small-teams and in the gray zone between military and civilian
    - Reliance on gray zone warfare (e.g., psychological and informational operations, targeting a society's culture)

[22]

Gradients of Warfare

The "gradients" of warfare model (xGW) proposed by Daniel Abbott is a reimagining of the generations and revolutions models of framing changes in warfare [23]. Although the gradient and generation are often used interchangeably, the gradient model abandons chronological development (generations) and instead describes movement along a single finite, abstract axis, representing an arbitrary gradient of diffusion or concentration related to a particular conflict [23]. The gradients described by Abbott [23] are summarized below:

- The Zeroth Gradient
    - Genocide and all-of-society warfare (e.g., ant colonies, ethnic cleansings)
- The First Gradient
    - Physical concentration of resources (e.g., chimpanzee border patrols, medieval warfare)
    - Placing troops in the same place at the same time
- The Second Gradient
    - Concentration of effort (e.g., coordinated fire)
    - Directing effort toward the same place at the same time
- The Third Gradient
    - Coordination and concentration of operational art (e.g., blitzkrieg)
- The Fourth Gradient
    - Focus on "degrading the opponent into an earlier generation of warfare"
    - Decentralized gray zone conflict
- The Fifth Gradient
    - Coordination and concentration of ideology

[23]

Kohalyk's Projection of xGW

An interesting result of abandoning chronology as a primary axis and replacing it with axes related to abstract state features is that Abbot's gradients may be "projected" onto other models to yield additional insights from existing models. For example, Kohalyk, based on Abbott's assertions about the nature of the gradients, projects the gradients onto John Boyd's famous OODA (observe, orient, decide, act) loop (see Figure 1) [24,25]. This exercise demonstrates that Abbot's gradients can be repurposed, not just to describe levels of diffusion, but also the basis for that diffusion and the changes to that basis over time, providing a more stable view on the generations of warfare model that gradients were originally intended to replace [24]. This projection can be summarized as follows:

- The First Gradient
    - "Characterized by prioritizing the transition between decision and action"
- The Second Gradient
    - "Characterized by prioritizing the gap between orientation and decision"
- The Third Gradient
    - "Characterized by prioritizing the disruption of orientation"
- The Fourth Gradient
    - "Characterized by prioritizing the gap between observation and orientation"
- The Fifth Gradient
    - "Prioritization of the disruption of observation itself"

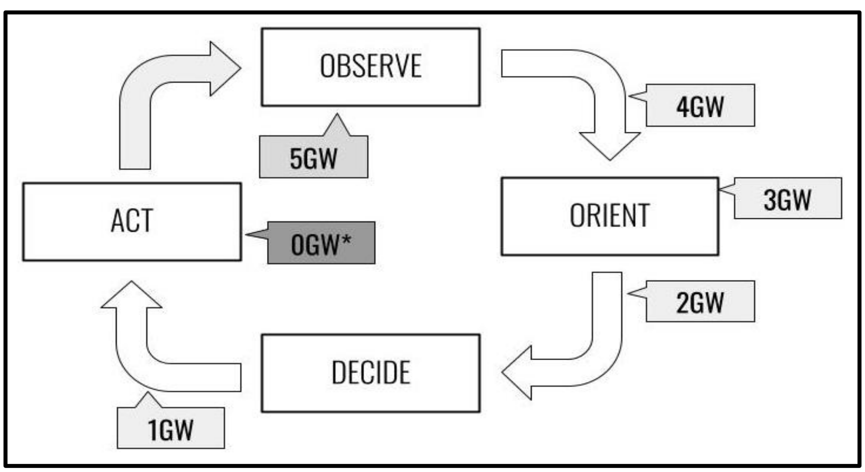

Figure 1. Abbott's Gradients of Warfare projected onto John Boyd's OODA loop. Adapted from [25]. 0GW not included in original figure.

Linn's Model of Strategic Narrative

Breaking rank from chronologically or technology driven models of war, Linn offers a heuristic model of approaches to modeling war and the narratives which accompany those approaches. He proposes three general, abstract narratives encoded into the theoretical groups which would hold them: guardians, heroes, and managers [26]. Guardians are those who model war primarily as a science that is "subject to laws and principles" which can offer the means to predict the consequences of specific policies. Heroes model war primarily as an art, dependent upon military genius, experience and training, morale, and discipline. The final group, managers, model war as a "logical outgrowth" of politics and economics, dependent on logistics, mobilization of resources, standardized and effective equipment, and the assignment of well-educated professionals.

Quantitative Models of Conflict

The term quantitative models of conflict is used here to describe the models of conflict which sit in clear separation from qualitative and narrative models, attempting to frame conflict in terms of formalized mathematics and computational structure. Several of these models are summarized here.

Lanchester Models

The Lanchester model is likely the earliest substantial quantitative model of warfare, being introduced in the early 1900s in the book *Aircraft in Warfare: The Dawn of the Fourth Arm* by Frederick Lanchester [27]. Lanchester introduced a series of quantitative rules, such as the N-squared law ("the measure of the total of fighting strength of a force will be the square of the sum of the square roots of the strengths of its individual units"), and differential equations to describe concepts like attritional dynamics and predict the likelihood of outcomes of engagements [27]. In addition, he used geometry to illustrate the resulting models of these equations in numerous examples across air, naval, and land warfare with consideration for various kinds of armament [27]. Though introduced in the early 20th Century, Lanchester models are still being adapted today to represent things such as force ratios and information importance in guerilla warfare and insurgencies [28] despite the model's shortcomings in describing real-world dynamics [29].

Fault Tree Analysis

Fault tree analysis was developed to decompose potential failure states of a system or operation into subevents to better understand potential for cascading failures [30]. Each of these subevents can be given probabilities and relationships with other events, allowing risk analysts to calculate the probability of compound events and specific outcomes [30,31]. Using fault tree analysis, conflicts can be modeled in terms of various system states and their likelihood to trigger undesired system states or cause cascading failures via complex threat surfaces [1].

Effects Based Operations

Effects Based Operations (EBO) planning, is a form of course of action planning for military operations which is characterized by its use of Bayesian graphical models ("Bayes nets") and models of complex systems [32]. While EBO is primarily a planning tool, it embraces a systems warfare approach by modeling an area of operations as a series of components which may be acted on to generate effects which cascade throughout the system. As a consequence of this approach, conflict becomes more general and less weighted with connotations of violence, instead being better described as friction or disruption, making it particularly useful for planning within and describing gray zone and narrative warfare [32,33].

DoDAF

The US Department of Defense Architecture Framework (DoDAF) and its variants are "military architecture" frameworks intended to improve planning, procurement, and the deployment of various military systems [34,35]. While it is not intended to model conflict explicitly, the DoDAF system incidentally generates a model of conflict consistent with Linn's conception of a "Manager's" view of war [26] as a consequence of its modeling of future military needs. Under this view, various kinds of conflict can be described and analyzed by modeling the resources, sub-organizations, missions, and logistics of a military organization itself as a system-of-systems interacting with constraints and limitations (e.g., adversaries and their military organization).

Systems Warfare

Western network-centric warfare, Chinese systems confrontation warfare, and the Russian Gerasimov Doctrine are all examples of modern updates to military doctrine necessitated by the rise of gray zone warfare. Each focuses on permanent conflict, a fusion of hard and soft power across numerous domains, and describing war in terms of whole-of-system conflict over networks, such as those of influence (media) and exchange (supply chains and economies) [36–40]. While the details and documentation of modeling approaches for describing systems of interest within Chinese and Russian doctrine are not easily available [38], those used within network-centric warfare are extensive and often make use of agent-based, Bayesian, and complex system-of-systems modeling methodologies to describe and analyze the structure and risks of abstract conflicts [40–42].

Models of Conflict Information Flows and Decision-Making

The preceding categories of conflict models focused on the historical and qualitative (Narrative Models of Conflict) and the quantitative and data-driven (Quantitative Models of Conflict). In this section, we describe models that have been developed with a behavioral focus, whether they take a qualitative or quantitative approach. These models of information flows are not just explanatory - they are used in national militaries to inform design and decision-making and as such, they have real impacts and need to accurately and appropriately describe systems [39]. Many information flow and decision-making models have been considered for use within national militaries, such as Shewhart's Plan-Do-Check-Act (PDCA) model [43], Wohl's Stimulus-Hypothesis-Option-Response (SHOR) model [43,44], and the Endsley model [43,45] (see Figure 2). However, two models in particular, the Observe-Orient-Decide-Act and Rumsfeld's Triad of "Knowns," have seen broader adoption and adaptation than others. Here, these two models are summarized.

Observe-Orient-Decide-Act (OODA) Model

The Observe-Orient-Decide-Act loop (OODA) model is among the most familiar and commonly used decision-making frameworks in modern times and is used "ubiquitously throughout the branch-specific and Joint doctrinal publications of the US Military" [46]. While the OODA loop is now contained within a scholarly corpus, its creator, John Boyd, never directly published on the topic, instead choosing to share the ideas behind OODA primarily through his presentations [46–49].

The OODA loop was originally designed to help describe and inform real-time decision making by pilots, wherein a "pilot observes the variable and surrounding, orients the aircraft to an advantageous position… [decides] the following course of actions in order to engage" and then acts them out (see Figure 3) [50]. The generalizability and simplicity of this "loop" of factors in decision making led it to enjoy reasonably high levels of adoption, not just in the military, but also in areas such as business and healthcare [50]. However, this simplicity, paired with the lack of published clarifications and formalizations by Boyd, means that it is constantly being reinvented, reconsidered, reinterpreted, and modified to fit various situations leaving it lacking consistent definition and coherent development as a model that could further enhance its usefulness [43,50,51].

Rumsfeld Matrix of Knowing

The Rumsfeld "Matrix" [52], "Paradox" [53], or "Quadrants" of knowing, was not initially formally proposed as a framework for action and perception, but rather was merely a response provided by Secretary of Defense Donald Rumsfeld to a question asked about the lack of evidence of weapons of mass destruction in Iraq:

> "Reports that say something hasn't happened are always interesting to me, because as we know, there are known-knowns; there are things we know we know. We also know there are known-unknowns; that is to say we know there are some things we do not know. But there are also unknown-unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones."
>
> [54]

Though Rumsfeld only offered 3 informational states in the direct quotation, the suggestion of known-knowns, known-unknowns, and unknown-unknowns implies a combinatorial requirement for an additional fourth state: unknown-knowns, which has led this framework to be referred to as "Rumsfeld's Matrix" [55]. Interestingly, many analyses ignore the presence of this 4th implied category [53,56–59].

While other decision making and information flow frameworks discussed above focus on linear steps in the decision making process itself, the Rumsfeld Matrix of known-knowns, known-unknowns, unknown-unknowns, and unknown-knowns is different. The matrix is invoked to help describe the static abstract information spaces and voids that decision makers must navigate and explore (see Figure 3) with gradients of greater or lesser information and lack of awareness of degrees of ignorance - a double hurdle to situational awareness.

