Narrative Information Ecosystems

Conflict and Trust on the Endless Frontier

EDITED BY

Richard J. Cordes

Daniel A. Friedman

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Mankind are not held together by lies.
Trust is the foundation of society.
Where there is no truth, there can be no trust,
and where there is no trust, there can be no society.
Where there is society, there is trust,
and where there is trust,
there is something upon which it is supported.

—Frederick Douglass, *Our Composite Nationality*

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"Striving with Systems to deliver Individuals from those Systems"

— William Blake, *Jerusalem 11*

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The 2021 cohort of COGSEC Contributors; ActInf Lab; Complexity Weekend; The Davids; The seen and unseen heroes who tend to their trimtabs with diligence and vigilance.

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There is no power for change greater
than a community discovering what it cares about.

—Margaret J. Wheatley, *Turning to One Another*

EDITORS' FOREWORD

In 2021, the Cognitive Security and Education Forum (COGSEC, cogsec.org) intended to apply the research findings of its 2020 volume, "The Great Preset: Remote Teams and Operational Art", to facilitate research related the management of information with respect to its impacts on sensemaking and narrative. To this end, the COGSEC 2021 research initiative was titled "Narrative Information Management" and made a call to action to researchers and professionals of myriad disciplines to inform the development of tools which could reduce the cognitive load and stabilize the cognitive security of users. We hoped that, through the use of project "catechisms", a type of lightweight project documentation proposed in two separate chapters of the 2020 volume, this year's initiative would see more collaborators, more interdisciplinarity, and more impact than in any year prior. As 2021 comes to a close, we can say that this year's initiative has been a success and an important developmental phase. So much so, that this edited volume is but one of the resulting traces of this year's initiative - in addition to the four chapters included in this edited volume, COGSEC facilitation helped to produce a number of other deliverables, including a number of externally published articles (e.g., "Games with Serious Consequences - Extremist Movements and Kayfabe"), 2 playbooks ("The Innovator's Digital Playbook", "Facilitator's Catechism

Playbook"), and another full book on narrative influence and formalization ("The Narrative Campaign Field Guide"), with over a dozen other attributed and unattributed contributors. In this foreword, we will distill the insights of each of the chapters included in this volume and discuss COGSEC's ongoing initiatives and intents for 2022 and beyond.

Chapter 1, "Narrative Information Management" provides an integrative overview and a series of disciplinary explorations regarding Narrative Information Management (NIM). General features of NIM include enabling situational awareness, distilling large knowledge databases, providing actionable insights to users, and facilitating collaboration synchronously and asynchronously. Some of these general features of NIM systems had been historically emphasized in the field of intelligence analysis, while other NIM features (such as the centrality of narrative in the neurophysiology of sensemaking, or relevance of computer graphics) have arisen more recently and in fields outside of intelligence analysis. A finding and implication of NIM is that fields which have not traditionally been information-centered are increasingly dealing with informational and cognitive challenges – motivating a transdisciplinary effort to learn best and emergent practices across fields. The project catechism used to produce this work is included in Appendix A.

Chapter 2, "Digital Rhetorical Ecosystem Analysis: Sensemaking of Digital Memetic Discourse" integrates rhetorical, ecological, and computational approaches towards studying online communication and addressing the ongoing epistemic crisis. The introduced Digital Rhetorical Ecosystem three-tiered (DRE3) model allows for distinctions among instrumental observations of discourse (e.g., observations of image memes or text online), contextualized rhetorical claims (audience-specific arguments and deployments), and inference on hidden states (important attributes of rhetorical ecosystems such as capacity for innovation and risk of extremism). This work builds on previous work on image memes as quasi-arguments, as well as advances in pipelines for high-throughput ecological analysis and computationally-aided sensemaking. The project catechism used to produce this work is included in Appendix B.

Chapter 3, "Knowledge Management Archipelago" presents a literature meta-analysis of keywords and themes related to knowledge and information management. As the title of the chapter suggests, publications on these topics are like an island archipelago in that they are fragmented and disparate, however potentially with a higher-level pattern visible from high enough elevation. Keyword co-mention overlap quantification and network analyses found that terms differ in how they bridge concepts and fields. Future analyses could include time-dependent methods to explore the interactions of keywords through time, and estimation of literature corpuses outside of public databases (e.g., relevant texts that are patents, proprietary, or classified materials). The project catechism used to produce this work is included in Appendix C.

Chapter 4, "Active Inference in Modeling Conflict", provides a review of past qualitative and quantitative approaches to modeling conflict, then proposes the Active Inference Conflict (AIC) model. The AIC model applies Active Inference, a first-principles framework for action and perception, to the setting of conflict. Several features of the AIC model that facilitate its use include its powerful computational basis, interoperability with previous conflict models, and generalizations relevant for contemporary settings. Additionally, the AIC model provides continuity between the various manifestations of human conflict, and modern work in cognitive sciences. Combining the AIC model with a BOLTS (business, operations, legal, technical, social) lens on conflict leads to rethinking of risk management, and suggests future directions for research and application. The project catechism used to produce this work is included in Appendix D.

These four works which comprise this volume are not the total scope of work performed during the year, or necessarily the end of work on Narrative Information Management. The call to action by the 2021 COGSEC NIM research initiative generated and impacted working groups and collaborations that are continuing on, placing us in a novel, and in some ways inconvenient position. A position which prompted questions such as:

- Do we continue on to a new research initiative next year, while still providing support for the previous call to action?
- Do we extend the period of the NIM initiative to 2 years?
- Do we abandon annual periodicity entirely?

Answering these questions required consideration of this year's approaches, feedback, and achievements. During this review, we came to the realization that underneath the set of deliverables and their contributions was another success - the success of the methods, process, and tools developed in 2020. In particular, the successful implementation of project catechisms provided the opportunity to observe their impacts in moderating the cognitive load of teams and increasing reliability of outputs. This led us to an interesting opportunity, one which would allow us to continue active support for 2021's call to action regarding Narrative Information Management while still being able to focus on the development of tools and applied research as we had hoped to do in 2022.

In 2022, the primary COGSEC initiative will be "Catechisms for Open Source Science Integration" (CAT-22), building upon the research in prior years. In CAT-22, COGSEC and collaborators will explore applied research and the scalability of the project catechism approach, and the development of tools related to their implementation. During a time of rapid change in the global research and innovation ecosystem, new approaches for research funding, implementation, communication, and reducing time-to-impact are desperately required. Catechism-based research for emergent or instantaneous remote teams presents an actionable and scalable framework for modern collaboration, consistent with values of rigor, accessibility, inclusion, participation, and open-source intelligence (OSINT).

Additionally during 2022, COGSEC will continue the 2021 NIM initiative, as a test of the catechism approach for distributed research teams and its scalability, by integrating the 2021 initiative into collaborations with the University of Washington Applied Physics Lab's Information Risk and Synthetic Intelligence Research Initiative (IRSIRI), through its participation in the US National Science Foundation's (NSF) Convergence Accelerator. This integration will allow us to further test and refine the methodology with many more collaborators while continuing to facilitate research on NIM and pursuing COGSEC's goals related to tool development. COGSEC will next seek out partnerships with other organizations which may benefit from the methodology being integrated into funding, work, and reporting processes, and look to develop tools which help facilitate adoption and implementation. We do not know what the end of 2022 will look like any better than we knew what 2021 might look like (we were certainly all wrong about 2020). But just as we did in the years prior, we will strive for rigorous, productive, and meaningful collaborations.

In early 2022 or any future moment, we are calling for collaborators who are interested in helping to build a more resilient future (see cogsec.org for updated information on participation).

CHAPTER I

Narrative Information Management

Richard J. Cordes, Shaun Applegate-Swanson,
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ABSTRACT

There are many areas of research defined by their interest in information dynamics related to facilitating organizational sensemaking, such as knowledge management, information management, and library science, and many more areas of research, disciplines, and even hobbies which are facing information-related challenges. While all may be concerned with very similar challenges, lack of information exchange and common ontology between these areas may be causing silos, missed opportunities, and potentially even friction among areas. In this paper, we address the need for synthesis and exchange of knowledge, tools, and approaches among various fields by proposing Narrative Information Management (NIM) as a unifying term and framework for the fundamental features and challenges of facilitating collective sensemaking. Through this framework, we offer an initial common set of features of impactful information systems found in literature on information-focused disciplines, such as knowledge management, and explore what insights and ad-hoc solutions may be found in an eclectic set of fields facing information challenges, including personal finance, ancestry research, hybrid cloud infrastructure security, translational neuroscience, and genomics. Finally, we offer recommendations for future research.

Introduction

When the brain cannot reduce the complexity of the environment, it reduces the complexity of the strategy used to make sense of it [1–7]. This difficulty in reducing the complexity of a given information environment is often referred to, depending on context, as either data overload [8,9], reference overload [4], information overload [5,9,10], or, more broadly, as cognitive overload [3,11,12]. The volume, density, and structural complexity of information has impacts on cognition beyond increasing time-to-insight [1,3]. Unfortunately, simply providing more information as a basis for improving decision-making and sensemaking may make outcomes worse rather than better [3,7]. When an individual is exposed to potentially relevant yet contradictory information at a rate inconsistent with the time and effort required to integrate, and does not have access to appropriate tools, a trusted network of experts, or domain-specific training, they may withdraw from their role in the environment or experience anxiety and reduced ability to manage stress, set priorities, make decisions effectively, and detect logical inconsistency [1,3,6,8,13–16]. Failures of individual cognition and decision-making can lead to cascading errors in systems, highlighting the importance for understanding the nature of these informational pathologies and how to avert them in modern settings [17].

In this paper, we highlight the need for synthesis and exchange of knowledge, tools and approaches among various fields concerned with addressing these sensemaking challenges through the framework of Narrative Information Management (NIM). First, we present a broad summary of the challenges faced by information-centered disciplines such as knowledge management. Following this summary, we consider the value of using NIM as a unifying category of features, or functions, within information systems used or designed by these disciplines. We then synthesize a set of common features which contribute to effective NIM systems and consider how they can be understood from a NIM perspective. Next, in the interest of discovering additional feature needs and requirements which may not be well-recognized within information-centered disciplines, we explore an eclectic selection of disciplines that, while not primarily focused on information dynamics, are increasingly experiencing informational challenges. These disciplines include retail finance, amateur ancestry research, genomics, neuroscience, and hybrid cloud infrastructure security. In each of these areas, insights about requirements and the domain-specific challenges and ad hoc solutions for NIM are considered. Finally, we conclude with a discussion assessing common features found and discovered amongst the discussed domains and with recommendations for future work on NIM.

The Past and Present of Solutions to Cognitive Load

Throughout human history, solutions designed to reduce cognitive load and facilitate individual and organizational action have emerged as a response to increases in local information complexity. Broadly, human action-oriented sensemaking can be seen as a type of narrative inference, where individuals are able to act appropriately to the extent that they have identified the story they are in and role they play [18,19]. Domain-specific approaches to sensemaking have also been developed. In economics for example, mechanisms for externalization, abstraction, and communication of financial information emerged in response to the numerous explosions in economic complexity caused by the opening of new trade routes [20–22]. In science and scholarship, changes to methodology and tools for research and the maintenance of doctrine have traditionally followed paradigm shifts in science as well as sociotechnical changes such as increased volume and accessibility of research publications (e.g., such as those caused by the introduction of the printing press) [2,23–25]. Changes to the scientific process and research methodologies are not just lagging indicators of change to publication systems – historically, the development of information management systems has resulted in shifts in how information is synthesized and communicated. For example, the first reference management systems and formalized cartographic procedures were generated at the Library of Alexandria and funded by its stakeholders in order to process and exploit an unprecedented flow of information and new discoveries [26–28]. Finally, in military operations, documentation and intelligence processes and tools have consistently been adapted and updated in response to increased complexity in geopolitics and mobility in the battlespace [29–32].

The introduction and continued development of digital communication and storage technologies have caused changes in the accessibility, communication, structure, presentation, and production of information at a historically unprecedented rate [33,34]. The challenges and opportunities presented by these new technologies have illuminated the need to reduce cognitive load and facilitate sensemaking. The need for research in this domain will only continue to grow as these technologies develop and increase in informational complexity and volume in the coming years. Nearly 60 zettabytes (60 trillion gigabytes) of data were created in 2020 and the expectation is that the amount of digital data created between 2021 and 2025 will greatly exceed the cumulative amount created since the advent of digital storage [35,36]. Data sets alone and in any size can overwhelm analysts if data are ambiguous, inaccurate, structurally complex, or require specialized analysis. Additionally, transdisciplinary projects for small teams as well as larger organizations require groups of analysts to come to a shared operational understanding of the topic, potentially involving significant data engineering, modeling, and analysis. For example, with over 7,000 peer-reviewed scientific and engineering articles and countless preprints, datasets, and other relevant materials being published each day, academics and researchers are prone to a state of information overload without the presence of big data dilemmas [37–40].

Unlike past paradigm shifts in information dynamics, where only certain groups such as generals, government officials, or employed scholars were faced with significant demands for adaptations to these changes [26,27,29,31,41], broad adoption of digital information technologies implies that the majority of organizations and citizens, outside the context of any particular discipline, are now in need of tools to overcome challenges related to managing streams of digital information and reducing informational complexity [16,42–46]. Now in the throes of the COVID-19 pandemic, not even children are spared of the need to spend additional effort on narrative sensemaking [47]. The timelessness of challenges related to sensemaking, paired with their distinctly-different application across sectors, means that research addressing information overload has the potential to become siloed and disconnected due to differential usage of keywords, citations, and types of deployed systems [42].

There are already many formalized fields of research which focus on how to design and implement systems, protocols, and procedures to store, manage, communicate, synthesize, curate, and search digital information to help manage the cognitive load of users. Significant examples of interacting fields and topics include knowledge management, information management, and library science [42]. Modern organizations operating in information-rich environments look to these information-centered fields for the solutions that they influence, design, and implement in the interest of reducing cognitive overload. For different users in different scenarios, such sensemaking tools might assist in maintaining situational awareness, facilitating reduction in information complexity, navigating users toward effective action, or the creation, sharing, use, attribution, synthesis, and management of intelligence and knowledge products. As the volume and structural complexity of the available or presented information increase, systems in this category tend to shift from a facilitating role to being essential to operations. In such cases, the usefulness of a given system can be related to its efficiency in helping users meaningfully aggregate data, develop understanding, and navigate toward action, as opposed to simply being tied to the provision and access of information [1,48–51].

Knowledge management, information management, and library science are representative examples of fields which have information dynamics as a primary focus; however, these are not the only fields concerned with information dynamics [42]. There are many other areas of research, disciplines, and even hobbies which require attention to theory and implementation of information-related systems and data-rich processes. Solutions for domain-specific or even generalized sensemaking may arise within these areas, potentially drawing from the literature within the fields listed above, or using tools reflecting these fields. However, this relationship may be one-sided between information management in the general cases, and domain-specific applications: various fields may draw tools and frameworks from the informational sciences, but rarely translate their feedback or requirements back to the informational sciences. This disconnectedness may cause failures to communicate insights and implementations across areas of theory and practice, leading to further siloing, confusion, and disconnection [42,52]. Recent analyses have suggested that even the fields which share information dynamics as a primary focus show only partial bibliographic and theoretical overlap, reflected by divergent ontologies and professional scope [42,53].

The fields and specializations which are primarily focused on how to design and implement systems, protocols, and procedures to store, manage, communicate, synthesize, curate, and search digital information are numerous and divergent, and have been for centuries. For example, by 200 AD the Roman Army had formalized many roles associated with management of information, including interpretes (interpreters who worked to archive translations of written and vocal communications), librarii (archivists), notarii (secretaries and records managers), exacti (recorders and scribes), exceptores (short-hand recorders and scribes), frumentarii (messengers and information collectors), quaestionarii (human source development), and spectulatores (information collectors), each representing a formal discipline with its own specialized training [31]. By roughly 1100 AD, the storage, access, synthesis, sharing, and curation of documents, records, and knowledge held within libraries was considered a formal science in China with overlapping sub-disciplines [54]. As noted earlier, the introduction and development of digital storage and communications technologies has meant that modern organizations and individuals are contending with increasing information-related challenges. As sensemaking processes diverge across fields, there is a higher potential for divergent ontologies to develop and siloed practices to occur. It may be time for synthesis and generalization of the underlying sets of challenges and requirements within these myriad domains in order for research and solutions to become more easily discovered and integrated, as well as to prevent redundant research [51]. Here we offer a brief summary of 3 categories of divergent, information-centered fields and areas of research.

Meta-Information Fields. The term meta-information fields is used here to describe the category of fields which are concerned with information flows and use in general, with no defining interest in any particular field. In this category are the fields of (1) knowledge management, (2) information management, (3) information engineering, (4) records management, (5) document management, (6) archive management, (7) reference management, (8) data, information, and sensor fusion systems, and (9) information resources management. For example, knowledge management refers to the design, implementation, and study of processes and systems related to creating, sharing, using, attributing, synthesizing, and managing the knowledge and information of a group or organization in order to improve situational awareness, decision making quality, knowledge transfer between organizational components, and productivity [42,46,55].

Interdisciplinary Information Fields. The term interdisciplinary information fields is used here to describe the category of fields which are concerned with the provision and design of information systems which are intended for use in some common category of disciplines. In this category are the fields of (1) library science, (2) intellectual capital management, (3) relationship management systems, (4) decision support systems, (5) case management systems, (6) situation awareness systems, and (7) intelligence management. For example, library science is primarily focused on providing features and insights for the management of documents within organizations whose primary purpose is to lend and manage information resources [56], and intelligence management is concerned with the protocols and procedures that facilitate situational awareness and the creating, sharing, using, attributing, synthesizing, and managing of relevant intelligence products and information streams in law enforcement, military and intelligence, and manufacturing and industrial settings [57–60].

Application-Focused Information Fields. The term application-focused information fields is used here to describe the category of fields which are concerned with the provision and design of information systems which are intended for use in a specific discipline. In this category are the fields of (1) command and control systems, (2) intelligence, surveillance, and reconnaissance systems, (3) intelligence fusion systems, (4) asset management systems, (5) supervisory control and data acquisition (SCADA), (6) security management, (7) business intelligence systems, and (8) learning management systems. For example, an asset management system is a set of protocols and procedures tied to software which facilitates situational awareness of, decision making related to, and the planning and controlling of financial assets, relationships between assets, and asset-related activities [57], and SCADA researchers are primarily interested in providing information tools to organizations which have to remotely monitor and intervene in mechanical or industrial systems [58].

Instead of focusing on simply storing, moving, reading, and writing bytes of data, these information-centered fields are concerned with the facilitation and meaningful direction of data-transfer. A formidable gap exists between the raw syntactic inputs provided by information databases and the semantic or action-oriented representations that an end user might expect to receive as a result of an interaction with the system [51]. Even records and archive management, which might rightfully be assumed to be primarily about storage processes, are equally concerned with the nature of access and user dynamics [59–62]. This focus on facilitating semantic interactions with humans helps distinguish these areas from disciplines like computer science and from meta-disciplines such as information science, which may include within their scope both consideration for use-cases and practical aspects of digital transfer and transformation of information [63,64]. It also reflects one of the earliest maxims from the oldest of the information-centered fields, library science: "Libraries are for use" [54].

Systems that are influenced, designed, and implemented by information-centered fields have disparate use-cases; however, many integrated sensemaking systems can be generalized, or reduced to parts that can be generalized. We identified several features commonly used in information management across domains, such as search, curation, situational awareness, and predictive analytics. While essential within subdomains, these common features already represent generalized areas of research of their own, rather than generalizations of the ensemble of features, emphasizing the exponential expansion of domain-specific information burdens. Here, in addition to the various other framings for integrated sensemaking, we propose Narrative Information Management (NIM) as a term to both unify the common features of these many information-centered disciplines and provide a lens through which to consider their requirements and development. Where narrative information in other situations may refer specifically to the information contained in a given narrative, for example a book or self-reported experience [65], we intend for NIM to refer to the management of information in the facilitation of narrative sensemaking.

Narrative Information Management

Narrative has received many definitions, and in some cases these definitions contradict [66]. Where there is consensus, there is often some ambiguity regarding scope that parallels analogous debates in memetics (e.g., what isn't a meme/narrative?, is this a single meme/narrative or a cluster?, is this a meme/narrative or a component of one?) [66]. However, even where narrative has been labeled a "buzzword", there is agreement that it practically represents story, patterns of expectation, plot, and sequence patterns, that it is encoded and decoded through stories, images, symbolism, and metaphor, and that this encoding represents internalization which impacts how humans integrate, store, compress, and communicate information and navigate moral, physical, and social terrain [67–69]. Many examples exist of narrative-driven approaches in various domains attempting to differentiate from scientific-, evidence-, or data-driven approaches, usually focusing on the use of what would traditionally be defined as a "story", such as the use of fictional or real accounts of events in order to influence behavior as opposed to leaning on data or evidence [70,71]. Attempts to define narrative usually provide similar differentiations between narrative and other forms of communication, some in poetic fashion:

> *"Science explains how in general water freezes when (all other things being equal) its temperature reaches zero degrees centigrade; but it takes a story to convey what it was like to lose one's footing on slippery ice one late afternoon in December 2004, under a steel-grey sky."*
>
> [72]

However, the line between these forms of communication (science and story) present in the quote above is inherently subjective [66,73] and there is a reasonable argument to be made that the scientific explanation is simply a narrative constructed from interpretations of scientific data and that the explanation through story is a narrative constructed on common experience and metaphor [74]. Further, raw data in any sufficient volume fails to communicate anything meaningful without visualization, descriptive statistics, and presentation—all of which are used to allow different components of the data to "tell a story" [75]. "Nobody walks into a bookstore and asks for a narrative" [66] but it could be argued that nobody walks into a book store without one, as one has to have internalized some set of stories about book stores and what they provide in order to consider shopping there as an option.