Rumsfeld's strategic categorization has since been adopted as a rhetorical framework for considering information gathering and prioritizations in planning and decision making in the military and elsewhere. The Rumsfeld Matrix, like John Boyd's OODA loop, enjoys an informal rhetorical ubiquity - it is a popular reference across other fields, such as in science [59,60] and energy infrastructure [52].

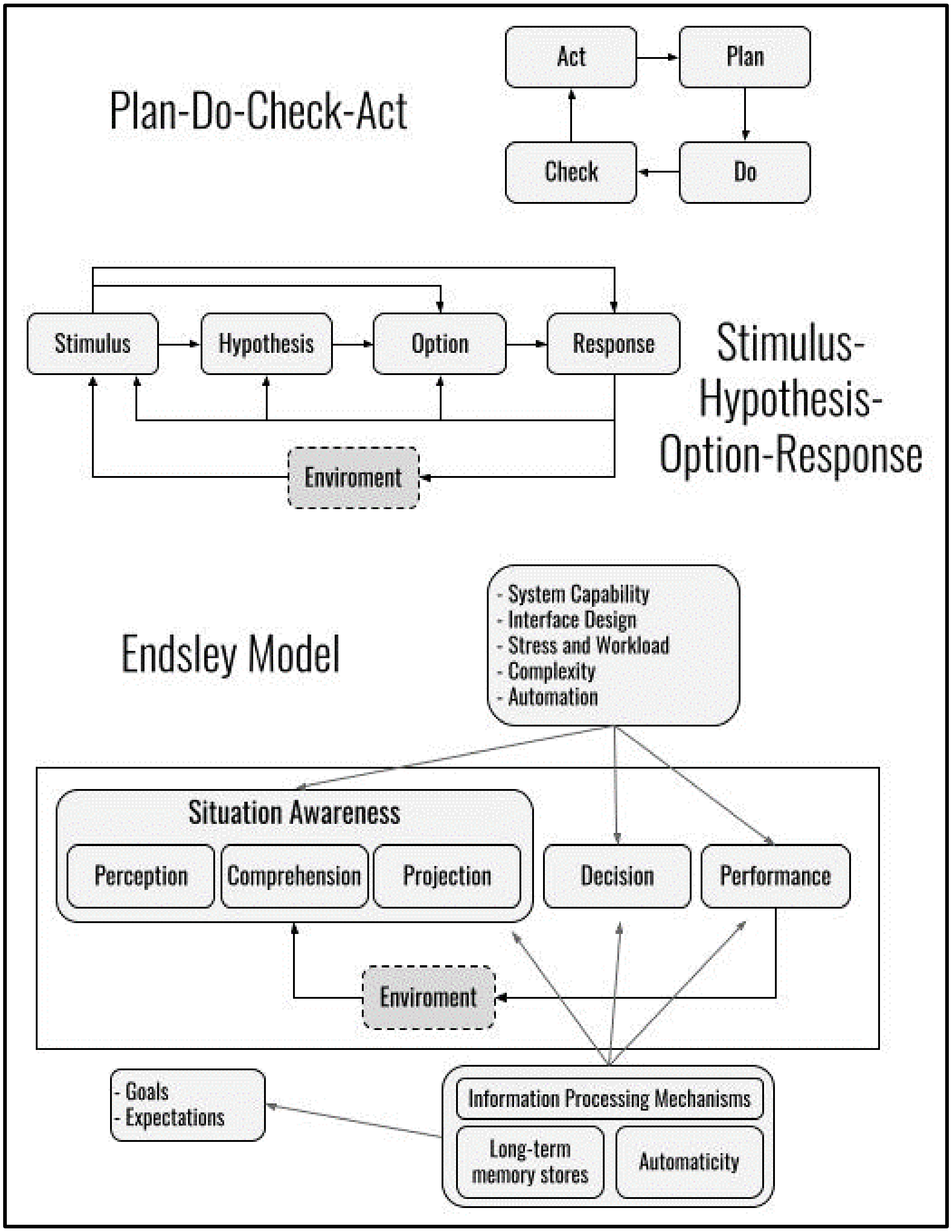

Figure 2. Various Decision-Making Models. Plan-Do-Check-Act Model from [43], Stimulus-Hypothesis-Option-Response from [44], Endsley Model from [45]

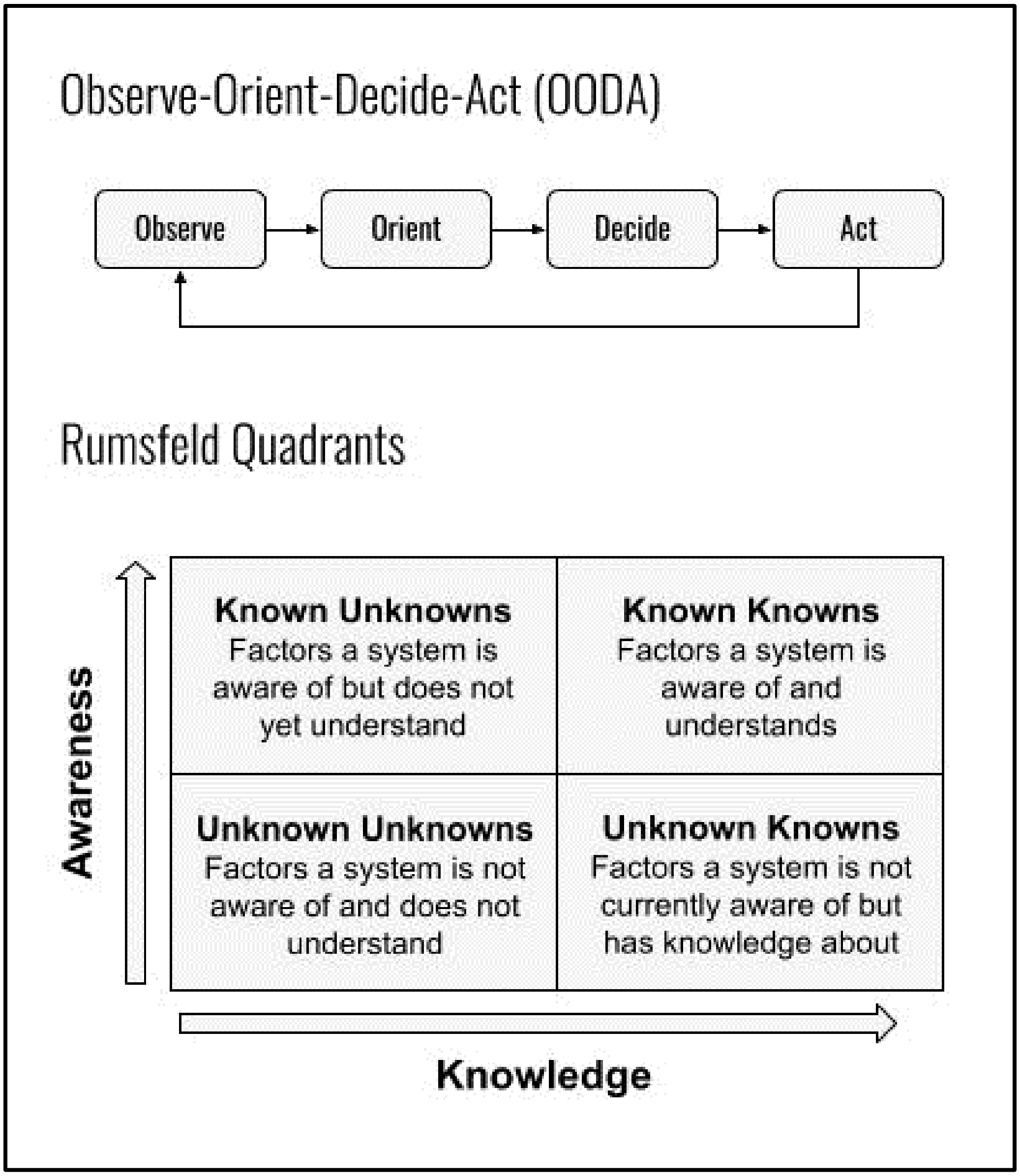

Figure 3. OODA and Rumsfeld Quadrants

Essential Features and Limitations of Past Conflict Models

This brief survey of conflict-oriented models used within military contexts reveals an arc of abstraction across time from simple pattern collection, to formalisms, and finally toward generalized models. The survey also reveals a persistent challenge through time of the problems of change management in the conduct of warfare, i.e., of inconsistency and adjustment to new paradigms and changed historical circumstances. While each of the models described had an important place in the history of the development of theory and within military scholarship, each also suffers from weaknesses which prevent it from offering sufficiently comprehensive predictive and descriptive power in the gray zone conflicts of the 21st century and beyond. However, each prior model has strengths and offers insights which should be captured by new models. Below, we consider some key insights to be preserved and brought forward from previous models. These insights will inform the AIC model introduced herein.

Changing Expression of Conflict

Numerous models show signs of aging as the expression of conflict changes. As a first example, aspects of Clausewitz's trinity are still quoted as a basis for informing doctrine at the highest levels of the US Armed Forces [17] in a way which is consistent with Clausewitz's view of his theories as a "basis for study, not as doctrine" [15]. However, even when used in a limited way as a basis of study or theory, it still faces serious challenges in capturing significant aspects of modern conflict. While some argue many aspects of the trinity may be applied through analogy to asymmetric and low intensity conflict, the model may have to be somewhat contorted to be applied in many conflict scenarios; for example, in the conflicts between the Medellin Cartel and the Colombian Government [15]. Further, Clausewitz's trinity simply cannot explicitly or sufficiently describe the categories of conflict most relevant to modern organizations, such as narrative warfare and terrorism where many actors may be individuals motivated by ideology [14,32]. Even within defenses of the trinity model and of Clausewitz we find the suggestion that attempting to torture the model into explicitly describing aspects of modern conflict may be "profoundly confused" [61] and stem from the likelihood that Clausewitz "has been more often quoted than read and understood" [14]. While the underlying components of reason, genius or strategy, and passion are still valid, the central tension, or as Clausewitz described it, the "balance between these three tendencies", will no longer express itself in the same way and may need to be paired with other models in order to continue to provide value and insight [21].

While the Clausewitz trinity has seemingly received the most attention in terms of adaptation for the changing expression of war, approaches such as Lanchester models and Generations of Warfare, have also seen numerous adaptations in order to fit new paradigms. Replacements, such as models of conflict within the purview of network-centric warfare, fare far better in describing these new paradigms but might make a polemologist or military historian wonder if they describe old ones well. Even with the Generations and Revolutions of Warfare models, which are intended to capture the development of war historically, may unfortunately create a unidimensional or linear view of war as consistently developing in sophistication. Further, they place all conflict prior to the first millennium as “precursor activities", creating a paradigm of study and thought similar to that which is found in “traditional Western historiography, in which all of prehistory — the bulk of the history of our species on earth — [is] consigned as an afterthought on the far left side of any historical diagram — the historical terra incognita before classical antiquity” [62].

It is important to consider how models built for new expressions of war might represent old ones given what is suggested by Abbott’s Gradients of War: that the expression of war may degrade in sophistication rather than increase linearly. There is a need to address how we represent conflicts within abstract space in order to capture not only the essence of previous and current expressions of warfare, but also to help project and consider what may come next.

Limited Interoperability

The value of a model of a system might be derived not just from how well it handles updates to information about that system, but also from how well it interfaces with other models. How does a system reflecting one model come to “know” what is already “known” to a different model? For example, it would offer tremendous value via interoperability to be able to project or map models onto each other. However, among all the models considered above, only limited capacity for backwards- or forwards-compatibility was found (the exception proving the rule was the mapping between OODA and the Gradients of Warfare in Figure 1). Though some models seem quite general, they have poor interoperability with others, for example, the value of computational systems such as those within EBO and Lanchester models is siloed from the insights within information flow and decision-making models. Though some work has been done elsewhere to map heuristics and narrative models to computational frameworks in gray zone and narrative warfare through the use of "pattern languages" [63], or collections of practice and risk heuristics which can be layered into EBO-like frameworks, it isn't apparent that any substantial work has been done to generalize this approach to conflict in general [32].

Separate from attempts to map relationships among narrative models and their computational and informational counterparts, there is also significant dissonance within each of these categories. For example, Lanchester equations, by merit of their structure, cannot easily interface with EBO or systems warfare models. Further, within narrative models we find rampant disagreement on how to describe conflict in terms of priority. In addition, within informational models it is unclear how models like OODA can scale from local or single-actor tactical decision-making to strategic or multi-actor decision-making with adversaries in-the-loop as EBO or systems warfare models would indicate may be required. Inconsistencies or incompatibilities within and among models hinders the ability of applied composite models to provide superior insights into the origins and operations of human conflict.

There is a need for a computational integrative framework that connects tactical (micro) and strategic (macro) timescales, and builds on the strengths of narrative, quantitative, informational, and decision-making focused (meso) models. In the next sections, trends in the understanding of human interactions generally are brought to the challenges of analyzing human conflict, including war, and the synthesis introduces multiple new metrics of system performance from previously neglected contiguous domains of human behavior from which a richer, and more extensible, computational model of human conflict and war emerges.

Generalization

In addition to being able to handle updates to information and interface well with other models about a particular system, the potential value of a model might be further discerned based on how faithfully it is able to describe and integrate with other systems with one or more similar attributes. The history of conflict modeling, as illustrated in the summary of warfare literature above, reflects an ever-increasing awareness and integration of variables from the studies of interactions in conflict beyond those traditionally classified as "war." As humans migrate their interactions from physical space to abstract online "information" space, the potential for integration of other knowledge about managing interactions and conflict in non-warfare contexts becomes increasingly relevant - and increasingly possible.

In fact, as the human species migrates an ever increasing portion of its interactions from physical interaction pathways to information-rich digital and online networks, the nature of conflict, including war as conflict, is changing. In traditional interactions and conflicts, the physical landscape and kinetic actions of stakeholders had the greatest influence on the models used to study those systems. In digital online information interactions, the "landscapes" are not physical, but instead are conceptual, narrative, and even memetic [64]. At one level, conceptual conflict might be seen as more amenable to dissipation without resort to irreversible destruction of rivalrous physical objects of value. On another level, abstract spaces lend themselves to myriad different simultaneous characterizations, each of which can provide pathways to conflict resolution, together or in combinations.

In the past, conflict might be explained with reference to people speaking different languages or seeking control of rivalrous physical territories. Increasingly, however, conflict can be described with reference to different paradigms, argots (trade languages), and risk concerns. Much as prior conflict might arise between speakers of different languages, so too might future conflict be analyzed as conflict between and among the different languages, paradigms and interactions patterns of business, operating, legal, technical and social domains (BOLTS).

Since war is a subcategory of human conflict, BOLTS-based parsing can also help to introduce potential pathways to integration for models of nation state level conflict, including war. As the proportion of of conflicts between and among people, organizations and nations becomes less focused on violent physical conflict, it is increasingly better described as occurring over surfaces characterized using business [65,66], operations [67], legal [68,69], technical [67,70], and social [32,71] (BOLTS) components. As the case for traditional battlefields, the ability for modern models to capture both violent and nonviolent aspects of conflict at varied scales of organization in myriad contexts, digital and physical, becomes existentially important. BOLTS has become an approach to analyze this continuation of (information) warfare by other means.

While the popular models of conflict described thus far tend to focus on describing and providing insight into violent conflict, outside of the warfare-oriented corpus there is fortunately a rich history of models developed in an effort to understand and address non-violent, non-physical, or indirect conflict [72,73]. These traditional models of human conflict management are nonetheless non-traditional models of warfare. As warfare is migrating from physical to informational domains these non-traditional models present themselves as candidates for integration with traditional models of warfare.

Unfortunately, at first glance,these non-warfare models of conflict tend to appear to be focused on interpersonal and intragroup conflict, rather than inter-organizational or violent conflict, and some may explicitly avoid discussion of these topics [72,73]. However, within this corpus of non-warfare conflict work, concepts have been developed that can be helpfully brought to the study of war. For example, non-warfare conflict research includes research on negotiation and intragroup organizational conflict presenting concepts which are ripe for generalization to interorganizational business and legal contexts [73–75], research on task and process conflict directly applicable to understanding larger scale operations frictions [73], and research on relational and diversity conflict which has already been applied to better understanding cultural and social frictions [72,73].

Other potentially useful non-warfare models of human conflict and its management include those models that analyze conflicts within a "commons", which has its own storied computational and narrative corpus. Research on commons management focuses on conflicts which can arise in markets (both abstract and real) and the access to resources in which varied groups and actors have individual interests but collective ownership or stake [76,77]. For example, the oceans, the polar regions, the atmosphere, outer space, and non-earth heavenly bodies, are beyond the direct control of any nation, but provide resources and spaces in which nation states, and their resident citizens and companies, increasingly interact. In those spaces, conflicts of interests among stakeholders are bound to arise as competition for resources and conflicts of interactions emerge.

Elinor Ostrom won the Nobel Prize in Economic Sciences in 2009 [78] for her work in describing co-management regimes for addressing conflict in historical settings such as the conflicts that arise in the context of shared grazing and forestry resources, fisheries, and riparian (water) rights. Her work has been instrumental in the international management of fisheries and other resources in international waters, and for models of managing both outer space and knowledge space as well. Hess and Ostrom, in their book, Understanding Knowledge as a Commons [79] lay out eight principles for "robust, long-enduring, common-pool resource institutions", which are:

- Clearly defined boundaries
- Rules that are well matched to local needs and conditions
- Individuals affected by these rules can participate in their modification
- The right of community members to devise their own rules is respected by external authorities
- A system for self-monitoring members' behavior has been established

- A graduated system of sanctions is present
- Community members have access to low-cost conflict-resolution mechanisms
- Nested enterprises - the "appropriation, provision, monitoring and sanctioning, conflict resolution, and other governance activities" are organized in a "nested structure with multiple layers of activities".

To help communicate the impact of these principles, Hess and Ostrom present the "Institutional Analysis and Development" (IAD) framework (see Figure 4). This framework presents a map of the relevant variables to the expression of friction, or conflict, within what it calls the "Action Arena" and represents a key example of a model comprised of elements which are generalizable to a great number of kinds of non-violent conflict. In addition, it makes use of narrative models regarding common "patterns of interaction", such as "freeriding or misuse", which can be layered into the model with probabilities and expectations about outcome, offering implications for how narrative models and pattern collections may be generalized to interface better with computational models.

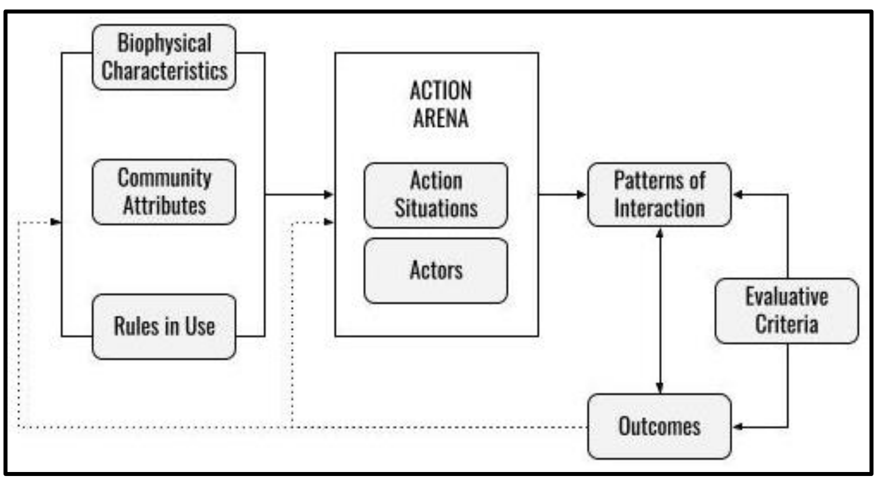

Figure 4. Institutional Analysis and Development Framework, modified from [79]. Biophysical characteristics refer to ideas, artifacts, and facilities, the relevant factors which relate to the physical or quasi-physical affordances, boundaries, capacities, and limitations of a particular commons. The attributes of the community, refer not just to measurable qualities of the community, but also to those which comprise it, such as users, consumers, providers, and policymakers. Rules in use refer to administrative procedures, legislation, and contracts, as well as other activities considered to be pro forma even where they may not be codified or observable.

With this discussion about models of warfare above, there appears to be a need to account for new frameworks that encompass modern expressions of conflict, are interoperable across domains, and generalize well enough to encompass peaceful and rapidly-changing times as well as classical forms of conflict and related operations other than war (OOTW). An open challenge is for a computational model to capture the value and insights provided by various forms of previous narrative, quantitative, and information flow models of conflict. In the following sections we address this need by proposing a framework based on Active Inference. Active Inference is a framework arising from cognitive science, which has had demonstrable value in unifying certain aspects of cognition and sensemaking, and which may be used both computationally and qualitatively at different scales (e.g., single agent or multi-agent) [80–82]. The following sections present an overview of Active Inference, followed by its application towards the domain of conflict – the Active Inference Conflict (AIC) model.