While certain disciplinary approaches have been interpreted as being "free" from narrative (e.g., objectivity in the sciences), it has been argued that these are professional narratives about objectivity that serve to reduce cognitive load and facilitate sensemaking in complex, information-rich environments; although such simplifications may not always be helpful [76]. It has also been argued elsewhere that formal documents such as instruction manuals, medical records, project documentation, and historical documents being categorized as narrative-free or not being meaningful in the construction of narrative is largely up to interpretation, presentation, and context—especially where these kinds of media create expectations for navigating the world and taking action [32,65,73,77,78]. Broadly, action-oriented sensemaking can be seen as a type of narrative inference, where individuals are only able to act appropriately when they have identified the story they are in and role they play [19,78]. Frameworks from cognitive science, such as active inference, are increasingly considering psychological, cultural, and narrative aspects of individual decision-making [79,80]. In such frameworks, narrative inference is cast as an ongoing process by which agents estimate hidden environmental states (variables that are not directly observed but bear strongly on how observations change through time). Estimation of narrative state variables can reduce uncertainty about future outcomes. For example, knowing that one is watching a movie in the romance genre as opposed to horror, would reduce one's uncertainty about the relationship status that the characters might be in at the end of the film and what actions they may or may not take.

While narrative frameworks and approaches have been dismissed by some as too theoretical, passing fads, or superfluous cognitive layers [81], their utility should not be underestimated. A core function of the human brain is the detection of event boundaries in order to construct and maintain episodic memory [82,83]. Studies have shown that areas of the brain related to narrative comprehension are active when segmenting events [82,84,85], indicating that narrative structure is not an extraneous layer that we apply to experience, but instead anchors our perception of reality. This has led some to synthesize features of episodic and semantic memory as a single area or subcategory referred to as "narrative memory" [86,87]. Similar work on narrative comprehension has led others to characterize large portions of human sensemaking as a function of "narrative intelligence" [88,89]. If the brain's sensemaking about the world is, at its core, structured around narrative, and if knowledge management and similar systems aim to scale sensemaking from individuals to groups, then the role of narrative in developing shared understandings cannot be dismissed. Further, if the study of narrative provides tools and frameworks for communication, reduction of cognitive load, and extraction of meaning, then narrative study may be of use in generalizing aspects of systems which facilitate meaningful communication.

Features of NIM Systems

Below, we describe features common to the systems and processes employed by information-centered fields, which generally reduce cognitive load and facilitate sensemaking, thereby helping to manage and communicate narrative.

Managing Information Gaps

Discovering and handling information gaps is a key feature of many information systems for a number of reasons. In learning management systems, finding and filling knowledge gaps is not just a challenge, but often the reason for their implementation—as learning management systems assist learners in discovering and managing prerequisites to new competencies [90]. In knowledge and intellectual capital management, knowledge and resource gaps are seen as a primary challenge but also as an opportunity to build new knowledge [91]. When making decisions under uncertainty in industrial, commercial, military, and intelligence settings, command and control, information fusion, business intelligence, intelligence management, and decision support, systems are used to rapidly identify where more information is needed or where information needs to be verified or integrated cautiously [92,93]. In archive, records, and document management systems, the faster a document can be identified as missing or missing pieces, the more likely it is that it can be repaired or found [94–96].

Narrative itself has been described as a "dynamic system of gaps", where well-structured written stories manage information gaps strategically and efficiently—to build suspense, to prompt the reader to focus their attention on details, and maintain engagement [97]. Narratives help form expectations for patterns in and across classes of systems and event sequences, acting as a tool which helps facilitate the agent in directing their attention to areas needing further investigation, where to expect surprise or uncertainty, or where they will simply have to cope with the absence of information [32]. Frameworks built from research on narrative and scenario structure have been used to define and frame information expectations, project documentation, and document annotation needs [32], and could be broadly applied to any system which manages information gaps. For example, signals about gaps in expectations within the lifecycle or typical "stories" of a document's use and transformations can reveal potential tampering [98] or help to identify linked documents that may be missing [96]. In addition, media communicating personal experiences, case studies, or reports of types of professional tasks and encounters can also be used in a variety of use cases, such as helping to fill gaps in tutorials and formal descriptions as well as to help contextualize events or use of knowledge [99–101].

Facilitating Situational Awareness

Situational awareness is an explicit and primary feature of interest within the domains of command and control, situation awareness systems, intelligence management and fusion systems, security management systems, SCADA, and sensor fusion systems, but due to divergent ontologies, often goes unmentioned in areas such as knowledge and information management. For example, in records, document, intellectual capital, and archive management, knowing who should have access and who has access to documents or materials is a vital feature [102]. Moreover, in knowledge and information management systems user awareness of potential bias in curation systems helps manage expectations [103].

There is a general consensus that multiple factors are necessary to reliably measure situational awareness [104–106], and these factors could be reduced to a smaller set of key components when considering the agent's goal orientation within a given operating environment. The factors to consider in measurement of situational awareness include (1) perception of the components and processes within an operating environment—that the agent can recognize the phenomena, agents, or collections of agents which are relevant to the current situation [105–108] (2) awareness of the spatial, mechanical, and abstract relationships between environmental components [48,108], (3) temporal awareness—awareness and knowledge of sequences of events occurring within the operating environment and in past scenarios [105,108] (4) communicability—how easily the information about the environment can be synthesized and communicated to others [105,107,109] and (5) projection and prediction—how well an individual can synthesize and fuse information about the situation and tie it to similar cases in order to project what is likely to happen next [104–106,108,110].

The use of narrative frameworks in facilitating, measuring, and understanding situational awareness in myriad contexts requires no exhaustive argument, as this has already been done elsewhere over the course of the last 40 years [111–116] however, a brief summary of insights is warranted. The study of narrative comprehension is robust due to the varied research interests which include it as a key measure, such as the cognitive development of young children [117,118], empathy and theory of mind development in adolescents [119], reading comprehension in educational settings [120], and cognitive decline due to disorder or aging [121].

Reframing situational awareness under the same umbrella as narrative comprehension would allow both areas to benefit from generalization and otherwise siloed research. Situational awareness research tends to prioritize raw knowledge of the environment, as opposed to filtering and comprehension in complex information-rich environments [108]. Given that narrative comprehension consists of components which are nearly identical to those of situational awareness, provides frameworks and ontology (e.g., plot, setting, character archetypes) for comprehension of those components, and intends to address many of the same challenges posed to situational awareness [106,108,122,123] the likelihood of benefit from generalizing the challenges and requirements of situational awareness within narrative frameworks is quite high.

Providing Descriptive and Explanatory Information

The provision of descriptive and explanatory information about systems of interest is essential. Rapid provision of descriptive information is an area of rich overlap between the most disparate of the information-centered fields described, such as intellectual capital management and command and control systems [42], where the ability to acquire more information about a particular object and its place in a system becomes a highly generalizable feature. Some systems may have more need for explanatory information than others, such as in IT-related knowledge management and decision support systems, where addressing why a particular event may be occurring is essential to addressing the event itself [124], but all may benefit from providing access to a deeper explanation about resources or components (e.g., how was this data produced?) [125,126].

Past work on narratology and the management of narrative information fits explanatory and descriptive information to patterns and formats which can help the brain parse or construct a story in the absence of traditional storytelling structure [65,111,113,115]. These methods, such as knowledge graphs, can be used in conjunction with situational goal-orientation in order to reveal those elements of incoming information which matter most [113,115], thereby reducing the information load on the user:

> *"When a reader summarizes a story, vast amounts of information in memory are selectively ignored in order to produce a distilled version of [a] narrative. This process of simplification relies on a global structuring of memory that allows search procedures to concentrate on central elements of the story while ignoring peripheral details."*
>
> [115]

Framing the provision of descriptive and explanatory features under the domain of narrative frameworks and ontology may allow for new avenues to handle challenges posed by information systems which need to be context aware (e.g., role, goal-orientation, and mission awareness) in order to avoid triggering scope creep (continuous or uncontrolled growth in a project's scope), unintended access to resources, and/or overwhelming (or underwhelming) the user with information [127–129].

Facilitating Exploration

Exploration of an information environment with high structural complexity and a large volume of resources is similar to any other kind of complex work in that it leaves teams "susceptible to scope creep because new opportunities, interesting ideas, undiscovered alternatives, and a wealth of other information emerges as the project progresses" [130], resulting in the fundamental explore-exploit dilemma [131–133]. In most information-centered fields and the systems they design and provide, the user's ability to explore beyond their known unknowns and forage for unexpected information in novel locations is an obvious feature, even in records or archive management where the usual use-case is mundane access and retrieval of documents [98].

The ability to traverse beyond known unknowns unfortunately comes with a number of consistent challenges. Chief among them is the fact that each exploratory step constitutes both a context shift and expansion, accompanied by the risk of fatigue and scope or mission creep [134]. Further, both risk and success in exploration are difficult to measure, which is why explore-exploit maintains its position as a fundamental dilemma [131,134]. Narrative approaches such as the use of thematic maps [135], narrative archetypes [136], and the ability to review side-by-side comparisons of narratives about similar or the same events [137] have been proposed as approaches to remedy these challenges, as they may help frame what should be explored or what is missing from current analyses, thereby calibrating and improving precision in exploration. Of particular interest are tools which help the user construct a narrative about their own exploration beyond a simple search-history. Narrative construction tools could help the user form timelines and annotations about their "expedition" which enable the rapid recollection of the location of information, the selection of appropriate tools for the job, and facilitate the integration of their findings [137].

Compression: Visualization, Structure, Collation, Curation, and Interaction

All information-centered disciplines, either implicitly or explicitly, abstractly or concretely, have to contend with the need to compress information by merit of their need to communicate it. As the volume of relevant and necessary information increases, "the trade-off between 'relevance' and 'intelligibility' becomes akin to Heisenberg's Uncertainty Principle: as one becomes more precise, the other becomes dangerously less so" [138], especially under time pressure [109]. The ability to balance this tradeoff between relevance and intelligibility is essential for facilitating exploration and situational awareness. Information systems make use of a number of compression mechanisms available for reducing cognitive load in order to allow for intelligibility of the information environment while still including as much relevant information as possible:

Visualization. Though auditory cues can be of value [139] and some users may be more verbally focused than others [140], human beings primarily forage for information through vision [141]. Proper visualizations can facilitate or even enable the communication of enormous amounts of information that would otherwise be intelligible [75,142]. Designing systems that are visually informative about complex information, while also accessible to users with visual limitations, remains a significant challenge across areas [51,143]. Visualization does not necessarily refer exclusively to graphics and charts, though the strategic placement of text without multimedia content can facilitate more rapid parsing and stronger retention [137,139]. Text can also be strategically placed with multimedia content in order to trigger effects such as the temporal contiguity effect (better information transfer when relevant visualizations are presented simultaneously with narration) or the spatial contiguity effect (better information transfer when descriptions are placed near corresponding parts of graphics) [139]. Humans are also strongly predisposed to look for and interpret symbols and our use of sophisticated symbolic representation goes back to prehistory [144–147]. In fact, people are so strongly predisposed toward searching for symbols that we will often see symbols where there are none [148]. This predisposition can be used to compress large amounts of information into symbol sets which can be decoded rapidly by trained users in order to direct their attention or help generate situational awareness [107,139].

Structure. As described elsewhere, providing pattern and structure to content reduces cognitive load and improves the use of working memory, and the strategic composition and arrangement of content can allow even traditionally very dry or technical information, such as project documentation, to tell a story [32,77,149]. Further, when these patterns of content structure are in common use by users, they allow for deeper compression over time—memory studies on chess players and research on artificial intelligence has indicated that this pattern-based inference may actually be synonymous with what we know as expertise [150–152].

Collation and Curation. As volume and structural complexity of information increases, the need for collation and curation (or filtering) of information becomes increasingly necessary. Collations do not have to be simple lists of content and curations do not necessarily correspond to interactive search and retrieval. Rather, collations can be treated as part of a more abstract process of intermediation—where curation and collation can result in their own information products, such as ensembles and clusters, or new reports which take what might otherwise be an unintelligible list of disconnected content and create narratives and counter-narratives which are easier to parse [48,153].

Interaction. When visualization, structure, collation, or curation cannot be applied without sacrificing necessary details or nuance, information systems can make use of interactivity. Interactive elements might include real time user-driven rearrangement of view, restructuring based on focus or purpose, or linking and relationship views, all of which can allow users to make use of visualization, structure, collation, and curation more flexible or convenient across many more dimensions than they could otherwise [154,155].

Enabling Case Management and Providing Prescriptive Information

Case management is a key feature of many knowledge management, decision support, security management, intelligence management, relationship management, and, of course, case management systems. In medicine and human services, the care and services provided to vulnerable people are managed as to increase efficiency and reduce the likelihood of information and opportunities slipping through the cracks, warning signs going unnoticed, and basic procedures, or prescribed process, not being followed due to factors such as large caseloads or interorganizational information sharing [156,157]. These principles are arguably the same across the many disparate areas that require case management, such as security and law enforcement [158,159], counter-terrorism [5], customer service and outreach [160,161], law [162], and intelligence [48]. The typical case management system user could be described as either an individual whose job is to develop a plausible story using available information and requests for information (e.g., "Who is the most likely suspect given the information available?", "Which precedents can we use to structure a legal defense?"), or an individual whose job is to rapidly manage context shifts, develop or understand a story in order to fulfill their role, and figure out what to do next in some larger process while guided by prescriptive information (e.g., "Should this customer be given a refund?", "What should I be asking this suspect given what other officers have already discovered?").

As the structural complexity and volume of information increases and more parties become involved in the management of a particular "case", the potential for error also increases. Basic procedures or prescribed tasks may go unfollowed, very obvious or critical information may be uncommunicated, unused, or lost, and further, the conversion of available information into a coherent narrative can be impossible [5]. For example, the failure to apprehend the serial killer Paul Bernando was blamed on the lack of case management systems to help investigators collaboratively develop narrative [159]. Post-mortems on the investigation indicated that the organizations involved had the necessary information, but simply failed to connect that information in a coherent way fast enough [159]. Also alarming was the arrest of Brandon Mayfield, a lawyer from Oregon, on suspicion of his involvement in the 2004 Madrid bombing. His fingerprints were matched in an international, automated information fusion system, but the facts that he had never before traveled to Madrid, that he was arrested in Oregon and not Spain, and that the fingerprint system required additional checks after a match all failed to become immediately relevant to investigators during the multi-organization collaboration [5]. In yet another chilling case, a man mistaken for another individual with an outstanding warrant was arrested, placed in a mental hospital, and forced to take psychiatric drugs—"the more [the man] vocalized his innocence" by asserting he was not who they thought he was, "the more he was declared delusional and psychotic by [the hospital's] staff and doctors and heavily medicated" [163]. After nearly 3 years, a hospital psychiatrist decided to consider the possibility something had gone wrong and was able to confirm the mistaken identity with "a few Google searches and phone calls" [163]. This case is of particular interest because of how easily this might have been avoided had proper case management procedures and tools been available or used. A simple comparison of photographs, fingerprints, arrest records, and the story they told would have made his release obvious at any stage—as it was publicly available knowledge that the individual he was mistaken for was already incarcerated in Alaska at the time of his arrest [163]. Such cases may seem extreme; however, as data-driven policing and legal sentencing become more common, situations of mistaken identity and inappropriate communication of narrative confidence have the potential to influence the lives of many.

Narrative approaches have been recommended in the past to remedy the types of problems described above, such as the use of timelines and storyboards and the fitting of information to narrative structure and pattern to make information more parsable by, easily communicated to, and easily extracted from teams [137,164]. Narrative structure has also been recommended for use in problems of task-transfer, project documentation, and rapid onboarding, in which knowledge and case management systems are often implemented [32,77,165]. Case management in task-transfer contexts is especially important to consider in high reliability activities, such as in passing on all necessary information to understand what is happening and why in command and control [165] and mental health care settings [157,164].

Synthesizing Intelligence

Across all of the disciplines mentioned and the systems they intend to design and implement, there is, by merit of their interests in the various features noted above, an accompanying interest in using those features to collect, process, analyze, and synthesize information in order to create new information products. While this process may be best formalized by intelligence production [153], the myriad data and information fusion methodologies for taking raw data and other information and synthesizing them into viable intelligence could be considered a member of this category as well. Intelligence has been argued elsewhere, extensively, to be a primarily narrative process in which quantitative measures should play a moderating or bounding role, but not defining one [153,166]. Narrative and narrative-related sensemaking approaches have been recommended in the past on this basis in order to improve intelligence practice and systems [167,168].

Concluding Comments

While these common categories of NIM features are often discussed in the literature within information-centered fields, there are likely other features of importance that are rarely given attention. This may be in part because these features exist in ad hoc solutions in the field (unknown unknowns), have yet to be generalized (known unknowns), or have been studied and generalized in some other field (unknown knowns).

NIM in Various Domains

In the following sections we explore the past, present, and future of Narrative Information Management (NIM) in various domains. These sections were sampled based upon the experience of the co-authors, and by no means are exhaustive in terms of breadth (across disciplines) or depth (within a discipline). The sections serve to (1) raise awareness of the commonalities of some challenges faced by different fields, (2) explore both theoretical and practical insights about the implementation and design of NIM features, (3) provide opportunities to discover and generalize NIM features, and (4) begin the process of working towards NIM as a unifying framework.

Personal Finance

Narrative information management in finance can be divided into personal finance and institutional finance. Globally, affordances vary in both sectors. This overview will discuss the narrative pertaining largely to personal finance in the United States (although it may be applicable elsewhere). The individual financial narrative begins at birth. Even in the wealthiest countries in the world, there is a chasm that divides those who are able to consider what to do with their money and those who don't have ample funds to cover an emergency. The cost of poverty is very real, and can be compounded by various disparities (e.g., social, medical, educational, likelihood of experiencing trauma). It is important to recognize that attitudes and knowledge about money start to develop at a young age, vary across generations, and that intergenerational wealth has an impact on the personal finance narrative. Financial psychology is also shaped by genetic and biochemical factors, particularly the aspect pertaining to risk tolerance and power [169,170].

The variation in financial psychology makes it difficult to establish a single purpose that is achieved through processing relevant information. The standard K-12 curriculum does not include finance, therefore, the motivation to find meaningful financial information may come from life experiences, such as debt accumulation, or the desire to sequester financial resources. There is a limited time frame in which to accomplish any financial goal, leading to a temporal pressure. Investors must choose how to decide (what amounts, what investments to make), but also when to decide [171]. Furthermore, because financial resources are (relatively) finite, there is also competitive pressure. Common starting points for those who weren't exposed to extracurricular financial education in their early life include books by Suze Orman, Dave Ramsey, and Robert Kiyosaki. However, one substantial and important subject has been omitted from all of their books: detailed information about investing [172].

Investments maximize the accumulation of financial resources over time. However, searching for the right investments can lead to a deluge of information. This makes financial literacy difficult to achieve for the everyday investor. In fact, due to the increasing complexity of the economy, even experts struggle with defining financial literacy [173]. People with excess capital primarily invest in traditional investments (stocks and bonds). Some investors also include nontraditional investments such as art, real estate, foreign currencies, and cryptocurrencies or non-fungible tokens, among others. A mix of investments is frequently chosen based on investor demographics, including age, gender, portfolio value, interests, style of portfolio management, and risk tolerance [174]. Furthermore, real estate and stocks have intra-asset investment scales ranging from macro to micro. For real estate, macro scales include Real Estate Investment Trusts (REITs) and online lending platforms, whereas micro scales include rental properties and house flipping. For the stock market, macro-level investing is done in index funds or exchange traded funds (ETFs), and micro-level investing can be individual stock purchases, financial derivatives, or partial stock shares. Informational burdens can prevent individuals from making wise investment decisions, hence the relevance of NIM for understanding real-world behavior.