Active Inference Conflict Model

Here we propose a framework for modeling modern multiscale conflict, based upon an application of Active Inference (ActInf). ActInf is a behavioral modeling framework that integrates perception, cognition, and strategic action under a common currency – the reduction of expected free energy. As discussed below, expected free energy has several different compatible phrasings which facilitate its use in decision support in different systems and situations. Across these formal phrasings of free energy, a commonality is the emphasis on selecting actions that finesse both the epistemic (knowledge-oriented) and pragmatic (utility- or reward-oriented) aspects of action. Broadly, ActInf can be considered an approach that builds on quantitative approaches to action (e.g., cybernetics and control theory) with modern insights from cognitive sciences [83,84]. This action-oriented view casts the active sensing of systems as fundamentally about reduction of uncertainty. The sensemaking process goes wrong when inappropriate uncertainty-reducing behaviors are implemented, or the variability of the area of operations is too variable to be tracked effectively.

The Active Inference Conflict (AIC) model is an approach which unifies some aspects of previous models of conflict, and generalizes conflict in order to help capture business, operations, legal, technical, and social aspects relevant to modern gray zone warfare. Additionally, the AIC model has sufficient flexibility to be used both qualitatively or quantitatively across different timescales (e.g., tactical, strategic), structural scales (e.g., individuals, organizations, communities, and states), domains, and scenarios. Recently it has been suggested that autoethnographic organizational approaches (e.g., reflection upon one's own experiences and surroundings) provide an amenable on-ramp to the ActInf framework [85]. Multiple informal and technical introductions to ActInf and the broader Free Energy Principle exist [81,86–90], here we introduce some of the salient features and descriptions of key terms within the ActInf framework which predisposes it towards effective application to the domain of conflict and for use within AIC.

From a military science perspective, AIC provides a bridge between single-agent real-time tactical decision-making models (such as OODA), and broader strategic analyses (such as those provided by the GW framework). As ActInf itself is a development on Bayesian graphical modeling to accommodate multi-level cognitive processes, the AIC model can be seen as the integration of this ActInf framework with other key existing models of conflict and models of cognition more broadly. Due to its descriptive bottom-up modeling approach, AIC also provides an avenue for integrating the analysis of military, non-military, and non-kinetic models of conflict (as well as cooperation, and other categories of interactions). Below, we provide a primer on ActInf with a focus on how key ideas are applied in the AIC model. Figure 5 summarizes the scope of AIC and Table 1 provides a map for the territory we explore in the following sections (the core terms and features of ActInf as deployed in AIC).

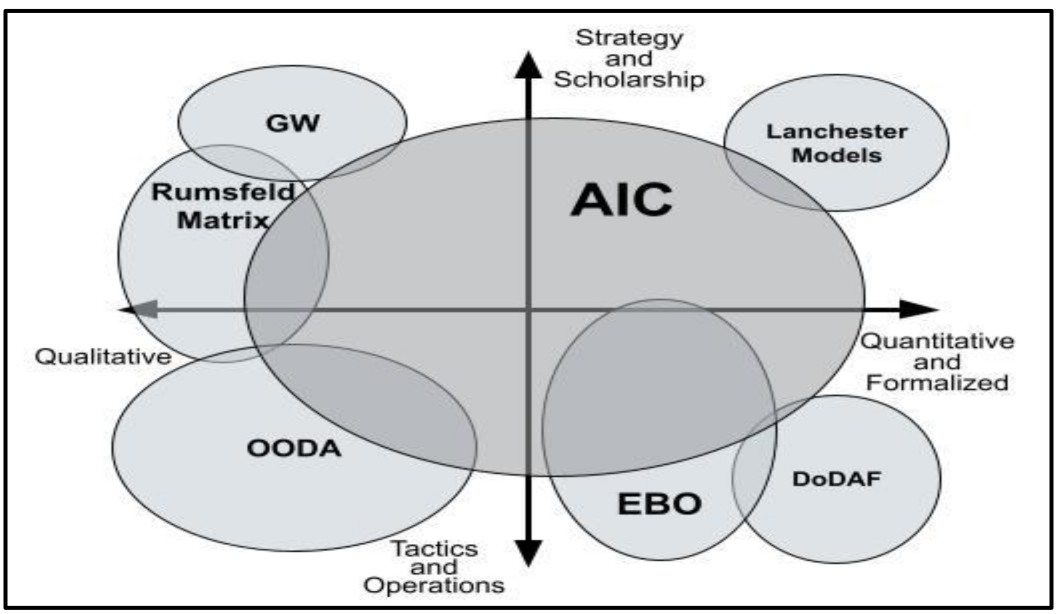

Figure 5. Scope of Active Inference Conflict (AIC) model along the dimensions of qualitative to quantitative (X-axis) and tactical to strategic scale (Y-axis). From the top-right and going clockwise: Lanchester models, DoDAF (Department of Defense Architecture Framework), EBO (Effects Based Operations), OODA (Observe-Orient-Decide-Act), the Rumsfeld Matrix, and Generations of Warfare (GW) model.

ActInf Core Terms	Usage at Tactical scale in AIC model	Usage at Strategic scale in AIC model	Tactical and Strategic scale in AIC model
Entity	Human, human – with tech in the loop, squads, teams	State or non-state group	Larger entities are made up of smaller entities
Generative Model	Short-term expectations for a given scenario, enacted & embodied by a tactical agent	Long-term expectation at a diplomatic or geopolitical level, of a strategic agent	Strategic-level generative models constrain/enable the function of tactical-level models.
Perception & Action	Perception: Bodily senses and (meta)cognition. Action: Physical movement including tools	Perception: Informational ingress, observations from e.g., markets, environment Action: Communications, operations orders	Scales can interact and influence each other through Action (one scale/system's action is another's Perception)
Affordances & Policy Selection	Decision of which button to press, what to say, or which route to take	Decision of which sanctions to apply, communications to release.	Large scale outcomes (movement of a legion) are jointly influenced by top-down and bottom-up implications and decisions
Expected Free Energy (FE)	Implicit or explicit prediction over a time horizon of the uncertainty associated with a given sequence of actions	Implicit or explicit prediction over a time horizon of the uncertainty associated with a given sequence of actions	Systems driven by tactical minimization of FE may not achieve strategic aims. Strategic minimization of FE may entail novel regimes for tactical elements (e.g., waking up early, or experiencing surprise)
Action-Perception Loop	Continuous flow of bodily sensory information and personal physical movements	Continuous flow of organizational/informational inputs and outputs	Action loops of tactical entities are faster/smaller nested systems within strategic entities (like players on a soccer team)

Table 1. Core terms in ActInf (left column)

Active Inference Overview, Terms, and Features

There are several core features and relevant terms from ActInf that are necessary in communicating the AIC model (Table 1). Here we provide an overview of ActInf topics and terms, with an eye towards how the concept will be applied in the AIC model and the general implications for the term's quantitative and qualitative use.

ActInf Terms

Here, the terms necessary for communicating the AIC model are described.

ActInf Entity

An ActInf entity is the minimal system description or model that is partitioned off as a separate (but interacting) thing from its environment or niche. The "thing-ness" of the system is specified by how relevant system variables are partitioned into several kinds of states. The scale of the entity might represent, for simulation and modeling purposes, anything from individuals to communities [91–93].

Some presentations and applications of ActInf differentiate two categories of Entities: "Mere" and "Adaptive" [94,95]. A "Mere" ActInf entity is one that passively synchronizes or reacts to external stimuli or causes. Relevant Mere ActInf entities in a model of conflict might include inanimate objects, smart contacts or blockchains, or any system with a well-defined, passive, or completely understood input-output relationship. In contrast an "Adaptive" ActInf entity is one that interacts with its environment in an embodied, agentic, anticipatory, cybernetic, and anti-dissipative fashion. Relevant Adaptive Entities in a model of conflict might include humans, teams, organizations, companies, countries, and non-state groups.

ActInf entities can be considered "generic" patterns that partition the statistical dependencies of agents into internal, external, and blanket (incoming: sense, and outgoing: action) states. This characterization of a generic entity type is useful for several reasons:

- ActInf entities have tractable interfaces for lateral interaction as well as nesting within other ActInf entities, allowing for modeling of complex heterarchical synthetic intelligence, or macro-cognition and organizational behavior [3,80,96].
- So long as ActInf entities have action affordances which can interface with external entities and sense affordances which interface with external stimulus, the representation of their internal state and policies can be modified in any way appropriate for the nature of that entity and the simulation or modeling task at hand.
- Even without full quantitative integration, the process of framing a system in terms of its entities and nested entities can help illuminate its structure as exercise in system modeling and sensemaking [85].

Generative model

The generative model of an ActInf entity refers to the ongoing creation by internal states of expectations, for example the states that the organism or organization expects itself to be in. Entity actions are selected in order to reduce uncertainty about the realization of those expectations, as the generative model includes expectations over sense, action, internal, and external states. In application across systems, the imperative for behavior in ActInf entities is not the maximization of reward but rather the reduction of uncertainty [97]. Reduction of uncertainty is always in reference to a specific generative model possessed or enacted by a system of interest, be it an organism or organization [3,92].

Perception & Action

ActInf entities are continually engaged in perception and action. ActInf builds on the predictive processing, embodied cognitive frameworks, as well as other Bayesian and computational models of perception [98,99]. Perception is the ongoing process by which sensory observations are predicted or inferred by the generative model of an ActInf entity. Action refers to the enacted outcomes or outgoing statistical dependencies of the system, whether they are digital, social, financial, or physical.

Affordances & Policy Selection

Policy selection, or action selection, is the process by which the entity will (act as if they) decide upon a course of actions (a policy). For a body, the action states might refer to the exact angles of each joint, while the policy selection "to walk" could entail a complex sequence of changes to action states. The space of possible policies for an ActInf entity at a given time is known as their affordances (opportunities for action and interaction in the niche), drawing on the use of the term in ecological psychology [100]. Policy selection is carried out in light of a preferences over sensory observations (e.g., having a preference for warm temperatures over cold, and then acting to light a fire to reduce surprise about temperature). Thus policy selection is cast not in terms of finding highly-rewarding states, but rather inferring which option from a given limited set of affordances is expected to lead to the lowest expected difference between expectations and experience (lowest expected "free energy") through time, in terms of pragmatic (utility) value as well as epistemic (uncertainty-reducing) value. When these expectations and preferences are for rewarding states, then ActInf models can recapitulate behaviors found in other kinds of reward-maximizers and reinforcement learners [81,97]. The selection of policy is in ActInf because entities can rapidly transition from utility-oriented behaviors to epistemic actions, as the flow of received information changes moment by moment.

Expected Free Energy

This expected free energy quantity used for policy selection, can be variously framed as achieving evidence for a successful self, resistance to dissipation, or the general reduction of uncertainty [98,101]. Several useful mathematical decompositions and equivalences exist for expected free energy, for example energy minus entropy (similar to Gibbs free energy), surprise plus informational divergence, accuracy minus complexity (as used in Bayesian statistics and machine learning) [102]. Classical decision-making constructs such as expected utility, informational foraging, risk-sensitive policy inference, and optimal control are special cases or derivations of more general formulations of ActInf entity behavior [81,103].