Many investors choose to outsource their financial decisions to a credible third party. Outsourcing can be done through financial advisors or even using online robo-investing platforms. Cognitive offloading through a third party reduces the decision space from high dimensionality (such as which house or which stock to buy, when do I buy it, etc.) to low dimensionality, consisting of, perhaps, only choosing a financial advisor or platform and the amount of money to invest. Moreover, crowdsourcing the reviews of financial advisors and investing platforms relieves the cognitive burden of even these basic investment choices. There is a great degree of trust that comes into play when putting money away, which has resulted in professional certifications and related duties (e.g., fiduciary duty) that reduce the cognitive burden on the investor and consequences for certified financial fiduciaries who don't act in their clients' best interests [175].

Regardless, choosing an accredited third party can be much simpler than trying to search through the glut of information that is available about investing, much of which is promoted by those with a vested interest. Furthermore, investment prices are swayed by the weekly economic statistics as well as other news pertinent to individual stocks, and it can be difficult for individuals to track this information as they navigate their own investment path. Individuals who take this route will confront many of the challenges from a NIM perspective, such as information overload, incorrect or misleading information, and the need for effective action-oriented sensemaking (buying and selling) amidst uncertainty. However, for those who decide to take investing into their own hands, informative resources are available.

Resources for investors are available on even the most basic investing mobile platforms. Platforms such as Robinhood include the price of the stocks over the last five years, stick charts, market capitalization, earnings per share, price/earnings (P/E) ratio and dividend yield. Higher level data is available on free platforms that retail investors can use, such as Thinkorswim, which contains more than 400,000 economic indicators as well as sentiment analysis tools that can be used to evaluate stocks [176]. Critical information that has the potential to give users an edge in investing is concentrated in the Bloomberg Terminal, which costs around $2,500/month for access [177]. This is what quantitative analysts use in professional trading. If you want to evaluate a particular company's stock, the terminal has all of the financial statements, a compilation of analyst research on the company, and a network of their biggest suppliers and customers that can be pinned to a world map, among many other features. Perhaps the most important feature of the Bloomberg Terminal is access to the Enterprise IB chat. This feature facilitates communication among brokers and portfolio managers, and is where many off-exchange trades happen. Off-exchange trades can be for over-the-counter (OTC) securities, which are unlisted stocks, or for publicly traded stocks. Publicly traded stocks that are sold off of the exchange are referred to as dark pools. These trades are usually for a large amount of stock, at a price that isn't always the listing price of the stock. Both

OTC and dark pool trades are prevalent in the cryptocurrency market as well, as cryptocurrency is starting to resemble more traditional asset classes [178]. Moreover, while cryptocurrency is not currently regulated by the SEC, top federal officials have called for guidelines on cryptocurrency governance due to the potential risk for investors [179].

The intersection of personal and institutional financial narratives is a tightrope walk, largely because it is illegal to leverage critical, uniquely held information about stocks for financial gain (a practice known as insider trading). Regulation Fair Disclosure was enacted in 2000 to limit the practice of selective disclosure, where companies provide material information to analysts and institutional investors in advance of public disclosure [180]. Essentially this regulation ensures that the institutional financial narrative is consistent. In 2013, the Securities and Exchange Commission (SEC) verified that social media was an appropriate non-exclusionary channel by which material information could be disclosed [180]. The SEC is charged with regulating instances of market manipulation, which is the intentional manipulation of security prices. Individuals working in business-financial news, technology news, and media news have restrictions on owning securities that extend to their family members [181]. This prevents overt manipulation of security prices by news outlets. However, social media provides potential rallying points for individuals to potentially participate in pump-and-dump schemes or other nefarious market-related actions.

Situational awareness is frequently co-constructed in emergent online investing communities. The diversity of user opinions in these spaces usually prohibits the development of a team consensus; however, there are some strong opinions that are widely held by the majority of users. For example, in the Reddit platform r/wallstreetbets, the consensus narrative asserts that you should never bet against Tesla (TSLA). Many users have, and continue to do so, and when they have lost lots of money, they will publicly seek absolution from “Papa Elon,” referring to the iconic Tesla CEO, Elon Musk. The price history of Tesla stock has been drastically divergent from their actual earnings. Reasons for this discrepancy could include the cult of personality that has developed around Elon Musk, or the herd mentality of investing communities [182]. The influence of the Tesla CEO is so profound that the SEC has mandated that Tesla pre-screens all of his tweets to prevent manipulation of the stock price [183]. He has also been accused of manipulating the cryptocurrency market [184]. Seeking explanations for the influence of Elon Musk points to the mechanisms people use to model and monitor the financial markets, such as the subreddit of r/wallstreetbets and FinTwit (Financial Twitter).

Investors turn to online financial communities on Reddit and Discord, or follow influential investors on YouTube, Twitch, or Twitter for many reasons. They could be seeking to confirm their own biases regarding the fitness of their portfolio, or trying to select their next investment. Online communities also serve as a way of monitoring information. A tweet from Elon Musk could serve as a buy or sell signal for cryptocurrency or TSLA (or even ETSY), because historically the prices can skyrocket or plummet depending on what he says. Investing communities also serve as a way to analyze sentiment about the current market and the herd mentality. These communities have largely superseded mass media news outlets for younger investors. However, the price of stocks will still increase when financial news personalities, such as Jim Cramer, plug stocks on their prime-time shows.

The management of narrative information related to financial decision-making amidst uncertainty plays out continually – every time an investing firm makes a trade, or a retail investor interacts with modern financial affordances. Amidst the barrage of technical information (e.g., charts, data, disclosures) and ongoing context (e.g., online chatter, memes, intuition about sector), investors seek to make wise decisions about which actions to take. As the discussion above reflects, there is significant fragmentation of platforms, markets, and perspectives related to finance, with the implication that there are inadequate frameworks for narrative sensemaking, especially for retail investors. This gap in sensemaking capacity can result in decisions that are sub-optimal in terms of value, risk, or cognitive burden. Further research into financial sensemaking specifically, and the role of narrative in decision-making more broadly, might find interesting applications and implications in the financial systems of the future.

Ancestry Research

Amateur ancestry and genealogical research have been steadily growing in popularity over the last decade and this growth has been accompanied by the development of a wide variety of tools to facilitate the process [185–187]. The COVID-19 lockdowns starting early 2020 greatly increased this growth, drawing millions of more people to engage in and contribute to private and collaborative research activity in the interest of understanding who they are in the context of their family, national and cultural heritage, and their genetics [188]. These individuals are not simply searching for existing information, but actively performing research guided by investigatory processes and questions. The motivations and methodology of amateur ancestry researchers are often identical to those of academic historians, and amateurs grapple with similar information load as professionals, even if they do so to inform the development of a personal and familial narrative rather than to contribute to a historical commons [189]. Further, there is often a dialectic and informal collaboration between academic historians and amateurs, as amateurs have different "rules of engagement" with sources, can take larger risks, and can forage for information "in fields where historians have seldom toiled" [190]. In this section we explore some of the past, present, and upcoming challenges of the field of ancestry research, with a focus on how Narrative Information Management (NIM) concepts are woven into the process.

There are tens of billions of digitized historical artifacts available for use to these researchers through available tools such as those offered by Ancestry or MyHeritage [191,192]. While only a minute fraction of these documents and images may be of use to any particular researcher within the scope of their family tree, this small fraction may amount to tens of thousands of documents, causing users to encounter information overload [193]. Among these documents are newspapers, letters, census records, church records, financial documents, wills, and many other formalized and non-formalized documents; some are in different languages, and some are written using shorthand, long forgotten slang, and other forms and styles of writing which are no longer common in modern times [194–196]. The collection and processing of these documents is done by a mix of professionals and users. The growing market for genealogy products has meant that companies are incentivized to broker access to document repositories and to hire experts to provide and curate archival materials and suites of frontend and backend tools to analyze them [185,189,191,194,196–200]. While the bulk of the archival material is supplied by these experts and document repositories, users also continue the development of annotations on available documents and forage for resources to add to collections to support their research, filling in the gaps within professionally developed archives [189,195,201]. The combination of professional and user-sourced objects and metadata means that there is an unfathomable amount of potentially relevant material for any individual researcher to engage with [193].

The development of resources to assist with research methodology and tradecraft has always been ubiquitous with the amateur genealogy community [194], but with the introduction of these large digital repositories, knowledge management, case management, and information fusion systems have become necessary in order to keep up with the information flow and avoid redundancy even in basic research activity [193,195]. Members of the online amateur genealogy community have taken to suggesting young or novice family history researchers to avoid structured research activity at first, instead recommending that they engage initially in "unstructured, exploratory activity" on these systems to familiarize themselves with the information environment before fully committing to semi-formalized work-flows [195]. These kinds of recommendations are not unfounded as introduction to the tool suites, dashboards, and document repositories is daunting enough that most new researchers fall into a common pattern during onboarding which focuses on off-platform collection (e.g., physical photo-albums and documents physically accessible to the user, taking physical notes before uploading to the platform) [195]. These kinds of common patterns within this community have been modeled as a series of stages with separations of concern, scope, and expectations which are similar to other sensemaking frameworks, such as the intelligence production cycle [195,202–204]. Unlike other sensemaking frameworks [109,202,203,205–208], these stages are generally represented as a linear process with key transition points being marked not just by progress in the research but in the capability and skill of the researcher, with the earliest stage representing the aforementioned pattern of onboarding [195,204].

This onboarding pattern typically begins with gathering information from within the family, off of the platform. This activity consists of collecting and uploading anecdotes, documents, physical artifacts, and photographs [195,204]. Following this, in a phase denoted "learn the process", researchers begin collecting itinerary-driven resources on how to handle information gathering, attending events, connecting with the staff of organizations who can answer questions or help them retrieve documents, and engaging in a trial-and-error approach of learning by doing [195]. The next phase is considered a key inflection point, referred to as "breaking in", at which point researchers finally become comfortable enough to begin searching census data [195]. Given that census collections do not contain "browsing" materials—use of census data indicates a transition in terms of comfortability with the tools as well as a transition from exploration to exploitation as users begin to use data collections to fill gaps in developing historical narratives rather than simply exploring other narrative material, such as old newspaper articles or family photographs [195].

Once users have begun the process of making use of external document repositories, tool-suites, such as those found within the ancestry.com or myheritage.com genealogy platforms, assist them with exploring and exploiting relevant materials [195]. These tools and the community education resources on their use are necessary for success given that some of the services available to amateur genealogists are adding millions of new documents per day [209]. In the case of ancestry.com, visual hints will be placed on relatives in the user's family tree which have information that is similar to objects in one of 32,000 external databases, such as dates of birth or mentions of surname—these hints allow the user to access links and context about these objects and are sorted based on likelihood of relevance [209]. If a user reviews an object via a hint and marks it as related to the relative the original hint was attached to, this will create an ensemble of "secondary hints", which are other objects which may now be considered potentially related (e.g. an individual is noted in one document with an administrative identification number, the individual in that document is accepted to be the same as the one in the user's family tree, so all documents which are associated with that administrative identification number now become secondary hints for the user to review) [209]. Hints are accessible in a variety of ways based on workflow and objectives, for example, a user can review all hints, to see if there are recent relevant updates to review in aggregate, or see hints related to particular individuals based on a number of filters if they're in the process of a scoped investigation [209].

For researchers in this space, it's not enough to simply associate a resource with an individual. The goal for many of these users isn't to simply trace a family line but to construct narratives which provide context both for their ancestors' experiences and their own place in history [188,189,194]. Much like academic historians, the narratives have to be constructed of ensembles of facts sourced from various historical documents and accounts—however, unlike academic historians, amateur genealogists have specialized tools that facilitate the rapid and collaborative construction of these narratives. Where academic historians are left with tool recommendation lists which are often either barren or limited to simple citation managers, collection and archive search managers, and ad hoc tools designed for other fields [210–214], tools available to amateur genealogists allow for case management workflows rarely found outside of legal case management tools, which are intended to construct well-cited narratives built to stand up against scrutiny [215–217].

The use of “narrative scenarios” for describing typical research itineraries as a basis for the design of adaptive, personalized, task-focused access to multimedia, multilingual cultural heritage knowledge bases has transitioned from theory to practical, accessible tool-sets to assist in case management [198,200]. For example, when amateur genealogists attempt to research ancestors who took part in migrations, the accompanying name changes, lost records, sudden transitions, and separation from loved ones means that their more common research methods are no longer adequate [218]. While many services use an entity-focused approach, allowing for many names (or referents) for any given object, increasing the likelihood of finding an opportunity to merge common ancestors found by distant relatives that may have found those ancestors via other paths, it may require a great deal of luck to make these connections [218,219]. To continue, researchers would traditionally have to either rely on this luck or shift from the use of document archives and qualitative analysis to the use of bioinformatics and statistical analysis [220,221].

Amateur genealogy software providers have now integrated new tool sets, built on genomic “identity-by-descent” mapping methodology, which place users themselves in multiple ensembles, called “communities” [200,220,221]. These ensembles are constructed of members which share ancestors which likely hailed from common populations, groups which either “traveled to the same place around the same time or from the same place around the same time” [200], helping users rapidly develop narrative about their ancestors which informs where to look for more information and, more importantly, who to collaborate with in order to fill knowledge gaps [200,221]. This formalization of a “narrative history” through the use of such tools has been argued to “allow for a group of individuals to be conceived as if they were united… for past and present individuals to be conceived of as one united group embarking on the same quest” [221–223]. Tool suites such as these help a community of practice that may not have had the benefit of STEM education connect with and make use of knowledge from communities of practice that use advanced tooling that would otherwise be inaccessible [221]. Further, this kind of connection creates incentives for the use and development of semiotic, visualization, and rhetorical techniques to construct micro-narratives that make the work of specialized communities accessible "without requiring command of an exclusive body of knowledge" [75,221].

NIM tool development in the amateur genealogy domain could benefit from incorporating design principles from other spaces with similar tooling requirements. For example, in terms of interoperability and information exchange between entities, which is often discussed in relation to geospatial intelligence, open-source intelligence, and the crowdsourcing of research and situational awareness resources [17,51], the amateur genealogy community currently has a one-way relationship with the expert communities that manage document repositories and provide them with tools—missing an opportunity to harness this massive collective effort of millions of hours a year in the research, linking, and annotation of historical documents [189]. Between competition over attribution [201,224,225], perverse incentives and social pressure associated with finding direct relations to famous or historically significant figures [189], limited consequences for incorporating poorly sourced facts or creating logical inconsistency [226], and the potential for errors resulting from these factors to propagate through the system, these user-managed knowledge bases are likely a negative resource for actual historians as aggregation would be too risky [189,199]. If user-generated knowledge bases were structured correctly with consideration for governance and trust signaling, taking account of the incentives generated by the desire to develop and present aesthetic and pleasing personal and familial narratives, then the data could be of more use not only to historical analysis and aggregation—but also for other purposes [51]. For example, data from AncestryDNA customers was filtered and cleaned for use in COVID-19 research but could have had much more impact had the system been built with protocols for information exchanges [227]. Further, the exchange of information between these communities could provide valuable feedback from more technically advanced, as the tooling they provide to the amateur genealogy community comes with great risk of being misused and misinterpreted [199,221].

Domains with similar tooling requirements could also benefit from considering NIM design impacts in the amateur genealogy space. For example, regular exploration of a knowledge base is essential to its maintenance [48], and there appears to be a tendency in general toward exploratory browsing over searching in general throughout most of the amateur genealogy research process, which may be linked to the focus on intrinsic incentives for activity [195,228]. The intrinsic incentives associated with outcomes is associated with increased technological adoption among demographics traditionally left behind as well as patterns of behavior which lead to advanced learning, information use, and information foraging [229]. The value of this exploration is amplified by the fact that the popular tool-suites help users identify where others are missing information they might have, and vice versa, through linking and hints [195].

In terms of research facilitation and production, the ability to programmatically generate scoped and formatted research reports, charts and graphics, and even whole books prevents researchers from feeling punished for intentionally or unintentionally maintaining a separation of concern between the research itself and the presentation and dissemination (the development of research "products") [230,231]. This conceptual separation of concern between analysis and dissemination is considered essential in high-reliability research and analysis communities and features which enable it would be beneficial to any domain concerned with or requiring NIM tooling [232–236]. Finally, enabling these research facilitation and production features are user experience (UX) design features that allow for the scoping of the user's information environment based on relevance, relationships, and degrees of separation between the object in primary focus or center of gravity for attention (e.g., a relative in focus) and other objects with which that object has a relationship which prevents information overload [193,230]. The underlying, universal entity identifiers that allow for these features also allow users to rapidly develop surfaces of agreement even where they do not agree on all facts or interpretations associated with content (e.g., we can agree that this is a photo, that this is a photo of this person, and that it was added by this user, but do not agree it was taken at this location) [191,218]. Similar to many other areas of ancestry research and amateur genealogy relevant to NIM, there is an apparent need to consider the incentives of the user and the potential damage that those incentives may bring to the knowledge base. If there was one insight to draw from this area, it would be that the failure to consider consensus, governance, and trust mechanisms in contributions will inevitably lead to a tragedy of the commons—in the case of ancestry research, this tragedy is expressed in the unusability of what could otherwise be a mountain of valuable historical data, robbing millions of their opportunity to contribute meaningfully to the corpus of historical knowledge.

Hybrid Cloud Infrastructure Security

The modern economy is supported by a vast array of layered and interconnected information systems, which enable the internet and various intranets, and generate dozens of zetabytes of novel data per year [35,36]. At all layers, from users accessing social media platforms to data centers processing underlying workloads, there is a persistent, complicated, and complex set of challenges associated with hosting servers that resolve website traffic and provide secure access to data. These challenges are generally associated with resolving who and what should be able to access particular digital resources and under what conditions identities should be allowed to interact by reading, writing, deleting, changing permissions, or other actions on said resources. Users, administrators, and machines engage in facilitated interaction with cloud infrastructure through credential, entitlement, password, and permission management systems, each of which are types of trust management systems designed to handle the aforementioned challenges behind the scenes and strike a balance between fundamental tradeoffs, such as the tension between security and convenience [237]. For example, password and permission management systems facilitate the management and safekeeping of a burgeoning list of access credentials and permissions for users of information systems and online platforms [238,239]. Trust management is becoming increasingly difficult—especially with the introduction of hybrid cloud computing. We will explore the current state and future possibilities of narrative information management approaches as they relate to the world of security for hybrid cloud infrastructure.

First, a primer on definitions is necessary for this discussion. A data center is an interacting network of computers across one or more physical locations, which handle computational or information processing workloads [240,241]. These workloads might be maintaining and developing web services, executing large-scale data management [240], offering compute power for research and data analysis tasks [242], managing data access, or enabling business continuity through disasters or cyber attacks [240,243]. Data centers can be on-site or externally-located, and they can be either owned or rented [244]. There are three terms commonly used to describe the nature of an organization's cloud infrastructure choices: private cloud, public cloud, and hybrid cloud (see Table 1).

Private Cloud. The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.

Public Cloud. The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.

*** Hybrid Cloud.** The cloud infrastructure is a composition of two or more distinct cloud infrastructures that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

* *Hybrid cloud can be seen as an overarching trend in industrial computing toward mixing and matching different private and public cloud options when deciding the infrastructure composition for a given organization.*

Table 1. Types of Cloud Infrastructure.

In all types of cloud infrastructure, computational resources and user privileges must be balanced and managed to keep development projects running efficiently, while also detecting and remediating technical and security issues in real time under pressure [245]. The number of issues that may arise is difficult to comprehend. Some estimates have suggested that, just in terms of security events, "analysts [can] be expected to handle only about 0.00001% of overall event volume". One analysis of a mid-sized enterprise platform revealed that, based on an average of 40 million log entries per day, 40,000 analysts would be needed to address all security events without triage [245,246]. Among these types of cloud infrastructure, hybrid cloud may contend with the most complicated and complex set of challenges, due to the scale and dynamic nature of the access required by various types of users and systems [247–249]. Hybrid cloud solutions are utilized despite all of these challenges because of the numerous advantages they provide, particularly in terms of flexibility and antifragility. For example, hybrid cloud infrastructure provides a customizability and specialization that permits a better fit between workload, platform, and users—allowing teams to choose the platforms and authorization systems best suited for their particular workloads and team dynamics initially and over time. Further, hybrid cloud solutions enable grouping by type of workload, thereby improving efficiency and the ability to maintain function under increased or fluctuating demand. Given these advantages, and the number of organizations now offering services in this domain, hybrid cloud infrastructure may become dominant.

The influence of trust management systems in modern cloud infrastructure is pervasive. As the modern world moves toward a reliance on hybrid cloud infrastructure, the control, ownership, brokerage, and regulation of information, information privileges, and the information infrastructure itself is becoming a very high leverage point—financially, geopolitically, and ethically [250–254]. On the horizon, citizenship, voting, and other core rights may be facilitated digitally. In fact, the digital facilitation of banking, taxation, access to electricity, and other core functions is already becoming commonplace. Therefore, effective management of credentials, permissions, entitlements, and trust may become one of the most important problem spaces of our time. The fundamental aspects of life in modern democracies that are currently being managed and manipulated digitally beg the question: what happens when adversaries successfully disrupt or compromise these systems? How do user-specific narratives of personal experience and action feedback into the computationally-aided design of trust management systems? How do these massive systems remain resilient when feedback loops and low-reliability nodes might interact to form complex threat surfaces [255], resulting in endogenous failure modes? Such targeted interventions and intrinsic failure modes in these complex cyber-physical systems might be subtle or unnoticed initially, with devastating repercussions.