Action-Perception Loop

The action-perception loop in ActInf describes how Internal states (constituting the generative model of an entity) update in response to incoming sensory stimuli, and how actions (outgoing influences of the entity on the niche) define the outcoming interfaces of the systems. This problem of real-time control occurs in the domain of robotics, public health, command and control systems, and elsewhere. To model these heterogeneous yet structurally-analogous scenarios with an ActInf entity, the entity can be modelled as a Partially Observable Markov Decision Process (POMDP) [88]. This POMDP specification is a Bayesian graphical model that lays out all variables required for minimal modeling of an ActInf agent (Figure 6). At each timestep of the POMDP model, the entity receives new observations from the niche, updates the parameters of its internal generative model, performs policy selection, then enacts an action consistent with the selected policy.

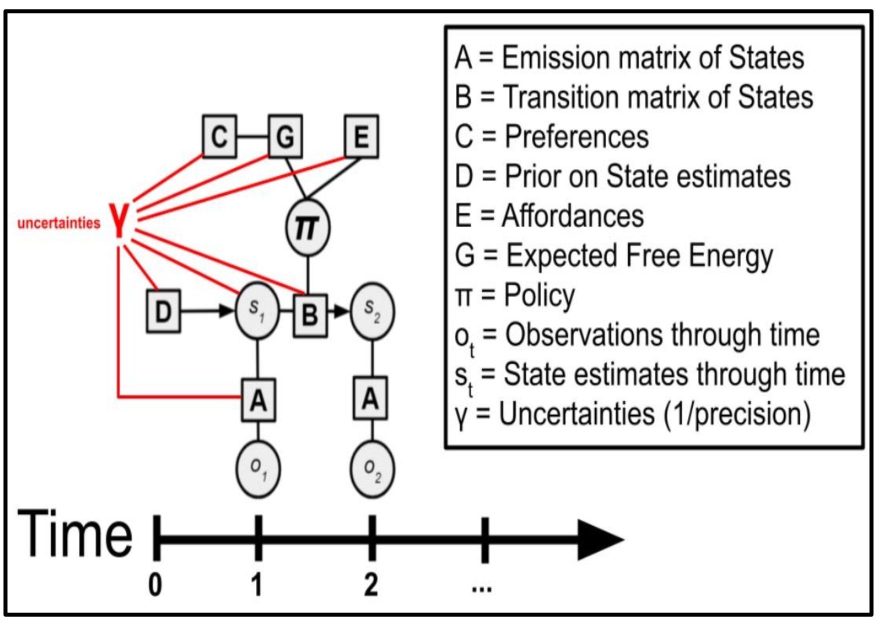

Figure 6. Partially Observable Markov Decision Process (POMDP) model of an ActInf entity.

ActInf Features

The ActInf framework builds on the key terms towards several essential features. These components and generalized structures offer myriad affordances to researchers and analysts. Here we discuss several ActInf core components, placing them in the context of the AIC model as a formal model of interacting systems in conflict.

Interactions with the Niche

Niche refers broadly to the surroundings or context of an entity, be it biological, social, or informational. The niche is the unobserved generative process that passes sensory observations to the entity (akin to how the location of the sun is not directly observed, but is instead inferred from the angle and type of impinging photons) ActInf entities interface with their niche through sense (incoming stimuli) and action (outgoing effects) states. Entity actions can modify their niche, reflected by changes in how the states of the niche change through time (for example tightening a screw so it doesn't wiggle in the future). This type of active co-construction between entities and their surroundings is known as niche construction or stigmergy [104]. This partitioning of the Internal, Action, and Sense states of the system of interest (the "particular states" [105]) entails that all features or data outside of the system of interest are external or niche states. We can consider the POMDP of the ActInf entity from Figure 5 as it interacts with its niche (Figure 6). The internal states of some system of interest can be modeled such that the external states provide observations (o_t) to the entity, and the selection of policies (π) are upstream of the enactment of action state.

Interacting Entities

This same ActInf framework can apply whether the external states (external from the point of view or partitioning of the entity) are of a very different kind than the entity (e.g., an ant colony inferring a raincloud) or a similar kind (e.g., two humans and their mental models of each other). Interacting entities can select policies with long-term expectation of net-positive interactions (e.g., trusted interactions from a game theory perspective), and this framing can suggest the formation of new kinds of organizations. The concept of Thinking Through Other Minds (TTOM) describes how the internal general model includes each Entity's own actions as well as the actions of the partner [106,107].

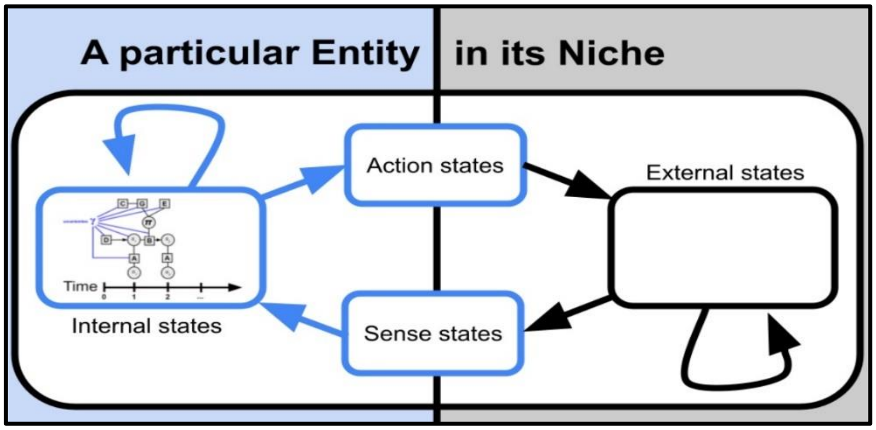

Figure 7. ActInf entity interfacing with external states. At right, external states are influenced by entity action states, and also external states may have endogenous dynamics. External states pass observations to internal states via entity sense states. Uncertainty in the flow of incoming sensory observation can be reduced through updating the internal model of the entity (learning) and action.

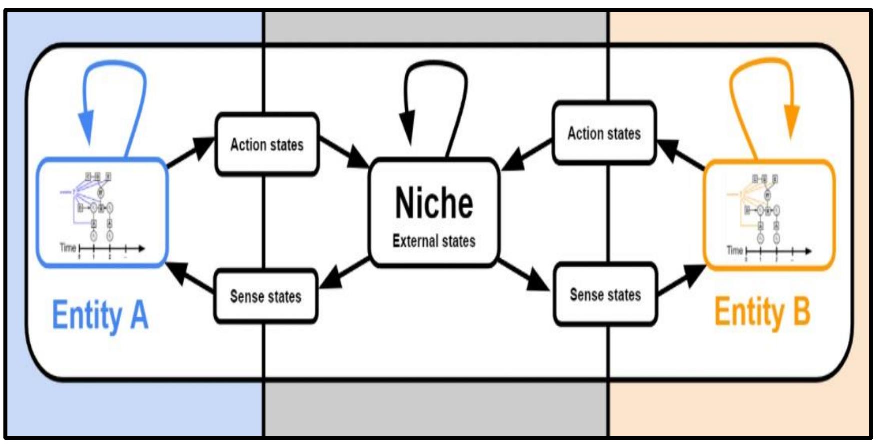

Figure 8. Two ActInf entities A and B, interacting via a shared niche (ecological, informational, or otherwise). The generative process of the niche is influenced by endogenous dynamics as well as actions from both entities.

N-Dimensional Modeling of Abstract Space

The advantage of a domain-flexible description of entities and their interactions, is that it facilitates the modeling of high-dimension interaction spaces, and detection of patterns across different interfaces or types of observations across BOLTS surfaces in way that may be considered analogous to the integration of different kinds of neuroimaging data (fMRI, EEG, and MEG) in the Statistical Parametric Mapping (SPM) framework [108]. General ActInf modeling, along the lines of complex systems models described above, can capture the dynamics of classical cooperation/conflict situations as well as extend to model heterogeneous, unconventional, and yet-unseen mechanisms and patterns. With the use of an event reporting framework, this ability to capture cooperation and conflict across myriad surfaces may help to identify not just yet-unseen mechanisms and patterns, but also difficult to detect opportunities for strategic attention and action [109,110].

Use of the AIC Model

Here we build on fundamentals and recent applications of the ActInf framework to work towards new models of systems in managed and unmanaged conflict, cooperation, and every sort of human and institutional interaction in between.

Entity Action Loop and Alignment with OODA

To understand the cycle of inferences and actions entailed by each timestep for an ActInf entity, it is helpful to consider this ActInf model and POMDP specification alongside the stages of the OODA model (discussed above). In contrast with OODA, the ActInf framework provides a model for “regimes of attention” [111,112], niche modification, and long-range/predictive/anticipatory policy selection in deep or nested generative models.

In both OODA and ActInf, the perception-cognition-action cycle is continuously unfolding, and can be thought of as beginning with the perception of new observations. Here we align ActInf terms and framings with the OODA sequence, with reference to Figure 9.

- **Observe:** incoming observations (o) are received by sensors, sense organs, measuring tools, or other signal channels.
- **Orient:** These observations are integrated with prior beliefs (D) about hidden causes or states of the world (s) through the bidirectional Bayesian mapping (e.g., constituting a generative model and recognition model) of the matrix (A) connecting observations to hidden states.

- **Decide:** The updated Internal generative model of hidden states is used to perform inference on action, akin to other cybernetic or control theoretic framings. This selection of policy proceeds by the integration of preferences over outcomes (C) and constraints over action possibilities (E) in the calculation of expected free energy (G) in terms of pragmatic and epistemic value, as conditioned on different possible policies.

- **Act:** Having selected the policy with the lowest expected free energy over the time frame of analysis, action states are updated.