Novel types of hybrid cloud infrastructure and trust management systems are now being explored in various areas, such as the digitization of Department of Defense and civilian supply chains [256], intellectual property [257], 3D manufacturing [258,259], and bioinformatics [33]. These explorations in disparate areas bring new interconnected risks, and raise questions of how different types of organizations should respond to threats and anomalies, both alone and in concert [260]. Compromised hybrid cloud infrastructure results in security events of varying type and severity. While some security events can be limited in scope, other events can prove costly, and even fatal, to individuals, governments, and businesses in terms of loss or discovery of identity, irreversible loss or inappropriate access of data, or denial of service at critical moments (such as voting intervals for a government, holiday shopping period for an online store, or loss of trust due to exposure of personal data). Additionally, unauthorized access can have network effects leading to further inter-organizational risks and threat surfaces, and are happening more frequently to both small and large operations alike [261]. Wargames and red-team events are currently used to help security professionals and stakeholders better understand and classify external threat actors and types of target organizations. This understanding can be compressed into categories for simple communication, helping to teach security professionals and students about common patterns and risks [262–264], sharpen team capabilities and resilience [265], and develop scenarios for emergent or unexpected events. While there is often an emphasis on threat actors, security threats can also be caused by misconfigured bots and human error, in isolation or in interaction.

The complex dynamics of human-machine interfaces (the basis by which human organizations interface with hybrid cloud infrastructure) results in another fundamental challenge in cloud computing security. As mentioned previously, analysts, developers, administrators, and users are all under time pressure to perform their duties using hybrid cloud infrastructure, engaging in a fundamental tradeoff between security and efficiency, sometimes resulting in the provision of permissions beyond what was needed. When admins fail to account for these overprivileging events and fail to take actions to minimize ongoing risk, these errors accumulate, leading to a phenomenon referred to as "privilege creep" [266]. Hybrid cloud administrators are thus tasked not only with identifying individual errors at a moment in time, but also with identifying cases of missed or unhandled error accumulation over time. They must then remove unnecessary privileges in so-called "remediation events." Unfortunately, these realistic and fundamental challenges run the risk of being ignored or underestimated in the academic literature, due to disconnects between theory and practice, the speed at which new security threats emerge, and the assumption that negative externalities borne of human-machine interface dynamics are linear and might simply be engineered away [267].

Hybrid cloud admins are usually assisted in the identification and tracking of privilege creep in their data centers and practically minimize it over time by using a framework called the "Principle of Least Privilege" (POLP). Examples of successful applications of POLP include issuing temporary access tokens for identities in a data center, right-sizing roles for particular categories of hybrid cloud workers, and limiting access to high risk resources or actions that aren't often used by that identity. Generally, POLP can help reduce the informational complexity of the narratives used by hybrid cloud admins when planning beneficial actions to lower risk over time. Similar to POLP, the Confidentiality-Integrity-Accessibility (CIA) triad is commonly used to simplify the assessment of threats to data center resources, where risk is examined in terms of potential for the theft or exposure of sensitive information (confidentiality), the corruption or malicious altering of information (integrity), or the removal of access to critical resources at a critical time (accessibility) [268]. In cloud settings, actors don't need to be intentionally-malicious to represent a threat; they may instead represent misconfigured automated users or service accounts (bots), or simply human users making mistakes, cutting corners to save time, or acting in destructive interference with others unknowingly [17].

In the face of such fundamental uncertainty, hybrid cloud managers adopt frameworks like POLP and the CIA triad as a practical means of rapidly developing a narrative from which to derive prescriptive information and explore risk minimization in data center operations. While these mental models are imperfect, they do offer a dimensionality reduction in information- and relationship-rich environments such as hybrid cloud infrastructure. This use of narrative to provide situational awareness makes it easier to form and communicate with stakeholders, avoid analysis paralysis, and take beneficial action. With this approach, effective hybrid cloud management occurs over time, with small actions of limited scope that make the environment iteratively more manageable and secure with each admin engagement [1]. Software that provides auditing and case management, streaming anomaly detection, as well as visualization of current state and projection of future state, enable both batch and streaming remediation as evidence of unusual and risky behavior accumulates past a certain threshold. In addition, information fusion methodology (e.g., automatic collation of data from multiple systems) is sometimes applied to weave non-privilege related events into a story of potential risks, such as equipment reported as lost or the misuse of software or hardware [269], thereby facilitating NIM in hybrid cloud systems. The value of information fusion systems increases as interorganizational credential management adds new layers of complexity. For example, the need for multiple organizations to share in governance and management of trust in providing access to common information and resources (e.g., computing power for biomedical image processing [270–272]), roles, tasks, and job assignments). Indeed, the operations of cloud computing infrastructure present a dizzying and evolving complex threat surface [32].

The field of hybrid cloud infrastructure security is still in its infancy, and it is unclear which technical solutions will remain stable given the presence of the fundamental, adversarial, co-evolutionary relationship between potential threat-actors and security professionals. Compounding the challenge of problem definition and solution development in the field of trust management, the number of relevant threat surfaces is increasing rapidly. As field devices (e.g., remote sensors, tablet devices in industry) are increasingly placed into use, exposing critical information systems to new complex threat surfaces, such as those created by requirements for use under sporadic connectivity, leave these systems more porous than ever before [273]. Further, credentials aren't just for people using technology, but also for autonomous objects such as IoT (internet of things) devices—as of 2010, it was estimated that there were already twice as many IoT devices than there were human beings [274], each of which represents a threat surface and new degrees of agency which may require new technical solutions. However, it appears that the approaches and frameworks noted here that are relevant to the management of narrative information, such as POLP, CIA triad, and information fusion are relatively immutable in the face of technical changes in the space. In other words, while the hardware, datasets, and software pipelines that compose data center and related trust management systems might be undergoing constant evolution over time, the centrality of narrative-based heuristics for actionable risk remediation frameworks may remain fundamental.

Due to the instabilities inherent in these early stages of trust management system development in hybrid cloud infrastructure, there is ample opportunity for the field of hybrid cloud trust management to both benefit from and contribute to narrative approaches and frameworks. With the right levels of generalization, transfer of models and tool suites between domains could be expedited. For example, the narrative models and tool suites which help inform scientists about the state of immune systems, homeostasis, and other elements of biological health could be converted to inform administrators about analogous features within hybrid cloud infrastructure, thereby helping to communicate and calculate risk more effectively [275]. Further, the use of models transferred from other fields may come with the benefit of established and tested collection and processing methodology in other fields such as crowd-sourcing and pattern analysis. A deeper dive into the specific types of narrative information (e.g., prescriptive, predictive) used in hybrid cloud management systems is recommended, and it should be noted that Trust Management exists well beyond hybrid cloud infrastructure. Many of the problems and solutions discussed here could generalize well beyond this domain.

Translational Neuroscience

Neuroscience is the scientific study of the nervous system. It is a multidisciplinary field that combines approaches from genetics, molecular biology, physiology, psychology, medicine, and many more. Translational research is the realm that connects basic research (performed on isolated systems in the lab) with clinical research (including diagnostics, treatment, and management of human diseases). Translational neuroscience research benefits greatly from the use of mammalian animal models such as mice and non-human primates to mimic and treat disease states in experimental ways, before attempting human trials. As a paradigmatic case of the challenges inherent in applying basic neuroscientific research insights, and example of Narrative Information Management “in the wild”, we focus on the area of neurodegenerative brain disease. Treating brain disease has its own set of challenges—mainly that changes in human behavior and cognitive skills often don't have a clear connection to the pathophysiology or systems studied in the lab. In this section, we provide some perspective on Narrative Information Management in the field of Translational Neuroscience, using Alzheimer’s Disease as a case study.

One of the first challenges of medicine and biomedical research is to describe the disease in the population and identify the cause. Patient case studies and postmortem tissue analysis provide the first glimpse at the connection between behavior and pathophysiology. Alzheimer’s Disease (AD) is an irreversible and progressive brain disorder that affects 6.2 million people in the USA [276]. It is the most common form of dementia, presenting clinically with memory loss and cognitive decline. Only 5% of cases can be linked directly to genetic mutations, for all other cases (called sporadic AD), the main risk factor is age; AD incidence doubles every five years after 65 [277]. Neurochemically, AD is characterized by the presence of amyloid plaques, neurofibrillary tangles (NFTs) and loss of synapses in the brain [278]. AD pathology is complex—it may present with all or some of these pathologies: amyloid plaques, NFTs, inflammation, oxidative damage, iron deregulation, blood-brain barrier dysfunction, and alpha-synuclein toxicity [279]. The relationship between these pathologies remains unclear, as observational studies cannot differentiate between "cause, consequence, compensation or confound" [280]. Clinicians are limited in their diagnostics for patients, because many of these symptoms do not have biomarkers, and the diagnosis of AD can only be confirmed post-mortem. The NIM challenge for clinicians and scientists remains: what causes AD? What is the "story" that connects disparate empirical results across decades and domains? Is there a causal link between the common symptoms? For now, the approach has been unidirectional in the sense that molecular changes are hypothesized to lead to changes in patient outcomes, and each of the molecular pathologies have been explored in relative isolation.

One shared process of NIM or sensemaking among scientists and clinicians is that experiments are designed to explore hypotheses. Following an established hypothesis, scientists design the experiments to support or reject. The design of the experiments depends on the perceived relevance of the proposed hypothesis and extent of support from funding agencies (e.g. the US National Institute of Health). To mimic AD neuropathology, scientists often make use of cell cultures and mouse models, where the neurotoxic proteins can be added externally in cultures or genetically encoded to accumulate in the brain of the mouse. Mice have a shorter lifespan, different brain structure, and different behaviors than humans; therefore, direct extrapolation from mouse studies to human biology is hardly straightforward. One caveat is that mice lack the core protein components involved in the plaques and NFTs, which are hallmarks of AD pathology. Mice can only develop these protein aggregates with human neurotoxic proteins

[281]. Another critical interpretation issue is whether or not it is possible to measure small, slow changes in the cognitive performance of mice, as typically measured in humans. Animal studies commonly measure changes in spatial memory, but often ignore neuropsychiatric axes, like anxiety [282]. The question remains—how can we model this disease in a useful way that allows for mechanistic exploration of the pathology? Can we treat the behavioral symptoms of memory loss by removing the underlying pathology? In a genetic mouse model of AD, yes, but in patients—no. Alarmingly, the same drug that removed plaques and improved memory in mice actually led to cognitive decline in patients, which continued even after the trial [282]. Among the proposed solutions are biomedical efforts to create mouse models with multiple pathologies [283] and connect the symptoms mechanistically. Thankfully, these findings are published in peer reviewed journals and are accessible to the research community. In navigating the wealth of publications, scientists are often taught to consider each publication as a story, such that specific findings are easier to remember in the context of the whole story. Due to the daunting amount of published literature and plausible research avenues, scientists and funding agencies are faced with a narrative challenge: which studies should be funded, which hypotheses should be explored? Such questions are often pondered by individuals, agencies, labs, and researchers, but such efforts are rarely connected back to the broader literature on narrative sensemaking.

Beyond the direct reach of academics, NIM plays an important role in research, strategy, and decision-making in industrial and pharmaceutical sectors. The actions of these large entities bear strongly on clinicians, who eventually deploy the solutions/therapies that stem from neuroscientific research. Pharmaceutical companies access the public knowledge of animal and clinical studies, but also create their own private research depots. As such, pharmaceutical companies navigate the complex processes of scientific development, FDA regulation, patenting, and marketing. Pharmaceutical companies work with clinicians and researchers to develop large scale clinical trials. Clinical trials require an interface between patients and the public. As of 2007, clinical trial data is compiled at the NIH clinical trial database, although timely reporting is not enforced (clinicaltrials.gov) [284]. In Phase III clinical trials, the drug is given to a patient for the first time and tested for efficacy. Therefore, designing these clinical trials is a multifaceted challenge, as researchers try to recruit the right number and type of patients, as well as determining the time of treatment and appropriate measures [284]. Collecting, storing, and analyzing such quantities for sensitive health information calls for NIM solutions. Recent advances for improving experimental design include Bayesian modeling for determining appropriate endpoints, classifying patients based on medical history, and novel detection of AD biomarkers [278].

The last mile for applied neuroscientific research is in the NIM of patients, especially in their interactions with clinicians. Patients and their families learn about potential treatments and manage disease in patients, based on information they integrate into personal narratives. All of this starts with access to medical care and proper diagnosis of health conditions. Outside of the doctor's office, patients receive a highly profitable stream of direct-to-consumer advertising (DTCA) from pharmaceutical companies, such that patients can learn about new drugs and request them from their doctor. A common side effect of DTCA is the increasing demand for new and costly treatments in lieu of existing low-cost options [285]. Another way that patients learn about therapies is through social media and scientific communication. Unfortunately, the headlines may give false hope, and animal research gets more media coverage if they don't include "mice" in the title [286]. The recent controversy around the FDA approval (and reversal) of the drug Aduhelm (which targets plaques) has done a lot to shift the narrative around accepted hypotheses for AD [287], which now include targeting NFTs, light/sound therapy and immune cell stimulation. Clinical trials on lifestyle changes such as exercise have shown that regular physical exercise prevents age-related brain atrophy and helps with neuropsychiatric symptoms of AD [288], however research on public health interventions can be misrepresented greatly [289].

Health NIM exists at multiple nested scales, and while AD is one such case, it's becoming clear that everyone is participating in the management of health narratives on some level. Researchers, clinicians and the public need new tools and training for making appropriate decisions about health policies. In the scope of treating human disease, translational research is positioned between basic and clinical research, and therefore experiences the burden of NIM challenges: managing information gaps, exploring the informational environment, and synthesizing diverse sets of information. Future studies in the NIM of health could examine how public policy influences the narratives of individuals. Particularly for individuals dealing with long term health issues, NIM tools may help alleviate the mental, psychological, and logistical burden of decision making.

Genomics

Genomics is an area of theory and application where biological datasets are analyzed to address a variety of questions related to human health, government policy, agriculture, industry-led research, environmental monitoring programs, and more. "Genetics" refers to the broader study of trait development and inheritance in biological systems, while "Genomics" usually refers to the modern (post-2000) high-throughput technologies used to measure biological molecules such as DNA, RNA, protein, and metabolites.

A failure of NIM for genomics at the institutional level could look like inadequate or grievous policy deployment, based upon improper assessment of biological information or risk (e.g., a false-positive or false-negative decision to institute a regional lockdown based upon the perceived risk of a virus identified only from genomic sequences). In contrast, for individuals a failure in genomic NIM could have life-altering consequences regarding the perceived meaning of genomic information obtained from medical experts or personalized genome sequencing services. Socially, when NIM in genomics falters, it can lead to increased distrust in the scientific endeavor and an acceleration of the epistemic crisis in the knowledge commons – especially as genomics technologies such as human personalized medicine and viral sequencing become prevalent. This may be linked to the nature of our own genomes, in that it is linked to our shared identities as well as personal uniqueness.

In this section we provide a few views on NIM in 2021 within the field of Genomics. This section is not a broad review of the wide topic of Narrative Genomics [290–292], rather it is a selection of enduring and recent features of genomics in the context of NIM and cognitive security. Genomics presents domain-specific and transdisciplinary teams with a set of constraints and opportunities, some of which are unique to genomics and other aspects are shared broadly across fields:

Underlying system complexity. Genomics data, while sometimes vast in terms of computational size [33], are only the tip of the iceberg in terms of the complexity of the actual biological system (e.g., the inner workings of cells and tissues). Even though genomic technologies provide high-resolution maps for humans to navigate biological systems from the cellular to the ecosystem scales, the underlying territory is vastly more intricate and nuanced. Biological systems consist of many kinds of interacting molecular components (proteins, lipids, nucleotides, carbohydrates); the overwhelming majority of which are involved in numerous relationships and thus, may not have a clear function when considered in natural contexts. As higher levels of organization in biological systems (e.g., social) are in dynamic feedback with lower levels of organization (e.g., cellular), it can be unrealistic or impossible to disentangle the effects of interactions among layers [293,294].

Sheer scale of data. Biological datasets have exploded in size recently, as the costs of genomics experiments drop and their throughput increases. Since the 1980's, the total amount of genomic data has been increasing roughly exponentially [33,295,296]. This access to genomic data is providing new opportunities for genomics researchers, technology developers, and medical practitioners. However, for researchers looking to investigate these data sets, even with relatively straightforward questions, a new level of computational skill is required. Even best-in-class information, such as gene expression profiling at the single cell scale, are very partial representations of living systems, and require extensive computational analysis in order to derive insight.

Social relevance and sensitivity. Genomic data play significant roles in individual and collective narratives around various topics, including the legality of discrimination (as per The Genetic Information Nondiscrimination Act of 2008 [297,298]), the nature of ethnic and sexual identities [299–301], and broader discussions around the relationship between inheritance systems (genetic, epigenetic, and cultural) [302,303]. As genomic editing technologies like CRISPR/Cas9 become increasingly accessible to laboratories around the world, contemporary narratives around human genome modification are of historical importance [304]. Also of note here is the recent deployment of almost real-time genomics analysis in response and policy planning around the emergence and spread of the SARS-CoV-2 virus, responsible for the COVID-19 disease.

Personal Identifiability. The data generated by genomics experiments are essentially personal – they can be used to identify relationships among living and dead people. Genomic information can be extremely informative or even conclusive regarding various questions related to forensics, law, heredity, and medical diagnoses. Biological and genomic data can be extremely sensitive in terms of personal privacy, to the point of being able to identify individuals who have not even submitted their own genomes for analysis (as in the recent case of the “Golden State Killer" who was triangulated using a combination of detective work and DNA evidence

[305]). Dealing with large datasets of potentially-identifiable or health-related information, genomic or otherwise, comes with new challenges.

Genomics is a technical area that recently is experiencing wide public participation in the analysis and interpretation of data. This expansion of social accessibility in the genomics process can be attributed to multiple factors, including the increasing prevalence of direct-to-consumer genomics tests, and the growing role of genetic data in driving individual health decisions and public biosecurity policy. Those who work directly with genomics data might fall into a few categories, each with different pressures, incentives, affordances, and narrative contexts:

Academic Researchers. Academic researchers are more likely to be working on non-human data, more likely to be working on basic or theoretical questions, and may have knowledge of the field but remain unaware of state-of-the-art tools used by computer scientists for secure cloud computation at large scale. Academic researchers face the pressures of science as a career (e.g., pressure to publish and their working environment).

Industry Researchers. In industry and government, researchers face a different set of affordances and pressures than academic researchers. These researchers may variously be working on human, microbial, livestock, or agricultural genomics data, often with a more direct focus on applications. Applied genomics research in industry occurs under direct or indirect business pressures, as the results of the analysis are financialized in a way that is distinct from other research domains. Government researchers may use genomic data in a range of settings, of particular interest is the consideration of public health implications for viral variants. As the SARS-CoV-2 pandemic shows, genomics data support governmental decisions in real-time, meaning that increased emphasis is placed on reliable bioinformatic pipelines, clear visualization of essential data features, and contextualization of genomic data so that it is informative for non-experts.

Medical Analysts. Medical analysts are more likely to be working with human (or veterinary) topics and data; thus, they are under pressures related to efficacy, timeliness, and data privacy. Medical decision-making occurs in the context of transdisciplinary teams, where genomic data plays an increasingly large role as the price of acquiring personalized genomic information drops. Genetic counselors, specifically, are the contact point between the technical details of genomic data and interpersonal communications with patients, most of whom are not familiar with the intricacies of genetic medicine [306–308].

Non-institutional Researchers. Individuals outside academia, industry, and medicine are also beginning to gain access to genomic data – for example through the use of personal genomics services, or public databases containing viral sequencing data. Developing communities that use genomic data and tools include citizen scientists, biohackers, and data-driven journalists. Many of the tools useful for genomics are open-source and utilize free public databases. However, non-institutional researchers may face computational constraints, gaps in their knowledge of genomics, or be unfamiliar with norms around communication of results. Not every citizen can be expected to have the knowledge required to perform bioinformatic analyses or write genomics papers – but when common topics of public discussion include nuanced and "science-informed" discussions, shared understandings are essential.

Genomics as a field stands at the intersection of biology, identity, data, and policy. Practitioners of genomics come from a wide range of backgrounds, and increasingly genomics data is playing a real-time role in decision-making. Some of these developments have been unfolding for decades, such as the continued trends of decreasing costs of sequencing and increasing capacity for genome editing. Other changes in the deployment of genomics have specifically arisen in response to the pandemic spread of the SARS-CoV-2 virus and subsequent global response. It is imperative that analysis and communication of technical findings be made rigorous and accessible, especially where genomics is playing a directly narrative role in the public eye, for example related to viral variants, genetically-modified agriculture, and disease-associated human alleles. Further research and collaboration can seek to understand the interface between the ever-expanding frontier of genomic technologies, and one of the essential features of human cognition: effective narrative sensemaking amidst uncertainty.

Discussion

Our initial search for commonality within information-centered fields, such as knowledge management, yielded a broad set of useful features common to Narrative Information Management (NIM) systems. In the interest of discovering other NIM-related features, which are perhaps understudied or obscure, we explored an eclectic selection of fields sampled from the experience of the coauthors.

Here we review our initial insights about common NIM features and introduce 4 additional features of NIM that were revealed upon deep, field-specific consideration: (1) facilitating communication, (2) handling of errors and inconsistency, (3) management of trust signals, and (4) social systems engineering and education. These features were illuminated while contemplating the challenges, requirements, and ad hoc solutions related to the management of narrative within the domains of personal finance, ancestry research, hybrid cloud infrastructure security, neuroscience, and genomics.

Managing Information Gaps

The need to manage information gaps was central in all fields considered, indicating a degree of overlap between various NIM features. In the case of ancestry research, it was not only essential, but the defining element in the domain—with a variety of ad hoc and platform-provided methods for identifying and resolving these gaps. Well-designed schemas and structures are used to help direct the attention of ancestry researchers to missing pieces within the knowledge base. In personal finance, externalization was a key solution to handling information gaps, both through community message boards and financial professionals. However, this externalization is accompanied by problems of its own—as the choices in who to trust is in itself a difficult challenge which has led in some cases to herd mentality and cult of personality. A key insight is that the presence of investing communities further complicates the space as the members are not just consumers but also components of the information economy. Where ancestry research and personal finance provided insights regarding implementation, the domains of genomics, neuroscience, and trust management in hybrid cloud illuminated the need for information systems that facilitate handling the sheer volume and complexity of the gaps, as well as systems that highlight and acknowledge areas that cannot be disambiguated. For transdisciplinary challenges involving multiple domains (e.g., a genomics researcher investigating the structure of a viral protein in order to make recommendations related to medical policy), information gaps may need to be bridged both within and among areas of expertise.

Facilitating Situational Awareness

Maintaining situational awareness was of obvious importance to hybrid cloud infrastructure security, where the need to monitor for security threats and vulnerabilities is constant, yet exploring these various domains indicated it's still vital in other areas, albeit in less pressing ways. Researchers in genomics, neuroscience, and in the sciences in general need to keep up to date on the never-ending stream of new literature, as do regulatory and funding agencies. In personal finance, situational awareness has some of the same aspects of time-sensitivity and risk-deterrence as those found in hybrid cloud infrastructure but with the added interest of spotting potential opportunities. This use of situational awareness for directing attention toward opportunities was more codified in ancestry research, where platforms are context aware and help bound scope to reduce cognitive load while prescribing actions. In order to make situational awareness achievable despite the high volume and complexity of information, personal finance and ancestry research were shown to primarily make use of streaming dashboard visualization and symbolic compression, whereas the fields of genomics, neuroscience, and hybrid cloud infrastructure security appeared to make more use of information fusion and modeling. An insight drawn from this distinction might be that both situational awareness and the processes by which it is achieved must be fit to the community. In other words: no single system would be of equal value to communities facing different kinds of informational challenges under different conditions even where those systems might benefit from common mechanisms.

Providing Descriptive and Explanatory Information

The ability for individuals to dig into particular components and objects of the information environment to find description and explanation was of obvious value in all fields, to varying degrees. In particular, IT administrators and those attempting to understand the market are faced with near constant changes regarding which objects are of interest day to day, or even minute to minute, making capabilities associated with accessing and committing information to working memory far more pressing than capabilities associated with storing it. In making sense of very complex systems, the use of mental models, schemas, and codification of patterns of expectation appeared to be of great value to all fields.

Facilitating Exploration

The ability to assist in the exploration of new information was emphasized in ancestry research and personal finance, where the untrained and self-educated are not provided with the same kinds of guides to the informational terrain as would be found in the sciences. In ancestry research, less focused exploration serves as a basis for helping to maintain the knowledge base, and, in the case of purposeful exploration, providing tools to help scope the needs and boundaries of exploration is potentially more important than providing curations of resources. As information volume expands, curation is simply not enough and recommendation systems need to be tuned to project and mission context, not just personalized to the individual's past interests and searches. In personal finance, exploration serves as a function of situational awareness—and here we acknowledge the need for methodology and tool transfer between domains, as those attempting to make sense of the market have an immediate, pressing need, yet do not have the kinds of tools available to ancestry researchers. This is seen in ancestry research as well, where it was noted that not even historical researchers have access to the kinds of tools of their amateur counterparts.

Compression

Compression of information through visualization, structure, collation, curation, and interaction mechanisms was of particular interest as it was so often embedded as a basis for performing other functions. While some fields emphasized certain mechanisms of compression more heavily than others, all were still relevant. The insight drawn from all fields in this case, is that this may be the most fundamental aspect of NIM—which is fitting, given that narrative itself can be considered an information compression mechanism.

Case Management and Prescriptive Information

Case management functions were only emphasized in ancestry research and in hybrid cloud infrastructure security. However, the need to string together disparate events encoded in myriad forms, which may have otherwise been considered unrelated, was apparent in all fields. The insight drawn here, as has been drawn from other categories, is that there is a need for more tool and methodology transfer between fields. Case management methodology is highly generalizable, as discussed when introducing NIM features, and those working in genomics and neuroscience or those trying to make sense of the market or their finances could have large reductions in cognitive overload should tooling be made available. The importance of trust and the value of structure and codification of patterns in prescriptive information, or information regarding what the user should do or look to next, are seen in ancestry research, through its use of data schema and platform structure, and personal finance, through its use of externalization. From hybrid cloud infrastructure security, a key insight was the importance of prescriptive information in terms of scale—professionals in the space have to contend with such a high volume of events, that externalizing to some level of automation to prescribe or suggest action and to triage and prioritize tasks is not just valuable but inescapable. Finally, in neuroscience and genomics, prescriptive information was generally found in the processes by which individuals perform the work—however the communities informed by the sciences, such as patients, clinicians, and policy officials, suggest a need for cross-community prescriptive information, rather than a focus on provision of prescriptive information within the field itself.

Synthesizing Intelligence

The need to synthesize extant information into new information products, similar to compression of information, appeared to be fundamental across the domains to varying degrees. There is a clear need to improve information sharing between research-oriented and application-oriented areas within a given field to ensure more comprehensive and useful synthesis. In addition, all areas, as discussed when considering insights about case management, had demonstrable need for information fusion capabilities in the interest of developing new information products from myriad sources. Further, insights could be drawn from neuroscience and personal finance, pursuit of what is relevant to funding agencies and personal investments may affect the resulting syntheses, respectively. In terms of potential solutions, ancestry research was an arguably surprising place to have found such advanced mechanisms for rapidly and automatically producing coherent documentation, reports, and even entire context-specific books about particular research projects—this automatic rendering of content could be invaluable to researchers in other domains.

Facilitating Communication

The facilitation of communication both within and between communities and users is the first of the features not included in the initial list. Much of the knowledge management and adjacent literature initially surveyed appears to assume, often for good reason, that the users of a particular, managed knowledge base will be a part of the same organization or profession. However, as shown in all sections, this will not necessarily be the case in practice. For example, in neuroscience and genomics, there is a complex interplay between scientists, researchers, governments, regulatory agencies, funding agencies, patients and concerned citizens, caregivers and counselors, and even ancestry researchers, as they share an abstract information commons without tools for managing the asymmetries in training, interests, and information access. A key insight can be drawn from both neuroscience and hybrid cloud infrastructure security, where there appeared to be a difficulty communicating between the application-oriented and theory-oriented aspects within those fields, as was noted in the discussion of intelligence synthesis. Facilitating communications within and between communities and users can enable both dialectics and interfaces for cross-community NIM.

Handling of Errors and Inconsistencies

The importance of addressing error and inconsistency was not addressed as a primary concern within the literature initially surveyed, except where it concerned fraud in archive and records management. In the fields sampled, however, handling of errors and direction of attention toward inconsistency appeared to be of notable importance. In trust management in hybrid cloud architecture, detection, preventing, and handling of error and inconsistency in terms of permissions was a defining characteristic. In ancestry research, the lack of methods to contend with error accumulation in crowd-submitted annotations means the enormous corpus assembled is arguably useless to historical researchers. Moreover, inconsistency in details such as birth dates on two documents may suggest either differences in identity or bureaucratic errors and changes. Neuroscience-centered inconsistency, such as the differences between expected effects in human and animal trials, isn't always about correction, but instead about direction of attention toward information gaps and acknowledgement of complexity. This same insight can also be drawn from hybrid cloud infrastructure security where inconsistent behavior or expectations about use of equipment can signal vulnerabilities.

Management of Trust Signals

An unforeseen addition to the list of NIM features was trust management, or more specifically, the management of trust signals. Our initial expectation was that trust management would be an area that would benefit from NIM, as opposed to an area which would be an explicit feature of it. As shown in numerous sections, contributions may contain errors, inconsistency, or be influenced by perverse incentives. Information quality in any knowledge base should then be expected to be somewhat unstable, and as such, there is a need to manage signals associated with the veracity and quality of information—lest all information become questionable, preventing users of the knowledge base from forming coherent narratives.

Social Systems Engineering

As a final discovered feature, possibly the defining, fundamental characteristic of NIM systems is the treatment of users as components of the knowledge base—not just consumers. In hybrid cloud infrastructure security, ancestry research, and personal finance, users are up against various tradeoffs while contributing to and interacting with aspects of information systems such as information quality and security, as well as aspects that run counter to the maintenance of the information commons, such as convenience, time, efficiency, and event reputation. In personal finance and ancestry research, where non-professionals make up a large portion of the interactions and contributions to their respective information commons, the risks, such as corruption of the corpus or the creation of feedback loops of negative interactions with the world outside the commons, are even higher. However, the benefits to narrative sensemaking which come from community involvement in the commons outweigh these risks, and there is a rich, social systems engineering literature to draw from in

> mitigating them. Investigating other domains may be of further value, as personal finance revealed the importance of role and duty assignment and judicial function, through the use of fiduciaries to moderate contributions to the financial information commons.

In this paper we proposed Narrative Information Management (NIM) as a term to describe the common set of system features that facilitate narrative sensemaking. In the interest of clarity, we define the term here as follows:

> **Narrative Information Management:** The design, use, implementation, and study of aspects and features of processes and systems which manage information in order to facilitate narrative sensemaking.

With increasing fragmentation and information overload in the very domains which intend to address these challenges, we propose the term in the interest of helping to unify research interests and connect those research interests to requirements, challenges, and ad hoc solutions in the field. We do so with the caution which should accompany any introduction of new terminology, and with consideration for its economy (does it compress and communicate well for its size?), precision (does it refer to one idea only?), stability of definition (will this still mean the same thing a year from now?), and other aspects [309]. Whereas past introductions of similar terminology in the information sciences have generally divided or generated new fields [42], NIM may instead be of most use if considered as an analog to complexity theory centered in the information sciences, existing as a nexus or bridge between many disciplines purposed with facilitating the discovery and codification of regularities, generalizations, and methodologies of global use. In the spirit this usage, we conclude by offering recommendations for continuing work on NIM.

Recommendations

- Continue the search for additional general NIM features through exploration of the challenges, requirements, and ad hoc solutions in various applied disciplines.
- Focus on development of common interfaces, common theory, and common data structures that help tools and communities communicate, rather than on singular, common tools. As evidenced by the exploration of the sampled fields in this paper, each community has their own unique needs, and no single platform should be expected to meet all of them.
- Developing education and curriculum around NIM and sensemaking in the interest of developing shared language and improving accessibility and communication of research on meta-sensemaking.
- Encourage interdisciplinary collaboration in research on information systems and their use in the interest of generating useful bridges and synthesis between fields.

Contribution Statements

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CHAPTER II

Digital Rhetorical Ecosystem Analysis

Sensemaking of Digital Memetic Discourse

Mridula Mascarenhas, Richard J. Cordes, & Daniel A. Friedman

ABSTRACT

This paper makes a case for integrating frameworks from two different knowledge domains, rhetorical studies and ecological studies, to catalog, monitor, and study digital image meme data, in order to support a more robust understanding of how memes produce and disseminate online narratives. In the digital public sphere, the primacy of image-based communication motivates an over-reliance on the image meme for public argumentation. Despite its ubiquity, the image meme format is currently understudied in large scale digital data analyses, relative to text-based formats such as natural language and hashtags. We argue that using a rhetorical approach (which emphasizes message form and audience) in large-scale analyses of multimedia and other digital artifacts can enhance analytic tools for categorizing, indexing, searching, and modeling online discourse. Further, by integrating a rhetorical and an ecosystem approach to studying digital discourse, we can formally trace multimedia rhetorical artifacts like image memes across platforms, media types, and languages. Combined rhetorical and ecosystem analyses can reveal how digital artifacts like image memes create, sustain, and disrupt public narratives and, thereby, socio-political dynamics. Three key elements of our approach are a) recognizing how parsimony and polysemy give image memes narrative power, b) focusing on how image memes engage audiences through

identity construction, and c) applying "Rhetorical Ecosystem" mapping, based upon toolkit transfer and system design implications. Drawing from concepts in rhetoric, ecology, and complex systems analysis we introduce a Digital Rhetorical Ecosystem three-tiered model (DRE3) to explain how memes impact public narratives and beliefs. We then explore implications of this DRE3 model for the design and development of systems for computational analysis of digital discourse.

Part I
A Rhetorical Approach to Understanding the Impact of Image Memes

We are in the throes of a widespread epistemic crisis that is damaging individual and collective sensemaking function and capacity ([1,2]). The crisis, articulated as "a state of affairs in which partisans disagree not simply on policy, but on facts themselves" [3], is attributed to a set of conditions including a "combination of political polarization, declining trust in media institutions, and asymmetric media ecosystems" ([3], para. 1). Concern about fake news, alternative facts, and misinformation has been escalating. Despite legitimate concerns about the degradation of public information due to the infusion of spurious content, we argue that viewing the information crisis as a competition between truth and falsity obscures the nature of the digital information crisis we are facing and, worse still, hamstrings efforts to restore trust and rework social consensus, which are essential for collective social action. Rather than approach the digital information problem as a battle between true and fake information, we urge attention to the rhetorical conditions and processes that contribute to eroding trust in established channels of information, and mainstream institutions and publics.

Framing the crisis as a battle between true and fake information has not proved effective in regaining the trust of those disaffected by mainstream channels of information. A simplistic true/fake dichotomy ignores the rhetorical conditions that have allowed competing narratives to displace mainstream ones. The hyper-complexity of digital information ecosystems is one such condition that makes achieving consensus on facticity and truth highly challenging [4], a condition that has, indeed, been exploited by malevolent actors. Nevertheless, addressing our epistemic crisis requires more than targeting and neutralizing sources of misinformation. We advocate a framework that combines rhetorical analysis with an ecosystem approach to trace the ebb and flow of narratives across digital publics. A rhetorical approach to understanding the information crisis focuses on message features that target audience vulnerabilities. An ecosystem approach goes beyond analysis of specific messages and audiences to highlight complex and long-term message-audience interactions, which can illuminate the changing web of narratives that influence public beliefs, opinions, and actions. Accordingly, we recommend addressing the epistemic crisis by developing a fine-grained understanding of the rhetorical forms and processes through which information circulates in the digital public sphere and introducing rhetorical intervention as needed, rather than focusing exclusively on source control.

Contemporary digital information ecosystems create particular burdens on individual and collective capacities for reliable sensemaking and robust public discourse. The increased volume and diversity of information on the Internet create unprecedented cognitive complexity, and challenge clarity and social agreement on issues of public concern [5]. The default mode of online engagement—rapid surfing through endless streams of information, rather than focused deep immersion in selective limited information—further curtails information-processing capacity. Platform affordances and constraints, such as limited expressivity in communication (e.g., being encouraged to use a "like" reaction button in lieu of natural language elaboration on a post), the ability to rapidly scroll on digital screens, and the glut of emotionally charged material can also encourage peripheral rather than central processing of information [6–8].

Digital infrastructures also shape digital artifacts. The rhetorical features of these artifacts further encourage superficial engagement with online information. In our paper, we focus on one particular online artifact form—the image meme—that has played a crucial, yet understudied role, in destabilizing former epistemic foundations and traditional sources for public sensemaking. As we demonstrate below, the image meme has evolved into a ubiquitous unit of public discourse. Moreover, image memes function consistently as quasi-arguments in digital public spheres.

The word "meme" has gathered a great deal of semantic elasticity at this point [9,10], stretching from a general "unit of culture" to the specific genre and form of the image-macro [11,12]. We adopt a narrow definition of the image meme that allows us to capture and trace its role in public sensemaking. While the image macro refers to "captioned images that typically consist of a picture and a witty message or a catchphrase" [13], we use the term "image meme," instead, because many specimens that draw from the image macro genre are devoid of text. In those cases, a juxtaposition of images within the meme compensates for its lack of textual elements. In image memes, configuration of the images themselves create meaning by making or implying arguments. We define the image meme by two features—form and function. The form of the image meme is established by the rectangular box frame which circumscribes one or more rhetorical elements, demarcating the meme as a discrete communication unit on platforms like Facebook, Instagram, and Twitter. While image memes perform a variety of rhetorical functions [14,15], we restrict our attention to image memes that play a particular rhetorical role—i.e., they participate in public argumentation by advancing claims [9]. In sum, the rhetorical artifact at the center of our paper is the ubiquitous rectangular box that is deployed to make a claim about a public issue.

The image meme has proved remarkably effective as a currency for public discourse, especially on Facebook and Instagram [16]. In particular, image memes have become integral to the destabilizing projects of the digital radical. They have been deployed strenuously in efforts to challenge and disrupt official and institutional discourses. The rhetorical dominance of image memes can be attributed to their ability to function argumentatively and, thereby, persuasively in the public sphere, constituting radical communities of discourse that are engaged in decoding, sharing, and amplifying their contents [17].

What does a rhetorical approach to the study of memes entail?

Aristotle defined rhetoric as "the ability to see what is possibly persuasive in every given case" [18]. Rhetorical study emphasizes the *how* of persuasion. Therefore, a rhetorical approach to addressing our epistemic crisis moves us past solutions like banning digital sources of information or playing fact-check whack-a-mole with spurious message content, to focus on the persuasiveness of the message medium. While rhetorical critics are invested in analyzing message content, they are also invested in analyzing message form. The digital artifact at the center of our paper, the image meme, is a powerful example of the persuasiveness of rhetorical form. Repetition of form contributes to the crystallization of a rhetorical genre [19]. The widespread and increasing deployment of the image meme in digital public spaces has elevated the image meme into a rhetorical genre, one that is capable of charging a large scope of content with persuasive appeal.

Image memes have immense rhetorical power to shape online and offline sensemaking and action. During the 2016 United States election, Internet memes "enabled users to rapidly take a stand on and react to developing political events in real time; they provided alternative parallel discourses to mainstream media viewpoints; and they enabled mobilizing voters outside of official political discourses" [20]. The rhetorical power of multimedia memes has strengthened since 2016 [21,22]. Therefore, we argue for treating these artifacts as serious agents that shape public narrative and action.

A rhetorical approach to analyzing image memes can advance our understanding of their persuasive influence beyond the current practices of syntactic tagging of memes, for example by text recognition [23]. A rhetorical approach fills in the gaps endemic to tagging practices by enriching analysis of image memes with rich semantic information embedded in the parsimonious combination of the meme components. Symbolic cues in the memes not only advance logical claims but also encode ambiguous yet intense emotional charge that could spur public action. Interpreting cues within the meme against contextual knowledge surrounding the meme is vital for the process of rhetorical analysis, and, as we will discuss later, computational analysis of digital discourse using a rhetorical approach.

A rhetorical approach encourages attention to the ways in which memes galvanize specific audiences to change their thoughts and actions. Image memes have constitutive potential; that is, they simultaneously call into being (constitute) audience groups while influencing audience thinking and possibly action—a process which rhetoricians call interpellation [24]. This constitutive potential is contained in the argument potential of the meme—its ability to advance claims, provide/imply evidence, and rely heavily on a discursive community to supply the necessary warrants (assumptions) to complete the argument [17]. The capacity of image memes to compel audience participation in semantic decoding contributes to the persuasive appeal of memes because the act of figuring out the meme's claim constructs the experience of truth-seeking, and consequently a sense of shared in-group identity, for the audience. Having successfully completed the decoding effort, audiences are interpellated as truth-seekers which enhances their investment in the meme's claim.

Another rhetorical feature of image memes that makes them conducive to interpellating audiences as truth seekers is that image memes are often free-floating. They seem to appear out of nowhere and do not typically disclose their sources unlike other digital content. As such, image memes represent an epistemic break. They gain credibility not because they arise from authoritative sources but precisely because they claim no source. The rejection of source credibility makes image memes a very powerful parallel discourse to more formal media channels and, in many cases, a direct challenge to information, claims, or narratives that emerge from publicly-vetted sources. When interpellated audiences decode and share image memes and engage in discourse about memes on forum threads, they build credibility for the meme in the absence of authoritative source credibility.