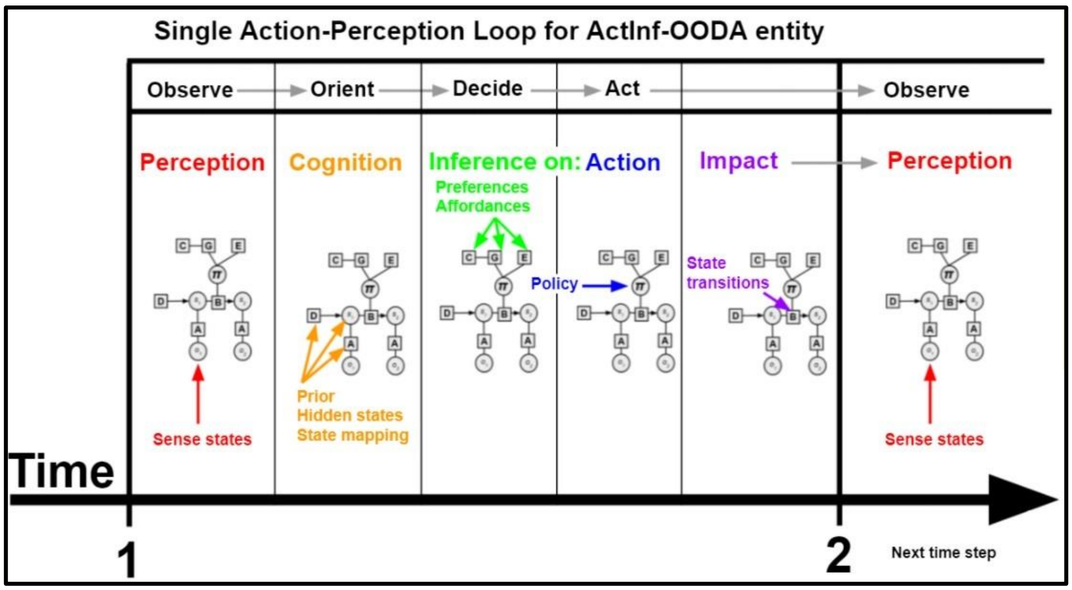

Figure 9. Comparison of Action-Perception loops for ActInf and OODA entities

Unifying Quantitative and Formal Models of Conflict

The AIC model does not replace prior quantitative models of conflict, it instead integrates them and offers a new medium for their expression (as well as a new environment for testing and formal development). For example, given that AIC can be nested into and applied in agent-based models [80,113,114], methods such as game theory matrices and Lanchester equations can be calculated at snapshots and be used to predict and project the outcomes of simulations and iterated games - as well as test other formalizations and counterfactuals. AIC isn't limited to integration with agent-based models, it can also plausibly be nested into EBO and network-centric warfare graphs and planning cycles. Additionally, given that ActInf is a development on Bayesian graphical network methodologies, AIC itself, without any integrations, can be represented as a graph akin to those found in other graph-based models. Further, it can extend these quantitative and formal approaches (EBO for cognitive effects) or provide a surface for interoperability between them (e.g., Lanchester variations for both infantry- and artillery-driven conflict within the same larger model) in myriad conflict settings.

Moving Beyond Generations of Warfare

The AIC model has the capacity to model structurally flexible, nested, and interacting entities and embedded decision-making processes. This allows for standardized and formal representation of conflict, whether it be between ant colonies or nation states, or between ant colonies and nation states. This formal representation allows n-dimensional measures of features and organizations within historical conflicts and thus opens the door to methodologies such as component factor analysis, which can allow for classifications and archetypes of conflicts that aren't limited by their place in history or by their placement on a single dimension. The analysis provided by AIC does not necessarily render previous narrative models of conflict classification obsolete - instead, it may offer opportunities to support and extend, and offer more insight into the similarities between these various models (for example returning to Flavius Vegetius Renatus' aphorisms discussing estimation, uncertainty, and expectation). In this same vein, AIC can be used to generate new narrative models akin to Generations of Warfare, as war evolves and adapts along numerous axes - for example, along axes such as the relative distribution of decision-making or the growth of intelligence requirements.

The decisions that are made today in this period of rapid transition will affect human conflict for many years. In this regard, AIC offers a potentially useful paradigm that can be extended, beyond the Generations of Warfare Model, into the past, anchoring it as a potential analytic tool to help predict efficient and effective strategies for future conflict analysis and resolution at multiple scales.

Modeling and Discovering BOLTS Conflict

As discussed, modern conflict is coming to be better characterized as occurring over surfaces with combinations of conflict measurement and risk mitigation structures drawn from multiple, previously-isolated domains. In this paper, we have applied the rhetorical mnemonic device "BOLTS" to invite simultaneous consideration of multiple separate paradigms, measurements, and languages to a given conflict use case. The analytical parsing encouraged by BOLTS is one of many possible mechanisms for such a multi-faceted analysis, and is useful because the individual B-O-L-T-S components are broadly familiar, and the conflicts among the silos (e.g., technological vs. legal considerations of data use, business vs. social goals of online social networks) are well known - even if they remain unresolved. The business, operations, legal, technical, and social components therefore provide a familiar backdrop against which AIC can be rendered more accessible. The visual integration of AIC with BOLTS is shown in Figure 10. Below, we note examples which emphasize each of these aspects and consider AIC's use in these settings.

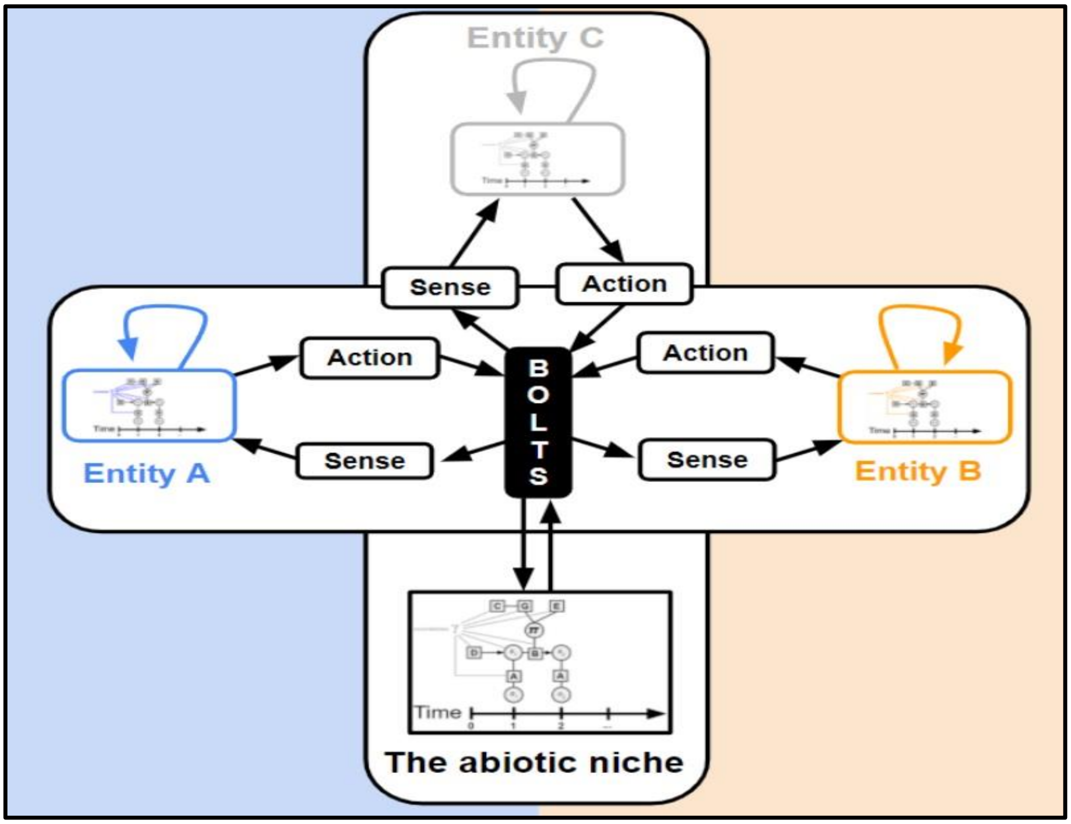

Figure 10. Two conflicting ActInf entities (A and B), a third entity outside of the direct conflict (C), and the abiotic niche interact via a BOLTS commons along specified interfaces.

Business

Business and economic relationships have always influenced human interactions from the earliest agoras to today's global online markets. The emphasis on metrics is driven by systems of risk mitigation and leverage associated with such business phenomena as production, resource accumulation, monetization, zero-trust trading, remote dealing, financialization, and myriad other "Business" concerns. Consider, for example, the many current structural global conflict surfaces that can be fruitfully analyzed as artifacts of the long term implications of once-admired cost cutting strategies (such as foreign production of domestic goods) associated with the historical transition from physical to information dependencies. For example, the domination of China in manufacturing (and the consequent dependencies of consumer societies such as the US) is a product of US companies seeking lower labor costs (and compliance with environmental, labor, and other domestic laws) in the past decades. The US became dependent on information and finance to maintain access to and control of such remote production activities, creating a period of relative order (in terms of environment and labor gains within the US), but deepening the dependencies on access to foreign labor and production apparatus - which creates disadvantages for the US in the event of conflict with China affecting trade. AIC can be applied to analyze, consider and identify developing price leverage within larger business and economic structures and their relationship to economic policy, or to help infer internal model or policy of adversaries (based on their policy "pings"), and can also be of use in identifying de facto adversaries that may not have coherent structure under the law or be otherwise be detectable through standard business or legal metrics (e.g., informal consortium-like entities, such as a category of businesses operating within a common niche, nascent cartels, mutually-dependent trading arrangements, online Distributed Autonomous Organization [DAO] structures). Looking at Business interactions through an AIC lens helps to reveal existing and potential interactions and their respective threats, vulnerabilities, and opportunities for new value creation, which will drive innovation in multilateral risk mitigating structures and in business entrepreneurship and innovation.

Operations

The concept of "Operations" in BOLTS overlaps with other BOLTS notions, but its separate consideration yields novel insights into conflict, particularly when brought together with the AIC model. Operations includes concepts such as supply chains, scaling of operations, organizational change management, operating efficiencies, human resources, and a host of other notions of human organizations that reflect attempts by humans to manage conflict for rule-driven behaviors across interactions at arbitrarily-large scales. In these contexts, the AIC model provides a coherent and comprehensive lens through which to analyze "operations in conflict." For example, consider that many current "supply chain" related conflicts and challenges are a result, in part, of "just-in-time" manufacturing, lean inventories, and other less-capital-intensive forms of doing business ushered in by the enthusiasm for outsourcing in the mid-1980s, and accelerated by the "bricks-to-bits" commercial information revolution. Those trends have continued and been accelerated by the overall migration from physical to information-based interactions and transactions. Consider that there is a large and still growing set of operations protocols that eliminate the need for organizations to maintain large and expensive inventories. The continuing advances of the information revolution allow the virtualization of internal supply chains and of the provision of access to parts, ingredients and subassemblies when as needed further disintermediating previous supply chain interactions - which changes can lead to conflict. With respect to the labor element of operations, the "outsourcing" of labor to other, less regulated, countries is also a part of this cost-cutting effort. The modern expression of this outsourcing is found in innovations such as eBay, UBER, or Lyft where the value steps in the management and structure of inventory and service provision, routing, and delivery are becoming increasingly separated. AIC can be used to model the structure and distribution of decision-making processes both in BOLTS and traditional conflict arenas and developing points of affordance and access leverage in relation to policy. Further, it allows for the modeling of operational niche and the processes and protocols associated with managing the potential conflicts within a given niche.