Therefore, tracking image memes (the claims they advance and the audiences they interpellate) in digital public spheres has become essential. Robust and far-reaching alternative and counter narratives circulate through social media platforms displacing mainstream narratives and flow under the radar of traditional mechanisms for capturing public belief and opinion. These online parallel currents of public discourse grew on social media platforms in relative obscurity between 2016 and 2020. The 2020 pandemic year, however, surfaced the proliferation of underground narratives when they started to manifest as widespread overt resistance to official COVID-19 narratives and policies, among large noticeable sections of the public. Towards the end of 2020, the galvanization of digital memetic energy around the visible public agitation against the 2020 US election results, culminating in the events at the United States Capitol on January 6, 2021, initially caught public officials and mainstream media off guard but subsequently drew further attention to the robust discursive spaces in which competing narratives have been spawning and flourishing. Competing narratives have had and continue to have global impacts, as digital public spheres transcend the national boundaries of mainstream and official media channels. As researchers and organizations, interested in improving the immunity of digital public spheres to misinformation, invest in understanding the emergence of competing narratives, we urge attention not simply to the content of the narratives but, equally, to understanding of how those narratives are constructed through the circulation of digital artifacts, such as image memes. The philosopher Bruno Latour has noted that "whether or not a statement is believed depends far less on its veracity than on the conditions of its 'construction'—that is, who is making it, to whom it's being addressed and from which institutions it emerges and is made visible."[25] To Latour's list, we add the importance of attending to the rhetorical form in which the statement is packaged, i.e. the form of the image meme . Understanding the rhetorical form and function of image memes is crucial for any effort to observe, model, and respond to memetically-driven narratives.

Rhetorical Anatomy of an Image-Meme

Although digital image memes can be used to circulate official narratives online, they have more successfully been deployed disruptively, across the political spectrum. Their truncated or compressed form is well-suited to inject targeted challenges to mainstream claims. The parsimonious form of the image meme provides a great deal of capacity for semantic encoding to advance persuasive claims while diminishing burdens of proof and elaboration that other rhetorical artifacts, like news articles, require. Various image meme formats such as text-only, image-only, screenshot, and image-text juxtaposition can all create polysemic affordances [26]; that is, the possibility of extracting multiple and multi-layered interpretations within a range of meanings. The strategic ambiguity inherent in memetic artifacts allows for rich semantic encoding. At the same time, the structural features of the memetic form (i.e., the containment of its content in a box, and the text/image syntax) strategically constrain meaning-making by setting up the key elements of an argument and cutting off counter-arguments. Below, in Figure 1 we illustrate the construction of an argument contained in one sample image-text meme.

Figure 1 constructs an argument with the simple juxtaposition of two lines of text above and below a stock photo. The choice of the photo combined with the double textual framing relies on the contextual knowledge of discursive communities to decode the argument. While the explicit memetic content is sparse, its signifying layers are rich, thus allowing the meme to argue a clear and persuasive claim.

The primary claim distilled from this image-text meme is that the official narratives about the origins of the SARS-CoV-2 virus, and the official masking policies to combat the virus, are not to be trusted. The rhetorical power of the meme draws from its strategy of juxtaposing two official narratives that appear to be mutually exclusive—that is, if the virus is virulent enough to escape the strict safety protocols of a world-class laboratory, then it can definitely penetrate the ordinary masks that the public has been asked to wear to stem the spread of the virus. The meme simultaneously alleges dissonance in official claims and expresses a snide disdain for those who accept the official narratives and are oblivious to the dissonance. The meme carries content designed to appeal to audiences' logical reasoning as well as to activate an emotional charge in the audience. The logic and emotion evoked by the meme are abetted by the meme's use of the "Condescending Wonka" image deployed memetically since 2011 to convey patronizing sarcasm [27].

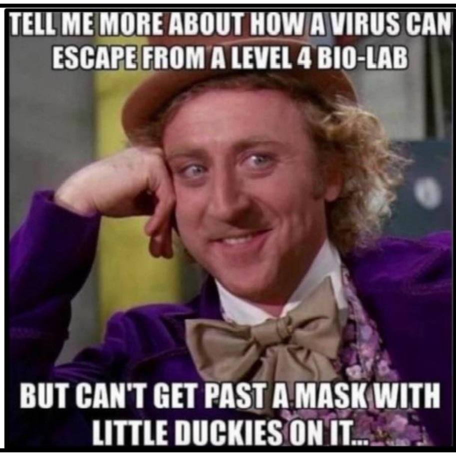

Figure 1. Rhetorical analysis Example 1. A "Condescending Willy Wonka" image meme, with top text reading "Tell me more about how a virus can escape from a level 4 bio-lab", and bottom text reading "But can't get past a mask with little duckies on it..."

The two lines of text interspersed with the image interpellate an audience into the persona of Condescending Wonka, questioning with disdain, not only the official COVID-19 narratives but also the intelligence of those who have not yet figured out the contradiction. The meme positions the audience that agrees with its claim on one side against lying officials and people that trust official narratives on the other. The rhetorical deftness of this particular image text meme lies in its ability to swoop an audience, in the course of a single engagement with the meme, into both the line of reasoning set up by the meme and into an interpellated audience identity. That is, even as a viewer might be encountering the meme's reasoning for the first time, having followed the reasoning and accepted it, the viewer comes to embody the persona of the one questioning the official narrative and condemning the naiveté of those who don't. The semantic decoding effort demanded by the meme works to enhance the credibility of the meme's claim by interpellating audiences as truth-discoverers. By advancing claims, memes not only shape public beliefs but also constitute powerful rhetorical audiences, knitting together discursive communities that share memes and bond over decoding and accepting memetic claims.

Furthermore, the boundedness of the image meme above (i.e., its containment with the rectangular box frame) and the parsimony of the rhetorical elements within the meme inhibit central processing and encourage peripheral processing of the meme's claim. The particular rhetorical form of the meme thwarts further questioning into possible reasons why the two supposedly contradictory claims may, in fact, not contradict each other. The success of the meme's argument relies on its ability to evoke the assumption that the initial event of the virus's escape signals its inability to be contained in any way. The possibility that initial spread was virulent because the virus encountered an unsuspecting maskless population is elided by the memetic structure. Likewise the claim that masks only mitigate but do not necessarily prevent infection, entirely, is also obscured by the certainty evoked in the meme's juxtaposition of claims. Memes often simultaneously function as assertive yet weak arguments. Their weakness lies in the fact that their parsimonious form limits elaboration. However, this form feature is also responsible for obscuring the weakness of memes. The limited information, visually bounded by the meme's rectangular box, seals a particular conclusion while deflecting attention from warrants (assumptions) that could challenge the meme's claims.

Figure 2. Rhetorical analysis Example 2. The image foreground has hands that are using a pencil to write in a small book. The image background is blurred and appears to show a person on the left. The top text of the image reads: "So is 'Antifa' in the room with us right now, Karen?".

In the second example (Figure 2), we see intertextuality of memetic discourse at work because of the ways in which the image meme deploys another previously established meme, namely the Karen persona. This image meme attacks the claims that Antifa are responsible for some or most instances of violent unrest in the United States, for example during 2020. The primary claim available for decoding by an interpellated audience is that right wing hysteria both deludes and fuels itself by using Antifa as a bogeyman. The claim and inherent interpellation of a left-wing audience are achieved through multiple semiotic layers encoded in the meme's rhetorical choices.

Whether the memetic content is sombre or lighthearted, explicit or implicit, memes are overwhelmingly deployed in the digital public sphere to assert and persuade through claim-making. The foundational intertextuality of memetic discourse demands that any study of memes as public sensemaking needs to go beyond rhetorical analysis of individual memes and consider how memes interact with and draw from each other to constitute, sustain, or destroy claims, and thereby narrative patterns, in response to unfolding events over time. Therefore, applying an ecosystem framework becomes essential to understanding how memes produce public sensemaking. Our next section details the rich potential in leveraging the ecosystem as a metaphor for studying the production and circulation of memes.

Ultimately, we coalesce a rhetorical analysis of memes and a digital ecosystem framework into our proposed Supervisory Control and Data Acquisition (SCADA) model for meme analysis. The SCADA focuses on identifying the key claim(s) embedded in image memes and the connections between memetic claims in order to trace the emergence, proliferation, and demise of public narratives on issues of public concern. The proposed SCADA system would provide a rich, real-time monitoring and analysis of narrative formation and propagation that circumvents limitations imposed by syntax and natural language-focused approaches. Further, open access to such a system would provide a counterbalance to both coordinated narrative influence campaigns and organic perturbations in memetic ecosystems, and provide more reliable analytic foundations for considering interventions to quell their effects.

Part II
Ecological Extensions of Rhetorical Analysis: Trends and Theory

Ecological metaphors for socio-technical systems have been applied productively to describe the physical and information aspects of the global operating environment, and recently notions of narrative, digital, and rhetorical ecologies are also gaining in popularity (Figure 3) [1,28–30]. Ecological or ecosystem metaphors for digital systems are applied as an integrative framework in different systems such as large-scale data analytics [31], "app ecosystems" [32] corporate strategy [33], and interactive role-playing games [34]. Across these diverse fields, ecosystem metaphors can encourage holistic analysis and connect abstract concepts to tangible systems and accessible experiences.

The idea and terminology of a "digital ecosystem" has been used since at least the 1980s, and has seen exponentially increasing use since the early 2000s (Figure 3B). A search using Google Books Ngram viewer revealed the recent growth of research interest in applying the ecosystem metaphor to online discourse (Figure 3A). While there is new interest in "digital ecosystems" as a term, as well as "narrative ecosystem" perspectives, the term "rhetorical ecosystem" is entirely absent from the literature corpus (Figure 3B).

Multiple previous works have applied the ecosystem metaphor to address questions related to digital discourse and memes. For example, empirical work on various popular websites has deployed the ecosystem metaphor to study the dynamics of the "meme ecosystem". These studies have analyzed copyable plain text memes, sometimes referred to as "copypasta", [35] as well as shareable image memes [36]. In these studies, the text and/or image data are downloaded en masse from publicly-accessible platforms. The ecosystem metaphor stands in the background referring more to the broad scope of data collection, rather than in the foreground as an appeal to see the data emerging from an ecosystem (e.g., analyzing the data in terms of interaction types among agents in an ecosystem).

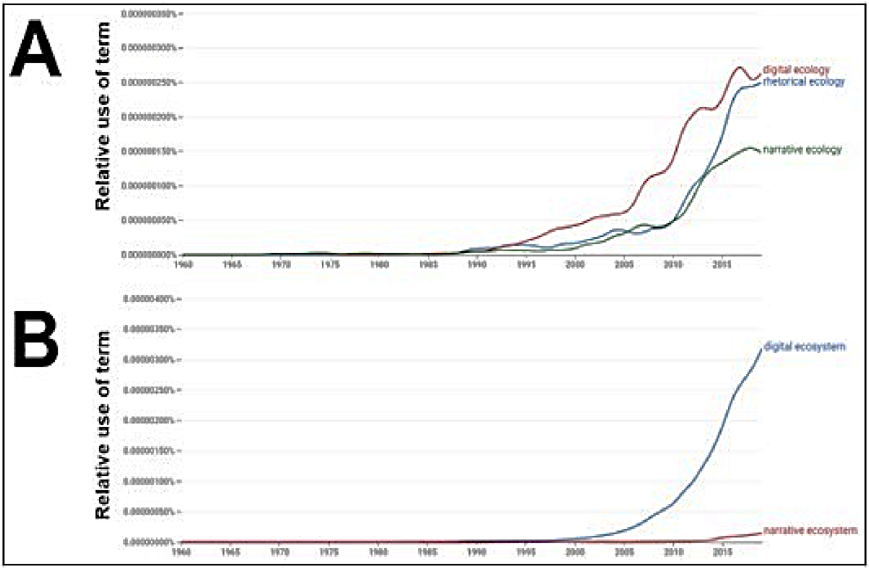

Figure 3. Trends in the usage of keywords in the Google Books Ngram search engine. Search terms used were (digital/ rhetorical/ narrative) + (ecology/ ecosystem).

A) Google Books Ngram search for "rhetorical ecology" (green), "digital ecology" (blue), and "narrative ecology" (red), from 1960-2019.

B) Google Books Ngram search for "rhetorical ecosystem" (green), "digital ecosystem" (blue), and "narrative ecosystem" (red), from 1960-2019.

This suggests that the ecological metaphor applied to rhetoric (especially online rhetoric) has been conceptual and qualitative, drawing on conceptual similarities with ecology but not formulating ecosystem models or deploying recent developments in ecological toolkits. Thus we worked from the assumption that pragmatic implications for high-throughput rhetorical analysis of online discourse might be found in ecology, if the connections could be drawn out more clearly.

Part III
The Digital Rhetorical Ecosystem Three-Tier (DRE3) Model: Mappings, Applications, and Implications

For research into socio-technical systems and digital discourse, the field of ecology provides much more than qualitative metaphors. Others have offered a variety of fundamental points of contact between ecology and rhetoric, noting that both fields explore how systems exhibit multiscale patterns of organization arising from interactions among many subunits [37]. Both rhetoric and ecology study how information is communicated through time, and how agents interact with or modify their context. In the case of rhetoric, this is through the production, perception, and interactions with artifacts and social entities, and in the case of ecology, this is the phenomena of niche modifications or stigmergy [38]). Here we extend the interface between rhetoric and ecology to argue that the mapping between these two domains can find productive application in the monitoring and design of digital ecosystems. The specific implications of ecosystem metaphors for digital discourse are explored in the following section.

"Rhetorical ecology" is an established term (Figure 3A) that refers to the context-dependent rhetorical implications of texts as they are deployed in changing spatio-temporal contexts. The concept of "rhetorical ecologies" has been used to describe the level of modeling and abstraction that generalizes above any given rhetorical situation or element [39]. The ecological framework surfaces relationships between texts. For example, in ecology, the concept of a predator-prey relationship refers broadly to a type of behavioral interaction between two species, where one species consumes the other. Understanding that two species are in a predator-prey relationship helps make sense of an otherwise-disconnected set of questions and observations in the world, for example the daily activities of both species and their bodily morphology. In the case of rhetoric, we can also imagine predator-prey type relationships—for example two digital communities connected because one systematically follows and attacks the other, through memes. Additionally, online ecosystems may present totally new kinds of relationships among interacting agents; so any framework for rhetorical ecosystems should be able to infer novel types of relationships without being limited to the archetypes present in wild ecosystems (e.g., predator-prey as above, symbiosis, mutualism, parasitism). We hypothesize that with appropriate ecological-rhetorical mappings in hand, new sets of frameworks and tools developed to study ecosystems could become rapidly useful for analysis of online discourse.

Here we introduce the Digital Rhetorical Ecosystem three-tier (DRE3) model (Figure 4) which expands previous work on the ecosystem metaphor for online systems and builds towards system design implications for analysis of memetic discourse.

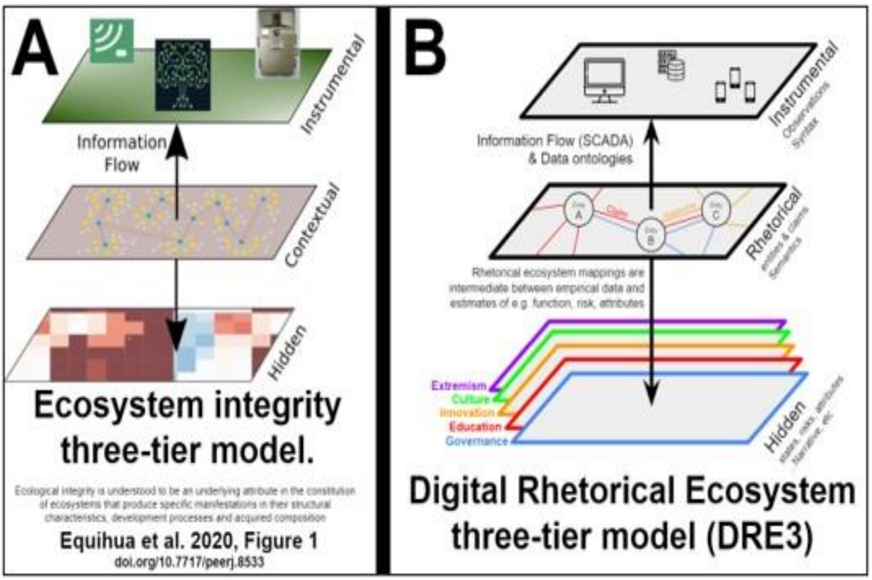

Figure 4. Ecosystem integrity model & the Rhetorical Ecosystem three-tier (DRE3) model. A) Figure 1 reproduced from Equihua et al. 2020 [40]. B) Digital Rhetorical Ecosystem Three-tier model.

The DRE3 model was inspired by the three-tier model of ecosystem integrity (3TEI) developed by Equihua et al. 2020 [40] (Figure 4A). In their 3TEI, the topmost tier is the Instrumental tier, reflecting measurements from the world, for example by sensors or cameras. The middle tier of the 3TEI is the Contextual level, reflecting the network of interacting agents in the niche that give rise to the observed information at the Instrumental tier. The bottom tier in the 3TEI are the Hidden variables of the ecosystem, such as risk of fire or capacity for agriculture. These variables are not directly observable through the use of any kind of physical instrument—hence statistical tools must be used to infer these states from the Contextual states that are in turn estimated from the empirical data at the Instrumental tier.

For the DRE3 model applied to digital ecosystems (Figure 4), we translate each of the tiers from the 3TEI into corresponding domains related to online discourse. The Instrumental tier of the DRE3 reflects the empirical observations of digital activity, for example rhetorical artifacts such as image memes, as well as metadata and other platform information (e.g., traffic logs, user ratings or responses to content). The middle tier of the DRE3 is the Rhetorical tier. This Rhetorical tier reflects the networks of entities, claims, and warrants evoked by artifacts at the Instrumental tier. The bottom tier in the DRE3 reflects the multiple possible Hidden layers which might be significant targets of analysis, for example the risk of extremism, production of subcultures, degree of innovation, quality of public information, trust in government, and process of governance.

Importantly, the information in the Instrumental tier is mediated and augmented by a Rhetorical tier in the process of Hidden State inference. The direct mapping from rhetorical artifacts to hidden state inferences can be challenging and noisy (e.g., in the case of hashtags or syntax-driven analyses used to identify conspiracy theories [41]), or essentially impossible (in the case of image and multimedia artifacts). A better approach to high-throughput analysis of multi-media digital discourse is needed. We suggest that the introduction of a rhetorical layer (consisting of entities, claims, and warrants) in between the instrumental and hidden layers is a useful direction to pursue.

Ecology: Key Concepts and Mappings

This section applies the DRE3 model in the context of the modern global information environment. Like insights gleaned from regional ecosystems [42], analyses of rhetorical ecosystems ideally should be use-oriented, in close-to-real-time, and able to be represented differently for different stakeholders. Contemporary and future analysis of online discourse will involve the use of heterogeneous data to detect, monitor, and perturb discourse. This requires a significant amount of actionable and estimative intelligence regarding the real-time state of online discourse, especially if the goal is to ameliorate the aforementioned epistemic crisis and increase the capacity to understand and respond to the use of image memes in online discourse.

In this work we do not present any formalisms or explore all possible ecosystem-rhetoric connections, but rather focus on deriving implications for rhetorical analysis and online system design by focusing on three key areas of ecological theory and application:

- Multiscale perspective on ecosystems
- Ecosystem antifragility
- Ecosystem services

For each of these three ecological topics, we 1) define the term, 2) clarify the mapping from ecology to rhetoric, 3) consider which concepts might transfer from ecology to rhetoric, and 4) provide a preliminary investigation of the implication of these mappings in terms of systems design.

Multiscale Perspective on Ecosystems

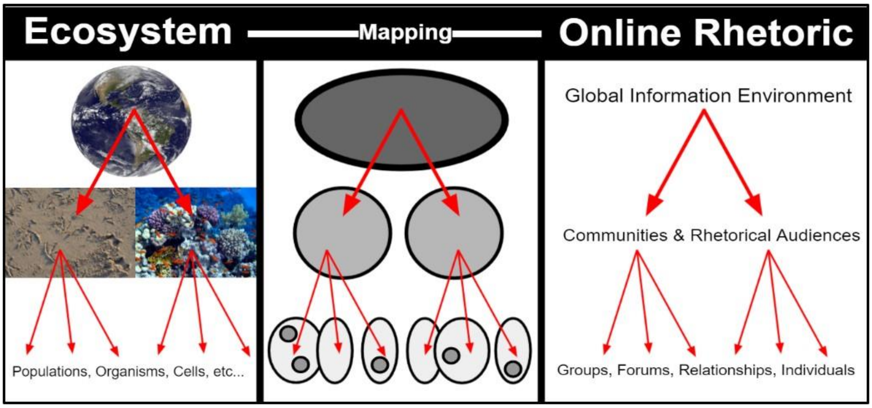

Figure 5. Representation of the multiscale perspective on Ecosystems. At left, ecological modeling of the world can proceed via decomposition into disparate ecosystems. At right, online rhetoric occurs within the global information environments, via increasingly-fragmented platforms, channels, and chats. The common mapping, in the middle, is the notion of overlapping and nested systems.