Legal

The laws of physics are universal, but the laws of people are not. The technology of the Internet is based on physics, but the regulation of the internet is not based on the laws of physics. The result of all this is that the Internet has the potential to be deployed globally (and beyond) with technical standards, but the laws of the 195 sovereign countries which are not globally standardized, creates conflict. Of course, it is not just the laws and regulations themselves that are in disputes, but also the interactions of the billions of individuals and organizations acting every hour of every day under such laws. The legal focus is fruitful in measuring and managing conflict since that is the intended effect of all legal systems. However, non-legal conflicts, such as political, economic, social, cultural, aesthetic, and other non-legal interactions, are beyond the reach of the risk mitigating help of legal systems. AIC applied with BOLTS can help to bridge the gap by bringing legal forms of conflict management into closer contact and interoperability with other BOLTS forms. In addition, legal confrontations in civil, criminal, and international disputes are in and of themselves conflicts which can be modeled by AIC. However, law is not just a source of conflict mitigation - it is increasingly a source of agenda-laden conflict engagement. Consider that beyond its role in helping to resolve individual conflicts, confrontations that apply law as a sword (and not just as a shield) are increasingly becoming a chosen avenue for conducting gray zone conflict and disruption between and among nation states and other entities. In the case of nation states, each of which as a sovereign can, by definition, create its own laws, legal warfare or "lawfare" [68,115,116] can be said to be composed of the development, amendment, and mobilization of "domestic and international laws" for geopolitical and military gain [117]. These forms of aggression are not typically characterized as "war," but rather in such forms as trade negotiations, immigration policies, tax and financial regulations, bilateral treaty negotiations, regional pacts, cartel arrangements and other similar forms. The development of legal standards for the protection of statutory and contractual rights, the enforcement of legal duties and the reliance on predictable legal processes when exploited as a means of deterring, binding, and protecting individual and organizational interests' actions in conflict with others is often difficult to detect in the churning and dynamic landscape of legal conflict. While legal notions such as "abuse of process" are intended to curb excessive and socially-destructive application of law as a sword, the subjective and contextual aspects of legal forms of conflict can obscure root causes and intentions of conflict in many cases. AIC, with its affordances for modeling and inferring internal models and policy, could be of use in classifying and detecting patterns of legal actions and consequent leverage within myriad interaction niches in order to more effectively measure, moderate, and manage legal conflict affordances at tactical, campaign or theater, and strategic levels.

Technical

Technical infrastructure, standards, and protocol are bounded by both computational and legal rules. The dynamic technical edge between these two areas is of particular importance for the future of conflict as human attention turns from a focus on data secrecy as a basis for conflict mitigation strategies, toward a focus on information integrity as a pathway to reducing information risk and interaction conflict.

Data plus meaning yields information. Data security is necessary, but insufficient, to yield information reliability and distributed security. "Meaning" security is needed to complement data security to manage information network conflicts. While data security is the focus of technical features of the Internet and modern computer science, "meaning" security is the focus of law. Consider that all contracts and laws can be viewed as enforceable "stories" about the past, present, and future. When those stories are agreed upon and acted upon, they de-risk future interactions in ways that no one person can achieve by themselves (for example the laws and technical specifications that interact to de-risk otherwise hazardous situations such as highways and exchanges). Such enforceable stories are the way that humans achieve "meaning security." Contracts and laws are all promises that we make to ourselves and others about the future, and the law is a mechanism to test our performance against those agreed upon parameters. In this way, it is not unlike technical specifications that set rules of general application for the technical performance and behaviors of engineered systems.

As the desire for verifiable information integrity supersedes yesterday's satisfaction with data security, the human and organizational components of systems will be increasingly recognized as critical system components, not just as users of systems. Legal and technical paradigms are tightly intertwined in information systems, where technical specifications help assure data system integrity and legal rules help assure meaning system integrity, with the result of enhanced information system integrity. Such "tools and rules" leveraging will be accelerated through application of AIC framings that will quickly reveal the potential alignments of such systems. Such analyses will be critical to the advancement of various information integrity structures to help manage the conflicts that are bound to arise through the introduction of such new distributed information integrity structures as decentralized management of intellectual property, the introduction of digital "twins", smart contracts, computer-aided governance, and the progression of data privacy- and information integrity-related legal structures.

Emerging interaction structures provide a sense of the challenges and opportunities that reveal themselves at the intersection of technical and legal interaction and conflict management use cases. Historically, notions of intellectual property law (involving copyright, patent, trademark, certification mark, and trade secret) have always blurred the boundaries between physical and intangible value of goods and services in commerce. In terms of decentralized management of intellectual property, consider that nation states and the Westphalian system are based on physical boundaries and borders, hence the exclusivity (rivalrousness) of ownership of real property (e.g., land). At its base, the Westphalian paradigm of enclosure and exclusive jurisdiction may be fundamentally inconsistent with the infinite duplication that is possible with information. This may mean torturing new technical expressions of intellectual property to fit this previous legal, business, and operations paradigms, for example through primarily interpreting and designing non-fungible tokens (NFTs) as an expression of ownership of a given represented object (e.g., a particular artistic image), or by developing new systems which acknowledge these changes, for example through primarily interpreting and designing NFTs as an expression of rights, stake, and affordances related to some given represented object. In terms of digital twins, the notion of the identity entanglement between the referent human and their digital extension, as well as tangible and intangible property and their digital extensions (e.g., NFTs), introduces just one category of many fundamental shifts ushered in by the transition from physical to digital worlds - similar in potential impact to the introduction of corporate depersonalization or personhood, or of nation states themselves. Further, consider the introduction of decentralized autonomous organizations (DAOs) which may be composed of both human and adaptive autonomous entities and what this means for legal accountability, internationally and domestically. The legal handling of these transitions is thoroughly non-trivial - as one path might lead to serious implications for nation states and the foundation of their sovereignty (e.g., no one can force or coerce a public blockchain to grant and revoke an affordance) while another might lead to a substantially more powerful, and consequently, dangerous foundation for sovereignty (e.g., governments able to computationally force or bar interaction in a digital-focused society).

Social

Simulation and modeling of narrative and social conflict can be notably difficult due to underlying challenges in accurately characterizing and modeling situational features that are relevant for ActInf agents [32]. AIC's nested ActInf entities and their affordances for flexible representation of internal models and policy offers a common avenue for various extant and new approaches in representing ideological, psychological, narrative, and memetic conflict, as well as deterrence. Recently various models of dyadic and collective social interactions have been implemented using ActInf entities [112,118–120], suggesting a strong possibility for these kinds of models to be deployed in the case of conflict. The implications of using AIC in work on cognitive security and narrative management is discussed further in the discussion of modeling cognitive security.

Modeling Cognitive Security

Cognitive security (COGSEC) here refers to the study, development, and implementation of "practices, methodologies, and efforts made to defend against social engineering attempts - intentional and unintentional manipulations of and disruptions to cognition and sensemaking" [121]. COGSEC is difficult to measure and model for the same reason simulation and modeling of narrative and social conflict is - there are distinct, underlying challenges in representing and predicting the effects and attributes of internal states. AIC, as previously stated, offers opportunities for representing internal states of entities in relation to external conflicts, emphasizing impacts on cognition and sensemaking. However, AIC's potential uses in the study of COGSEC go further: recent work on scripts and context-driven reflexes in ActInf [119] rely on the same structure and methodologies as AIC and have great potential in being applied better understanding relevant threat surfaces, given that so much of the threat surfaces relevant to COGSEC and social engineering are related to development and exploitation of reflex for both offensive and defensive purposes [122]. COGSEC methodologies found in social engineering and counter-deception literature could be simulated and considered using AIC, to better model and measure COGSEC and also consider how traditional methods such as the "reduction of the complexity of problems, introduction of routine and bureaucratic procedures, the choosing of satisfactory solutions rather than optimal ones, [and] giving preference to partial solutions at the expense of comprehensive ones and avoidance of new problems", and more recent approaches such as narrative information management [123], common vulnerabilities and exploits (CVE) databasing of narrative influence techniques [32], and engagement with narrative content [64,124] might affect state and expression of COGSEC in a variety of entities.

Implications from Use: Future Information Structures and Rumsfeld's Neglected Quadrant

Usage of AIC to represent modern conflict and the BOLTS structures which interact within it provides insights beyond the projection of winners and losers in iterated games. Of particular interest are implications regarding the nature of the BOLTS structures themselves and the prioritization of their objectives in the reduction of uncertainty in their niche. Here we consider these implications before concluding and offering recommendations for future technology development.

One of the implications of the move of the human species from physical toward information-based interaction landscapes is the reduction in efficacy and relevance of those historical institutions that provided reliability and protection for humans in physical spaces. As conflict becomes more abstract and less obvious, these traditional institutions are revealing their lack of fitness for governing in non-physical domains. While physical existence still precedes and is prerequisite for the achievement of other states and satisfaction of other needs, as reflected in Maslow's hierarchy of needs [125], human interactions will continue to be increasingly dependent on the information landscapes in which nation states, and other organizational structures, are struggling to replicate the status quo. This struggle of legacy institutions to understand and manage conflict in an inherently incompatible information landscape, is forcing individuals to seek alternative structures of risk reduction to help them navigate.

Using AIC as a qualitative lens renders all conflict as a form of information generation for the participating agents, with violent conflict constituting a "costly ping". In the past, the information generated from conflict might have been found in the numerous post-mortems and experience-informed treatises after campaigns [26] or in what could be called proactive intelligence, information about the enemy assembled after engagements [126] - however, now that conflict is increasingly situated in the information landscape and that the underlying "assets" and "territories" that are the objects of social, political, economic, and legal attention have shifted from physical emphasis to information emphasis, new structures are offered the opportunity for unparalleled management, monitoring, and facilitation of conflict. As well as the opportunity to define, via BOLTS norms, rules, and infrastructure, how conflict can be approached and resolved. AIC may be of use in both the design and implementation stages in these pursuits, and can provide alternative pathways that can be applied in those settings.

Another consequence of this move from physical to information emphasis is the non-rivalrous nature of informational assets. Physical property (whether real estate or tangible personal property) is rivalrous - its use and enjoyment cannot be simultaneously and exclusively enjoyed by multiple parties. Territorial expansion and the plunder of property reveal the rivalrousness of historical nation state conflict. In terms of digital materials - it is possible for two people to enjoy the use of the same software simultaneously, to read the same book, to watch the same movie, or to access the same data for different uses in different contexts without diminishment of the use and enjoyment of another. Further, physical assets are generally scarce and increase in scarcity over time - whereas the amount and complexity of information which can be generated as well as the rate of its growth is infinite. Both are expanding rapidly and creating structural hurdles to both individual and organizational situational awareness - the ability for organizations to manage this information effectively is strained [123].

Using Rumsfeld's Quadrants, which frame the information spaces and voids of value to organizations, as a lens over conflict both between organizations and between organizations and abstract phenomena (e.g., "war" on cancer, drugs, COVID-19), highlights Rumsfeld's neglected quadrant, "unknown-knowns". Further, it suggests that this neglected quadrant is a doorway from the static to the dynamic perspective on knowledge systems. The first three quadrants are described from the perspective of a centralized hierarchical party or bureaucracy - things are either known or not to that party, without reference to interaction with other parties that might alter the status of knowns and unknowns. On the other hand, this neglected quadrant appears to be a paradox: How can a given party not know a given "known"?