What is the multiscale perspective on ecosystems?

- Modern ecological frameworks are built around the idea that biological systems present as nested scales of organization [43]. At each scale of organization such as cell, organism, and population, the system consists of interacting agents of various types [44,45]. System subunits can interact in non-linear ways, and the integrated function of the ecosystem as a whole can be considered as cognitive in its own right in that the system can learn, integrate information, display persistent memory, and act in an anticipatory fashion [46].

What is the mapping from the multiscale perspective on ecosystems to online digital discourse?

- Today's digital landscapes consist of human and non-human agents, interacting with each other and with textual artifacts, as if they were on rhetorical landscapes. Ecosystems and landscapes are rich and generative metaphors that help capture the many ways in which agents of various types and in various roles interact massively in parallel. These distributed rhetorical interactions contribute to information integration, collective decision making, memory, education, and anticipation across the digital public sphere. Rhetorical ecosystems exhibit structure and regularities across multiple scales of analysis, for example the individual, relationship, group, and community. Thus digital rhetorical ecologies can be considered as an integrated multiscale cognitive system.
- The case of an image meme posted on a social media platform can be seen as a niche modifying action of mobile agents, with the intention of signaling to similar or dissimilar agents, resulting in functional consequences for the further evolution of the biosemiotics of the niche. These stigmergic processes in nature, such as an ant depositing pheromone, or large mammal making territorial markings [47,48], are essential for ecosystem function. Digital platforms present affordances for niche modifications, whether extremely limited (e.g., only a "like" button"), or more extensive (e.g., a Wiki model where content can be edited, or even a platform where the code and affordances can be modified by users). The availability and incentives for using different kind of digital affordances will be user-, platform-, and context-specific. This corresponds to ecosystem contexts where contextual

niche modification processes play out over rapid behavioral timescales versus slower evolutionary timescales.

Which key ideas and tools from the multiscale perspective of biological ecosystems transfer to digital discourse spaces?

- Ecosystems around the world vary in fundamental ways but still can be modeled with common frameworks. Similarly, in the case of online discourse, we are interested in the similarities and differences across languages, platforms, and settings. The multiscale perspective in ecology highlights how interacting agents and situations can generate emergent patterns that are stable (or metastable/oscillatory) within acceptable attractor states, rather than causing cascading failures [49,50]. In ecology, even antagonistic interactions such as predator-prey may be stabilizing at the macro scale. In the case of online rhetoric, we might map individual-level interactions to behavioral ecology, and group-level dynamics to macroecological outcomes. For example, a pairwise relationship might be unstable or antagonistic among two users of an online platform (behavioral ecological scale) yet be a part of a stable broader online community of users (macroecological scale).
- The idea of niche modification from ecology translates to the kinds of changes that agents make to their information niche. In the case of online communication, this is known as digital stigmergy [51,52]. Just as the behavior of individual animals is nested within (and in feedback with) surrounding ecosystem dynamics, rhetorical agents are actively exploring and modifying their informational niche.
- Various ecological toolkits exist to infer agent states and actions across spatial-temporal scales and use these inferences to understand how agent behavior is in feedback with broader trends. These toolkits include software packages and approaches related to movement tracking,

multi-scale network analysis [53], system simulation [54], and characterization of the relationship between animal behavior and the animal's niche [55–57]. In the case of online discourse, agents are moving across informational landscapes, updating their models of the world, interacting with other agents, and increasing or decreasing their likelihood of engaging in different kinds of action. In both ecological and rhetorical settings, one may be interested in modeling how interaction among agents influence individual and collective behavior, as a function of context in the niche.

Ecosystem Antifragility

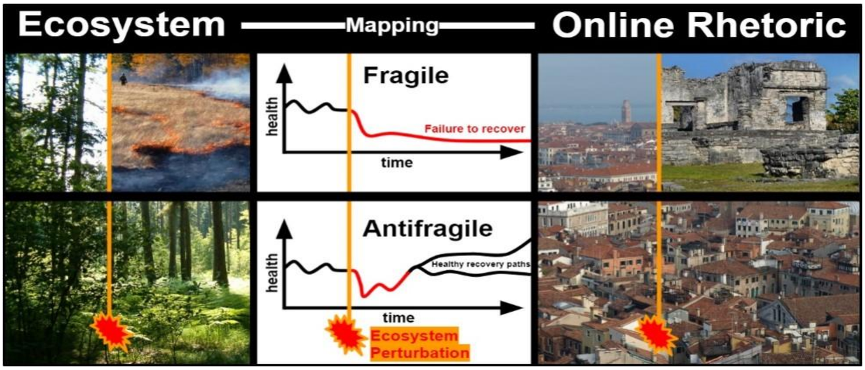

Figure 6. Representation of the concept of Ecosystem antifragility. At left, a forest experiences a perturbation such as a fire event. This event may either lead to devastation of the forest (top), or result in a forest that either burns completely and/or grows back stronger (bottom). At right, using a city as an analogy for the online rhetorical commons, a perturbation event can result in a destroyed commons (top), or a strengthened and vibrant community (bottom). The common mapping, in the middle, connecting biological ecosystem antifragility to digital ecosystems is that complex systems can undergo various recovery or response dynamics in response to perturbations, broadly classified as fragile (failure-prone, top) or antifragile (resilient and regenerative, bottom). For digital discourse platforms, fragility would refer to the inability to adapt or recover function following technological or rhetorical perturbation.

What is ecosystem antifragility?

- Ecosystem antifragility refers to the vibrancy, stability, and dynamic variability of a system. Recently, Equihua et al [40] have used various approaches from Complexity science to describe ecosystem antifragility as "beyond resilience and integrity". Their working definition is that an "ecosystem is antifragile if it benefits from environmental variability" [40]. Antifragility is similar to the notion of resilience, which captures how a system resists change or returns to functional capacity after a perturbation [58]. However, antifragile systems are those that actively grow or increase in capacity after stressors, as opposed to merely returning to previous operating modes.

What is the mapping from ecosystem antifragility to online digital discourse?

- **Health.** The stability and flourishing of the rhetorical commons is a primary goal for participatory communities and societies. This is akin to the concept of ecosystem health: even where different regions or seasons may have distinctly different healthy modes, maintenance of ecosystem vitality may be an overarching regional goal. While humans have long relied on qualitative or felt measures of ecological health, quantitative data collection allows for entirely new measurable notions of health only enabled by instrumentation and modeling [59–61]. We highlight the need to develop statistical indicators for the health and vitality of digital ecosystems so that policy for and management of digital commons spaces can be driven by shared empirical understanding rather than the potentially discordant experience of individuals.
- **Resilience.** The resilience of a rhetorical ecology might be defined in terms of the system's maintain function during a crisis, informational update, or structural change. The resilience metaphor draws attention not just to the regular or functional operating modes of rhetorical ecosystems, but also to the emergency and recovery modes available to these systems. Ecosystem resilience is critical when humans have a vital dependence on continued ecosystem function,

as in the case for agriculture [62]. Increasingly, online communications are a lifeline, and thus also need to be managed carefully with uninterrupted service and content integrity in mind. Disruption of internet services can occur through physical damage to infrastructure, as well as software intrusions (e.g., ransomware, denial of service attacks). Even when hardware and software are running according to performance standards, breakdowns of sensemaking (e.g., due to spam, targeted disinformation) can lead to perturbations on digital platforms and breakdowns in their typical functioning.

Which key ideas and tools from antifragility perspectives of biological ecosystems transfer to digital discourse spaces?

- Ecological antifragility has several kinds of ideas and tools to offer to the domain of rhetoric. Equihua et al. [40] characterize antifragile systems as those that benefit from variability, which provides a valuable parallel for measuring the health of the rhetorical commons by its type and extent of diversity (here of rhetorical claims and perspectives, rather than, for example, a species number). That the variability of rhetorical claims can be a source of collective vitality provides a helpful starting point for viewing online discourse and dissuades approaches that promote total consensus as a goal, or reflexive suppression of alternative viewpoints.
- Some approaches towards ecosystem antifragility feature participatory roles for ecosystem inhabitants, for example local cleanup events, long-running citizen science projects related to birdwatching [63] and regional ecosystem biodiversity events like a BioBlitz ("an event that focuses on finding and identifying as many species as possible in a specific area over a short period of time" [64]). In the context of digital ecosystems, these kinds of local programs

for ecosystem improvement can scale to include large numbers of participants, for a Wiki editathon, for example [65,66]. Coordinated efforts to "fix trails" in digital ecosystems could contribute to antifragility by providing a scalable approach for reducing risks from cascading or complex failure modes related to out-of-date information, fragile network structures, or incapacity to deal with anomalous system usage.

- Quantitative tools also exist to help stakeholders measure and model ecosystem antifragility from a Complexity perspective [67]. Dynamic models allow for simulation and analysis of various kinds of systems and their stability in different situations [68,69]. In the context of ecosystem health, these kinds of analysis ask how it might be possible to build stable networks rather than network structures. An exclusive focus on network structures might lead to fragility of network function when edges are lost or nodes change. Modeling ecosystem health as a phenomenon arising from interacting networks, offers new and potentially more-effective ways of thinking about how multiple ecosystem stressors interact [70]. Network models also can be expanded to include "games on graphs" models, which use the tools of game theory to explore how strategies interact on landscapes and how information propagates through groups [71,72]. In the context of digital ecosystems these kinds of models could provide descriptive, prescriptive, and proscriptive information on the general function and well-being of digital platforms.

Ecosystem Services

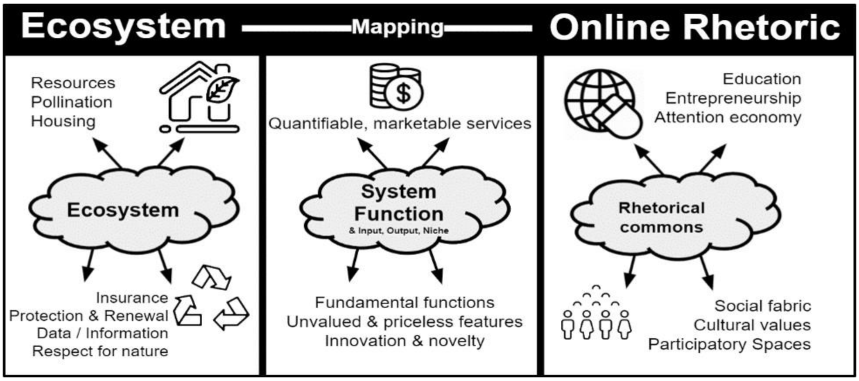

Figure 7. Representation of the concept of Ecosystem services. At left, physical ecosystem services such as natural resources and pollination are enacted by various actors within ecosystems. At right, online rhetorical commons can be considered to enact or emit services such as education and innovation. The common mapping, in the middle, is that value and valuable outcomes are generated through the function of the target system. Putting quantitative value on "intangible" outcomes can be challenging. Seeing online outcomes as analogous to ecosystem services is not a solution in and of itself, but rather a framework for approaching system management and design.

What are ecosystem services?

- Ecosystem services are the functions that ecosystems provide which are useful for humans directly or incidentally, for example the provision of food, erosion control, composting of decaying matter, recreational spaces, or generation of natural resources, [73]. As is the case with ecosystem antifragility and health, many types and measures of ecosystem services exist.

What is the mapping from ecosystem services to online digital discourse?

- If we imagine rhetorical ecosystems to encompass the biotic and abiotic aspects of the system that contribute to its function and regulation, "rhetorical ecosystem services" could include a broad range of outcomes, including education, communication, innovation, and development of cultural norms and practices. Just as high-level biological ecosystem services, like the production of food, arise from direct interactions among many kinds of actors (e.g., plant, pollinator, microbes), and might be influenced by indirect factors as well (e.g., noise/light pollution, presence of predators), rhetorical ecosystem services emerge from the direct and indirect interactions of many actors and artifacts in the space. Understanding these influences can support modeling and management of the valuable outputs of a rhetorical ecosystem.
- We can consider image memes as a special case of ecosystem services, in that image memes are valued or relevant products of an underlying ecological process. The image meme format reflects the intersection of digital content production affordances, and the rhetorical cross-pollination occurring online. The services that image memes provide in the rhetorical ecosystem can include advertising, information sharing, governance, entertainment, persuasion, and more– essentially any functional outcome of the deployment of image memes that can be tracked and valued.
- Other studies have investigated the dynamics by which images memes originate and diffuse through time among communities [36]. This is akin to a source-sink analysis common in ecology: source locations are net exporters (of

image memes on digital platforms) while sink locations are net importers (on digital platforms reflecting image meme consumption) [74]. This source-sink analysis of image memes can link the dynamics of memetic spread to their function for different audiences, and thus shed more light on the causes, context, and consequences of particular image memes for the rhetorical commons.

Which key ideas and tools from ecosystem services transfer to digital discourse spaces?

- Conservation & management of ecosystem services is an area of practice with a long history of analyzing the intersection of human individuals, human groups, and the rest of the biotic and abiotic surroundings. Some of the legal, mathematical, scientific, and game theoretic approaches to ecosystem services might transfer usefully to cases of online rhetoric. For example, when considering the design or regulation of digital platforms, various areas of law and policy interact, for example finance, business, and privacy. Framing digital platforms (and the functions they perform) as ecological commons introduces precedent for addressing legal dimensions of individual/public/private ownership, and processes for dispute resolution related to common resources [75].
- Ecosystem antifragility (discussed above) plays directly into the stability and accessibility of vital and valuable services [76]. Healthy rhetorical ecosystems will display variability in productivity through time. However, an ecosystem at high risk of catastrophic failure cannot be considered as valuable as a dependable ecosystem (e.g., a forest at risk of destructive fire presents higher uncertainty about its future productivity). The relationship between ecosystem health and productivity provides an economic motivation for policies that balance multiple contrasting requirements, by thinking about system function through time.

Implications

We argue that insights from modern Ecology can help scaffold the future of computational systems for rhetorical analysis. Ecological perspectives can retain the semiotic insights from rhetoric analysis while tracing meanings and their interactions within a quantitative framework [37]. At this time, manual rhetorical analysis requires trained experts who identify how artifacts produce meanings for different audiences, or, in the case of image memes, how memes generate claims. This process of rhetorical analysis is analogous to a natural historian observing a species operating skillfully in their niche, in that a specific occurrence (observation of a bird, or a digital text) is modeled in terms of its relationship to the context and niche (whether biological or rhetorical). Computational frameworks for rhetoric provide a set of ideas and tools that, if properly designed, could help accelerate rhetorical claim analysis. This type of "next-generation natural history" [77] for rhetorical ecosystems would integrate well with existing computational frameworks, apply well to the multimedia setting, and also work toward grounding analysis of digital discourse in rhetorical principles. Functionally, Ecology is the bridge that would allow rhetorical information to play a more central role in the computationally-aided analysis of contextualized digital discourse. We suggest that, in addition to the quantitative tools it provides (such as network analysis, sparse sampling, agent-based modeling, meta-community dynamics), Ecology can supplement rhetorical analysis by foregrounding concepts like ecosystem health, biodiversity, anti-fragility, and more. Below are some possible implications arising out of the application of the Ecological perspective to online rhetorical commons (by no means comprehensive).

- Create and adapt within the niche. Online platform and systems designers can ask what services they are providing to stakeholders and the broader ecosystem (defined as the entities, audiences, and cyberphysical systems constituting the stakeholders and zone of influence of the target platform). Platforms provide and interact with the rhetorical commons, and thus services of value are being provided or modified by them. As digital platforms require inputs from the broader ecosystem in terms of energy, attention, and other resources, platforms must be anticipatory and responsive to changes in their operating ecosystem.

- Trace artifacts and claims to understand function. The DRE3 model of digital discourse has the capacity of creating clustering, detecting thresholds, or permitting inference at the level of rhetorical claims, an extension of approaches built solely on syntactic inputs (e.g., hashtags, keywords) or lexical semantics (e.g., natural language processing, sentiment analysis). We need to integrate artifacts and claims (beyond, or instead of tracking individuals) for effective sensemaking of digital discourse. Thinking of claims in terms of functional patterns in the ecosystem, platform designers could analyze the relative fitness and spreading/mutation/co-occurrence dynamics of memetic claims, across communities, languages, media formats, and platforms.

- Consider dynamics, not just snapshots. Some of the dynamical systems and network analysis tools developed for ecosystem management could generate models that may transfer directly to online datasets. Similar kinds of observations can be made in the ecological as well as digital situation (e.g., about the movement or communications among agents through a space described as a network) and similar kinds of questions might be asked (e.g., which initial conditions and patterns of relationships might result in stable vs. unstable regimes). For example, migration can occur among geographical distances as well as among digital communities on social media. Complementary tools and perspectives for the analysis of migrations might be found across research on patterns of ecological and digital migrations [78,79].

- Design for multiscale interactions. Online platform design could take the multiscale perspective directly into account, for example by making certain peer-to-peer interaction mechanisms transparent, so that agents at various scales (e.g., individuals, groups, communities) are aware of how user-level affordances influence the niche and system as a whole. Top-down (e.g., platform-dictated) and bottom-up (e.g., user-generated) signaling mechanisms could be clearly marked (or if not marked, could be annotated as such by analytics platforms).

- Fit generative models (of rhetoric) that can deal with sparse as well as complete data. The task of ecosystem characterization is to go from sparse and heterogeneous observations (for example ambient conditions and bird sightings through time), to a useful and communicable model. This task of ecosystem characterization, depending on the scope of the analysis and desired level of detail, may require multiple kinds of models to be specified: the cellular, organismal, social, community, and ecosystem. For online discourse, integrating the multiple scales at which decisions are made (human internet user, community, networks of networks), ecologically-informed models might provide a principled path for modeling various phenomena of interest.

- Think about the ecosystem's leverage points and failure modes when designing an intervention. Ecosystem modification efforts are famously non-linear—careless interventions may be ineffectual or even have deleterious effects (as in the case of using broad-spectrum toxins in an attempt to eradicate the fire ant in the Southern USA [80]). For social discourse, influence operations used to be evaluated in terms of a direct rhetoric source, such as centralized media. Now the operating landscape is much more akin to a complex ecosystem, contextualizing diverse social strategies as types of social ecosystem modification [81]. Modifications of the rhetorical ecosystem through various means (e.g., algorithmic distortion, misleading information) might have behavioral consequences rippling out far beyond the locus of direct action, akin to the introduction of a new species to an ecosystem. The relative efficacy and risk of different ecological interventions is variable across different regions. Proactive, long-term interventions such as restoring native habitat are often at odds with short-term interventions like intentional introduction of novel predators (as in the case of the cane toad in Australia [82]) or application of broadly-acting chemicals. Ecosystem interventions are irreversible, and often have non-linear consequences for different kinds of actors and audiences [83,84].

- Consider humans in the design of platforms, as well as non-human and computational actors. Taking a human-centric perspective on ecosystem function would be incomplete or even fallacious, depending on the region and goals of ecological modeling. Similarly, today for online discourse, given the prevalence and influence of purely-computational agents or computationally-augmented humans, it is essential that platforms be designed for use by human and non-human agents. Already a significant fraction of internet activity is carried out by purely computational agents or networks (e.g., chatbots and automated accounts). While the exact amount of human and computer activity likely varies among destinations, already in 2016 it was estimated that certain types of internet activity might be majority non-human [85,86]. The multiscale cognitive perspective on ecosystems provides a framework for modeling rhetorical ecosystems consisting of only human actors, only computational actors, and any conceivable composition in-between [87]. Already falling within this scope are existing tools that distinguish the activity of human vs. bot actors online in games, forums, and other platforms [88,89].

- Frame healthy and antifragile rhetorical ecosystems as a common pursuit. Promoting antifragility is a broad social goal that can apply across systems and scales. Ecosystem health as a concept helps humanize otherwise-unrelated environmental phenomena and might be able to play a similar role in making online rhetoric more tangible. Exact specifications of "health" for the digital commons may differ, just as they do for ecosystems. Analyzing the health of a given ecosystem might require the consideration of the abundance, composition, diversity, function, and tolerance of various kinds of life forms in the system (such as microbes, invertebrates, plants, etc.) [60]. And even in this case, individuals may still disagree on the health of a given ecosystem, if for example they diverge on the optimal usage of the region (e.g., for development vs. recreation vs. agriculture). When designing platforms for digital discourse, it would be valuable to consider how differences in opinion about "what is healthy" among users could be harnessed and channeled, rather than lead to system failure.