For any individual ActInf entity, an unknown-known appears to be an impossibility - its known-knowns and known-unknowns are accessible within its internal state and its unknown-unknowns represent relevant voids within its internal state that it does not yet identify as such - which begs the question: Where is there room for an unknown-known? The AIC model helps to formalize several situations in which unknown-knowns exist:

Known but Inaccessible

An ActInf entity may hold relevant information that goes unused in policy formulation as a result of it not being immediately accessible.

Failure of Curation

An ActInf entity may hold relevant information that is technically accessible but goes unused because of poor cues or the absence of indications of relevance.

Back Turning

An ActInf entity may ignore relevant information because it may contribute to policy formation which conflicts with some other existing policy, prior belief, or contextual model.

Selective Disclosure

An ActInf entity may have information that is accessible but will not access it in the interest of security or efficiency.

Known but Undeciphered

An ActInf entity may have latent information available which has not yet been deciphered, extracted, or codified.

Insufficient Communication Dynamics.

An ActInf entity composed of nested Entities, each with their own internal models, may fail to make use of relevant information due to insufficient internal communication dynamics.

Most important among these several dynamics, is the notion of unknown-knowns within multi-agent systems. The moment that the ActInf entity interfaces with another in cooperation, they become a new perceivable entity, each with internal states that may be more or less synergized. Each has known-knowns and known-unknowns that the other is not necessarily aware of, constituting unknown-knowns in the context of the organization. The AIC model provides support for the argument that, in a turbulent and information-rich environment, top-down management of information dynamics is no longer sufficient - that Rumsfeld's initial prioritization of unknown-unknowns must give way to a prioritization of unknown-knowns, where "more than sufficient knowledge" exists but goes unused or misused in policy formulation due insufficient communication protocols, leading some to call for knowledge and rhetorical ecosystem approaches in the design of more decentralized information systems [123,127].

In this vein, the primary focus of the field of knowledge management might be considered to be addressing the problem of unknown-knowns. As has been addressed elsewhere, when the information management system in question begins to include parties outside the confines of a traditional organizational structure, the management of trust becomes a key concern [123]. The AIC model, in its use as a lens, demonstrates the value of trust in sharing unknown-knowns in a knowledge ecosystem in the form of several notable insights:

Trust is Synonymous with Reliability

Through an ActInf lens, trust is best characterized as projected reliability (e.g., high precision, or low uncertainty) of both other ActInf entities and indicators which inform projection.

Trust can be Externalized to Interfaces

ActInf entities don't necessarily need to trust one another, but instead, can externalize trust to interfaces and related protocols among them in their niche to reduce costs of communication.

Trust can be Externalized to Symbols and Signals

Given that trust is best interpreted within an ActInf context as projected reliability, symbols and signals can thus be "trusted". For example, traffic signals allow drivers to externalize their trust to signals which inform the projection of other drivers' behavior, as opposed to being left to develop trust with other drivers in order to share the road.

Trust is a Prerequisite for Efficient Information Sharing

ActInf entities that question the motives or quality of communications, have high costs in interpreting or accepting those communications.

Trust is a Prerequisite for Collaborative Enterprise.

ActInf entities require trust, commensurate with associated risks, in order to engage in collaborative enterprise. Recently this has been explored in the context of human-robotic interactions [2].

We argue that these insights about unknown-knowns, trust, and the non-rivalrous nature of the objects relevant to modern conflict should inform the development of new structures, and offer recommendations for how in the discussion below.

Discussion

In this paper, we have briefly surveyed models of conflict, considered their strengths and inadequacies, proposed a unifying model based upon the application of Active Inference (ActInf), and considered the implications of use of the Active Inference Conflict (AIC) model. The initial survey revealed that the study and modeling of warfare progressed generally through time from inventories of tactics toward more theoretical and ultimately more abstracted and context-informed analyses. That evolution of the models could be framed as mirroring the parallel development through time of human understanding of human structures of information, as well as structures of cognition, organization, and interaction across the sciences and social sciences, including patterns of conflict in those disciplinary domains. For example, as discussed above, early quantitative models of conflict such as the Lanchester model used mathematical tools that were modern at the time, such as linear regressions and differential equations.

Today, similar analytical and paradigmatic (r)evolutions are taking place in research and understanding about human commerce, behaviors, political governance, and other related domains, ultimately positioning the subset of behaviors and interactions associated with "war" as categories of a subset of patterns of human history and society - albeit patterns that are a non-linear in relation to others. Clausewitz's observation about politics and war is consistent with this notion of the evolution of the human understanding of the human condition, but following the results of the survey, we contend his famous quote, that "war is the continuation of politics by other means", is incomplete within this context as it would appear that both war and politics are a continuation of conflict by other means (and, in fact, conflict is a continuation of the normal function of living systems in just another analytical framing).

The survey revealed an increasing abstraction and formalism in the modeling and study of conflict and war, evolving from catalogs of physical battlefield heuristics toward broader and more detailed analytical framings of context and motivations for physical forms of conflict. However, it also indicated that many of the models are underdeveloped for current applications and struggle to address the changing expression of war and the migration of human interactions from predominantly physical interactions (i.e., kinetic warfare) toward abstract, symbolic, and intangible interactions within information landscapes. Further, the survey disclosed that existing warfare models did not have the necessary generalizability to be broadly applicable to the relevant expressions of conflict in other social contexts, and that the models are rarely interoperable.

Following this survey, we proposed the use of ActInf methodologies and terms in modeling conflict and named this application the Active Inference Conflict (AIC) model. The AIC model is intended to represent a needed updating of conflict framing to reflect changes in human interaction patterns, and also provides built-in mathematical rigor that could be used to facilitate the organization and operation of future conflict management architectures. The AIC model, as a consequence of it being founded on the matured quantitative models of ActInf, is tractable to simulate, can incorporate empirical data, and also can immediately be implemented qualitatively to produce novel insights about various forms of conflict. We discussed how this approach, with its affordances for sense and action loops, multi-entity interactions, entity nesting, and policy selection offers old models a new medium for their expression and interoperability while also providing avenues for generalizing conflict modeling which can capture relevant aspects of modern conflict.

Specifically connecting the AIC model to OODA and GW demonstrated the relevance of integrating previous tactical and strategic frameworks within a single multi-scale formal model. Of particular interest was the consideration for the ability of AIC to capture conflicts which have business, operations, legal, technical, and social components, to move beyond generations and gradients of war and offer a new medium for capturing metrics for classifying and clustering myriad forms of conflict, and to model emerging conflict surfaces involving cognitive security and narrative warfare.

Finally, we considered broader implications suggested by qualitative application of the AIC model to conflict generally. We reflected on the state of the information environment, noting the difficulties that traditional institutional and governance structures are having in handling modern information-based conflict and that new, alternative structures for risk reduction are being offered the opportunity to provide value. In addition, we reflected on the non-rivalrous nature of information-as-asset and the infinite potential for information growth, and how these factors affect organizations - mainly in terms of processing information load - which is a useful surrogate for risk. Within these reflections, we suggested that the AIC model is not just useful for the study of conflict but also in the design of systems which manage it. Finally, we applied the AIC model to reveal latent insights about trust and knowledge environments within the Rumsfeld

Quadrants, specifically regarding its oft-neglected quadrant, "unknown-knowns".

The AIC model, as previously discussed, provides an avenue for formal modeling of systems - but this same affordance also facilitates design and evaluation of the design of systems, and to implement and test BOLTS norms and rules. This is to say that a socio-technical system modeled with the AIC model can effectively be a "twin" of that socio-technical system, and thus can be used for more than just studying its conflicts, but also for managing and facilitating endogenous information conflict and friction itself. It took humans millennia to figure out how to convert the random motion of atoms energized by heat from fire into useful "work" through the use of heat engines. The AIC framing invites consideration of how the equivalent of a "combustion chamber" might be configured for converting the friction of disagreement into useful work within a knowledge environment in terms of developing new information, repairing faulty or incomplete information, discovering unknown-knowns and unknown-unknowns, and helping entities within develop trust and healthy information flows. Within this context, de-risking of interactions in which information exchanges occur could be seen not as a state, but as an ongoing process - which places pressure on designers of information systems to develop simple rules and effective protocols.

Past work has considered how humans and human organizations collaboratively organize, annotate, and structure claims as a form of narrative information management [64,123,128], and could be of use in conjunction with the AIC model to build tools which document, facilitate, and resolve informational conflicts with an objective dimensionality from the AIC model that leverages existing approaches. Further, these pairings of approaches could help give new life to the older narrative models of conflicts and unify them with the work on commons management [79], as it could provide a new medium for formalizing, documenting, and sharing of heuristics and practices for risk mitigation [32].

As the rate of information growth continues to explode outward in both volume and complexity, the AIC model reveals that the search for unknown-unknowns or known-unknowns may need to be deprioritized, as this information may fail to be disseminated and integrated - rendering most relevant information as unknown-knowns. Where "hope" was left in Pandora's box, it might be said that "trust" was left in Rumsfeld's matrix. The AIC model helps to demonstrate and codify the value of trust in knowledge ecosystems which facilitate the sharing of unknown-knowns, and demonstrates how trust can be externalized to protocol and signals through their being reliable indicators of quality and behavior. Ultimately, a primary suggestion of this work is that facilitating mutual interdependencies, interfaces, and trust-management frameworks, key prerequisites to sharing unknown-knowns, could attract an increasing subset of information conflicts into generative structures (perhaps best framed as structures which operate in the manner of what might be called a "risk commons") which can capture value and grow trust, rather than accelerate discord. Below, we distill these and other insights within this work into recommendations for future research and the design of new systems:

- Develop more work on the use of the AIC model in extending the value of OODA loops in simulation and decision-making models. This could utilize complex systems modeling software such as cadCAD [129], and those specifically for ActInf such as ForneyLab [130] or infer-actively [131].

- Explore the use of the AIC model in modeling past conflicts as a basis for measuring various attributes of those conflicts, and the use of those attributes for new classifications and "generations" or gradients of conflict.

- Explore the use of the AIC model and the integration of commons management principles and compensating controls across business, operations, legal, technical, and social (BOLTS) surfaces.

- In the design of information exchange systems:

    - Acknowledge de-risking as an ongoing process, rather than as a static attribute.

    - Consider trust as synonymous with perceived reliability.

    - Make use of the fact that trust can be externalized to signals and symbols so long as those signals and symbols are reliable indicators of behavior and state.

    - Consider disagreement, inconsistency, and incoherence as events which can be mined for value via shared protocols and standards rather than creating an illusion of security through attempts at their removal.

- Across many domains (e.g., war, scholarship, and design), reprioritize Rumsfeld's neglected quadrant of unknown-knowns.

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Administration and Facilitation: R.J. Cordes

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