- Use rhetorical measures as a diagnostic when modeling digital discourse by framing the resulting artifacts and functions in terms of ecosystem services. Failure of rhetorical ecosystem services could occur from an adversarial or unhealthy dynamic, such as an inability to communicate leading to breakdown of trust among otherwise-cooperative individuals. To thwart, or recover from, such failures, it could be helpful to search for analogous situations in ecology. For example, ecosystem services could be threatened by the introduction of an invasive new species, a toxic chemical, habitat fragmentation, light/sound pollution, or loss of biodiversity [90,91]. In the case of rhetorical ecosystems, being able to connect failures of services to past ecosystem interventions or modifications (influx of new users, introduction of toxic rhetoric, alteration of platform affordances, etc.) could provide a useful lens for protecting the valuable outcomes of digital discourse.

Part IV
The Digital Rhetorical Ecosystem Three-Tier Model Example Usage

The Digital Rhetorical Ecosystem three-tier (DRE3) model (Figure 4) integrates enriched rhetorical analysis of multimedia discourse with ecological theory and modern computational analytics pipelines. In this section, we present examples of rhetorical analysis using the DRE3 model. Specifically, we describe three analytic phases in the context of "boutique meme analysis" using two examples. At the end of the section, we provide a bridge between the traditional methodology of rhetoric and the types of computational representations that are useful for modern digital sensemaking systems.

There is a lack of usable platforms for computational rhetorical analysis, although several prescient calls have been made for such frameworks and tools [92–94]). Partially, this gap exists due to the challenge of accurately and effectively scaling expert rhetorical analysis. While multiple complicated sub-tasks are required for rhetorical analysis, digital tools exist today to carry out some similar functions (such as face-, voice- and text-recognizing algorithms, and natural language processing). We suggest that modern software algorithms are adequate to perform many of the sub-tasks required for the rhetorical analyses of image memes, and that crowd-sourced annotations (via participatory research, or micro-task platforms) could be used to support algorithms where the software alone are as yet insufficient. Already in the case of digital discursive ecosystems today, some fraction of users contribute their time and energy to improving discourse, for example by providing context or reporting behavioral violations. Approaches for online platforms that combine gamified participation with behind-the-scenes machine learning have been successful in advancing research in biochemistry and a variety of other fields. These crowd sourced projects can take a variety of forms, and can be designed to operate directly on the engaging digital platforms that people already use [95].

Here we present what a case-by-case rhetorical analysis of image memes might look like, within a framework that is ultimately designed to scale up to high-throughput ecosystemic annotation, while retaining the semantic richness afforded by case-by-case rhetorical analysis. These analyses are performed in three phases:

> **Phase 1. Entity Identification.** The first phase of analyzing the rhetorical function of a meme entails recognizing visual entities embedded in the meme. Entities can be of different types and are interchangeable across memes.
>
> **Phase 2. Rhetorical Analysis.** The second phase of decoding the function of a meme entails identifying its semantic and consequently persuasive potential. This phase begins with tracing relationships between the entities implied by their arrangement within the meme. The relationships will typically synthesize into an implied (or stated, if the meme includes text) claim, sometimes accompanied by evidence included in the meme. The claim often rests on implied warrants (assumptions) supplied by the viewer who is aware of the rhetorical context that the meme invokes.
>
> **Phase 3. Hidden State Identification.** The third phase of decoding the function of a meme is hidden state identification. The exact nature of the hidden state inference will be situational and depend on what the analyst is attempting to reduce their uncertainty about; for example, the extent to which the image meme in context is consistent with social values, providing specific valuable services, or eliciting violence. What distinguishes the various possible hidden state inferences from rhetorical inferences in Phase 2, is that hidden states are deeper than specific claims about entities, and reflect underlying attributes of the rhetorical ecosystem that gives rise to and are strengthened by such claims.

Two examples below (Figure 8 and Figure 9) represent the qualitative application of the DRE3 model to shareable image memes. The rhetorical analyses below uncover preferred readings of these image memes [96] and are not exhaustive in terms of entity or claim identification. Memes, as identified earlier, are polysemic. They are able to generate multiple and varied interpretations. A rhetorical analysis cannot comprehensively decode all meaning possibilities embedded in an image meme. Nevertheless, by following the rhetorical use of symbolic content within the meme, attending to the discursive contexts in which a meme may be harvested (such as a Facebook post thread or a Twitter thread), crowdsourcing the claims advanced by memes, and determining interpretation consensus across trained rhetorical analysts, we can identify likely, core, or agreed-upon, in other words the preferred arguments that memes advance [96]. In this case, we define preference by what a meme was originally designed to argue or the meanings that are most easily accessible (obvious) to the target audience. Even though the meaning of a meme can be altered by its discursive context (i.e., a meme can be deployed ironically to undermine its own message), such a subversive reading of the meme relies on consensus about its dominant meaning. Therefore, despite inherent polysemy, we believe it is both possible and useful to identify the dominant argument(s) that are encoded in an image meme.

Example I

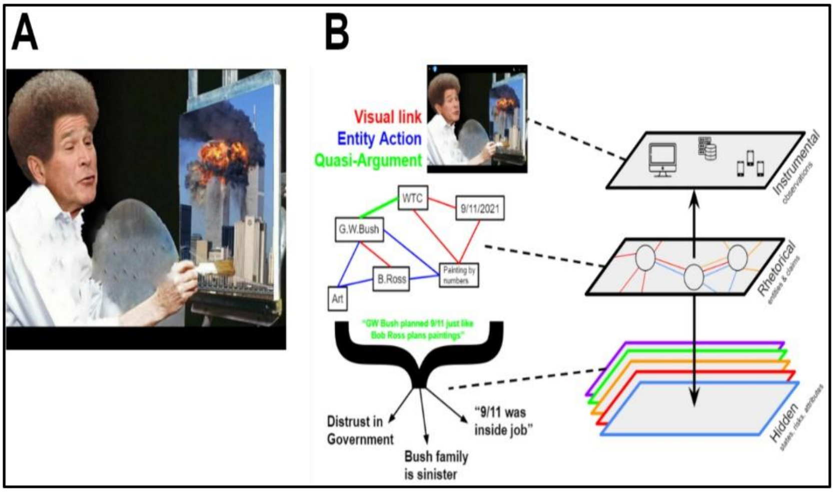

Figure 8. Illustration of the DRE3 model as applied to an image meme without text. A) a target image meme under analysis. B) Application of DRE3 model, breaking down the meme in terms of the Instrumental tier (what was observed), the Rhetorical tier (entities, warrants, claims), and the Hidden State tier (implications and use-specific inferences).

Phase I. Entity Identification

In the above meme, the following entity categories are rhetorically significant:

Persons: Bob Ross, G.W. Bush

Attributes: Hair, shirt, hand of Bob Ross, Face of G.W. Bush

Objects: Twin Towers of the World Trade Center, Painting materials (palette, paintbrush, canvas, easel)

Location: New York City skyline

Action/Relationship: Individual painting on canvas

Phase II. Rhetorical Analysis

In the above example, decoding the meme rhetorically by analyzing relationships between entities requires distinction between host images and parasitic images. The incorporation of the parasitic images to replace parts of the host images produces a parodic relationship between host and parasite entities. The insertion of G.W. Bush's face into the identifiable hair of the artist Bob Ross parodies the parasitic entity—Bush. The host image is the one that dominates the meme. An enculturated viewer recognizes the image as a still from the iconic Bob Ross televised painting class. Ross's hair, shirt, hand, palette, brush, and canvas on the easel are easily recognizable attributes/objects and constitute the majority of the image. The viewer is clear that it is G.W. Bush's face that is intruding within the Bob Ross image rather than reading the artist entity as the intruder. Having identified the host-parasite relationship, the viewer must now extract the semantic implications of this parody.

In deciding what the host-parasite parody means, the viewer recognizes that the visual juxtapositions in the meme are meant to paint former president G.W. Bush as an artist. The parasitic image that has taken over Ross's typical placid landscape scene on the canvas provides a stark contrast to what those familiar with Ross expect him to paint. The peaceful landscape of a Ross painting is replaced by a real scene of terror (the fall of the Twin Towers on 9/11) that is also highly recognizable because it has become widely circulated memetic content.

The face of G.W. Bush and the destruction of the World Trade Center towers in New York City are clearly linked in the rhetorical context available to the enculturated and interpellated viewer. The structuring of entities within the meme, however, superimposes an additional relationship that emerges out of the parodic analogy between G.W. Bush and Bob Ross. The parody is underscored with the use of an exaggerated expression on the face of G.W. Bush. This is the point at which the viewer arrives at the claim embedded in the image structure of the meme. The claim could be articulated as follows: Like Bob Ross paints a landscape from imagination, G.W. Bush fabricated the 9/11 terror attacks. In this case, the memetic argument advances only a claim. The meme contains no evidence. Instead, the meme operates intertextually. To unpack the meme's claim, the viewer must be aware of multiple rhetorical contexts, such as the 9/11 truther movement that has sought to expose the terrorist attacks of 9/11 as a plan of the United States' own government, and the imputed role of the Bush family within the construct of a global cabal that controls worldwide events. In this way, the rhetorical analysis of memes leads us to identifying salient hidden states (e.g., social, political, and cultural beliefs/practices) that both influence and are shaped by memetic arguments.

Phase III. Hidden State Identification

A rhetorical decoding of the Bob Ross-G.W. Bush meme both relies on and perpetuates claims about the Bush family, the G.W. Bush administration, the events of 9/11 and other global destructive events. Memetic argumentation analysis is ultimately useful to the extent to which it permits tracing evolving public beliefs and practices that could have real-world implications. We expect that, over time, the identification of rhetorical claims from varied memes will reveal patterns of connected beliefs that correspond to higher-order hidden states such as confidence in the government, or beliefs about the causes of past events. A hidden state in our framework refers to an implicit and volatile state of public belief, sentiment, or action. A belief that the United States government lies to its people is an example of a hidden state. This higher-order claim represents a public belief that produces a sentiment of distrust in the government. Tracing hidden state dynamics is useful because they can activate overt action in unrelated contexts, such as vaccine refusal because of a previously established distrust in government. Such a relationship between hidden states and public action can potentially be identified by tracing co-occurrence of memetic claims within networks.

Example II

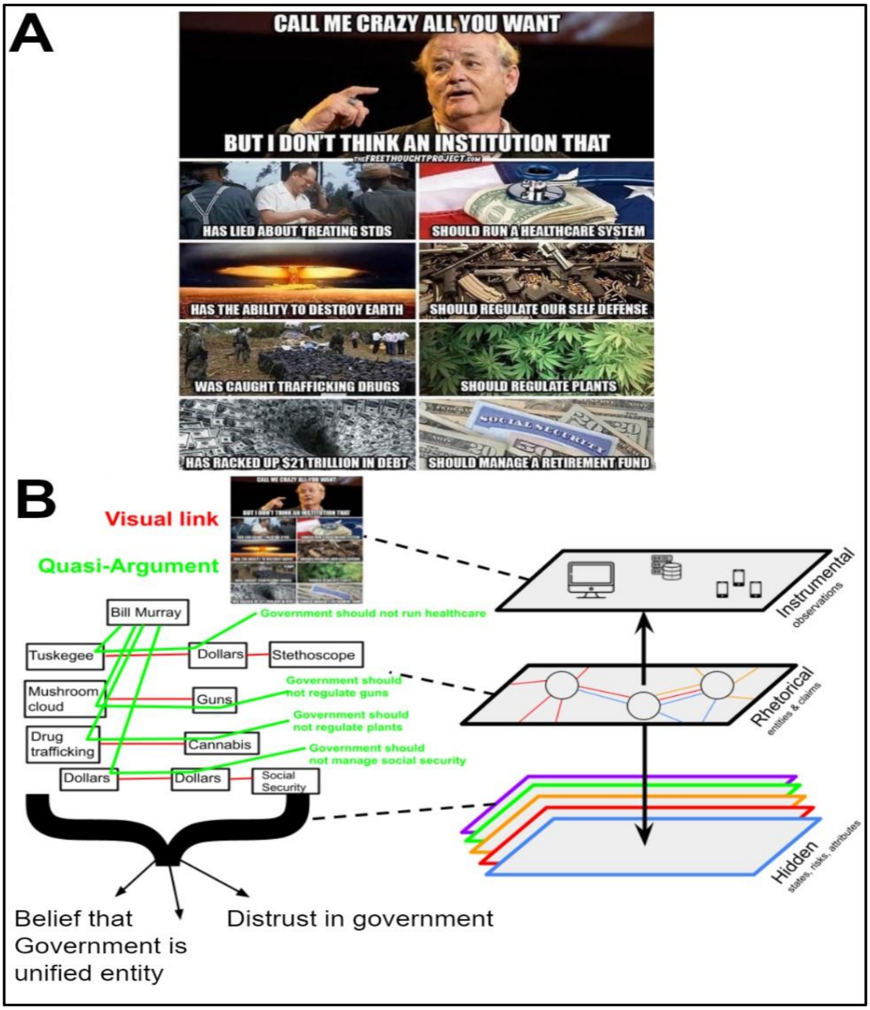

Figure 9. Example of the DRE3 model as applied to an image meme with text. A) a target image meme under analysis. B) Application of DRE3 model, breaking down the meme in terms of the Instrumental tier (what was observed), the Rhetorical tier (entities, warrants, claims), and the Hidden State tier (implications and use-specific inferences).

In this example, the higher-order claim that the United States government cannot be trusted is advanced by submitting lower-order arguments. The text-image pairing in this meme enacts argumentation differently than in Example 1. While the first example illustrates argument by analogy, this example supports its claims with visual evidence and follows an "if-then" pattern.

Phase I. Entity Identification

In the above meme, the following entity categories are rhetorically significant:

Persons: Actor Bill Murray

Scenes: Tuskegee syphilis study, mushroom cloud, drug heist.

Objects: Dollar bills with a stethoscope, stock of guns, marijuana plants, vortex of dollar bills, dollar bills with social security card.

Phase II. Rhetorical Analysis

The visual segmentation of the meme-box is crucial to how the argument is enacted. The visual sequencing relies on the viewer moving from the top to the bottom and from the left to the right. The top centered image features the actor Bill Murray. The text superimposed on this image invites the viewer into a dare with the person sharing the meme. The challenge "Call me crazy all you want" invokes the trope of the conspiracy theorist, a label typically branded on those who accuse the government of large-scale wrongdoing. The rest of the meme-box is set up to enact that challenge and rebut the conspiracy theorist label. Bill Murray, known for his antics that speak truth to power, functions as a symbol of interpellation for the conspiracy-minded, who are not taken seriously by the mainstream but are convinced of the truth to which they have awoken.

The lower order arguments are presented in claim-evidence pairs, each contained in smaller boxes in the left-hand column of the meme. Four claims about government malevolence are substantiated with images meant to provide evidence.

The first claim accuses the U.S. government of lying about medical treatments of STDs. The image over which the textual claim is superimposed features African Americans, a visual sign meant to invoke the Tuskegee syphilis study that abused black American bodies in a deceptive government intervention. The image in fact is an iconic historical photograph of the study. But, even in the absence of audience knowledge about the provenance of the photograph, knowledge about the Tuskegee study itself is enough to decode the image as representing that particular instance of government dishonesty and failure.

The second claim accuses the government of the ability to destroy the planet and is substantiated with the paired image of a mushroom cloud that invokes the Hiroshima atomic bomb disaster.

The third claim accuses the government of trafficking in drugs. The textual claim is superimposed on an image meant to invoke the plane crash that exposed alleged CIA involvement in drug trafficking in Panama.

The fourth box in the left-hand column claims that the U.S. government has $21 trillion in debt. Here the paired image simply shows a giant vortex of dollar bills illustrating the metaphor of "money down the drain". The preceding images which pull from historical archives construct the credibility of the meme, leading the viewer to implicitly assume the facticity of the final allegation, even though the fourth argument departs from the claim-visual evidence pattern established by the previous three.

The visual segmentation and sequencing in the meme optimizes the constrained space of the meme-box to deliver a relatively complex argument with multiple claims and pieces of evidence. Each text-image pairing on the left works in conjunction with the text-image pairing on the right to both verbally and visually enact the if-then argument pattern. The boxes on the left provide evidence for the claims on the right. For example, the government's dishonesty in the Tuskegee study is presented as evidence for the claim that a nationalized health care system cannot be trusted because of the ways in which it might abuse unsuspecting citizens. Likewise, its willingness to bring the planet to the brink of destruction by deploying nuclear weapons is provided as evidence that the government should not be allowed to regulate gun ownership. The strategic use of the meme-box to bound the argument is especially stark in this sequence. While evidence of the government's disregard for human life can be leveraged to support curtailing the government's military power, the corresponding claim instead attacks gun regulation, implying that citizens need to be prepared to defend themselves against an untrustworthy government. However, the implication that guns are powerless in the face of nuclear destruction, which would undermine the meme argument, is suppressed by the visual alignment of evidence and claim side-by-side. This visual formatting contained within the meme box constrains the possibility of additional lines of reasoning even more powerfully than a similar argument made through other forms, such as orally in a speech or verbally in a news article. The visual demarcation of the meme box has the powerful potential to restrict reasoning to the elements displayed within the box. Because of how distinctly recognizable the meme-box has become and how unique it is in appearance compared to other visual modes of public discourse, the meme-box is able to separate itself from the rest of the landscape of public argumentation and create both discrete instances of argument unique to its own content and structure, as well as to interact within the ecosystem of related memetic arguments.

Phase III. Hidden State Identification

The four boxes on the left in alignment with each of their counterparts on the right together advance the higher-order claims that the U.S. government is dangerous, unethical, and inept and its interventions should be substantially curtailed. This claim reifies the hidden-state sentiment of distrust in the government. It is important to note, also, how the argumentation enacted by the meme relies on some but not extensive contextual knowledge in the viewer. The parsimony of the symbols within the meme (restricted to a few words and images) relies on the audience's background knowledge and ability to supply warrants. For example, audience knowledge about the Tuskegee study and its targeting of African Americans is essential to reading the first image on the left-hand side as evidence for its paired textual claim. However, even minimal recognition of some elements is sufficient for the viewer to then accept the other image text pairings and submit to the lines of reasoning traced by the memetic elements. Likewise, the meme relies on an interpellated audience to supply the necessary assumptions (warrants) to complete the arguments. For example, the leap from the government's moral failing in the Hiroshima bombing does not automatically lead to an argument against gun regulations, unless the viewer is already concerned about the erosion of Second Amendment rights and is thus primed to read the atomic bomb image as evidence that the government does not have its citizens' best interests at heart and would therefore regulate gun ownership to reduce the threat of self-defense from its citizens.

Concluding Comments

The two examples elaborated above show the kinds of information about memetic claims and hidden states that can be inferred with a rhetorical approach. In the following section we integrate the insights from rhetoric and ecology to outline some considerations for the design of online discourse monitoring systems.

Part V
Toward a High-Throughput Rhetorical Analysis (Meme SCADA)

The example applications of the DRE3 model in the prior section show the kinds of information about hidden underlying states inferable with a rhetorical approach, that are impossible using syntax-driven analysis such as keyword extraction or entity recognition alone. Digital discourse moves at a very fast pace. Rapid changes in digital discourse (e.g., during an unfolding political event) are likely the times when monitoring and analysis are most needed. Unfortunately, the DRE3 model, as applied above, is low-throughput. This problem is not unsolvable. The field of ecology offers a hopeful precedent, because it emerged from low-throughput observation of natural history, and later increased in scope and rigor through the application of quantitative frameworks and large-scale monitoring networks. We propose that rhetorical ecosystem analysis is capable of making a similar transition to a higher through-put research phase, in the case of some digital artifacts.

The value of developing capabilities for cataloging, indexing, searching, mapping, monitoring, and modeling digital discourse is also not limited to facilitating research. Just as better ecological understanding and monitoring has enabled forecasts, such as those related to algal blooms, disease, wildfires, and the potential risks of construction or development [97], better understanding and monitoring of digital discourse could forecast outbreaks of violence, acceptance of government initiatives, the spread of ideology, and the potential risks involved in narrative influence [98]. A wide variety of disciplines undoubtedly have interest in tools for modeling, mapping, and monitoring digital discourse, such as public relations, public health policy, and military information support operations (MISO) [98]. Many high reliability organizations, or organizations which must maintain low-failure rates or risk cascading failure [50], have expressed or demonstrated a need for tools which perform these functions [99–103]. While recent crisis events have drawn particular interest to the potential application of these functions in monitoring and modeling digital discourse about public health and political extremism, there has been a long-standing need for these functions in areas which are entirely apolitical, such as of multimodal content regarding interpretations of emergency situations like forest fires, floods, and earthquakes [104].

Transitioning from low-throughput to high-throughput, and from theory and research to forecasting and decision-making support, will only be accomplished by considering the related requirements of the outputs, of the processes and methods which lead to them, and of the tools and infrastructure which enable them. Here we explore and frame these requirements, consider methodology, and propose the structure of a monitoring system best categorized as a type of SCADA (Supervisory Control and Data Acquisition) system for digital discourse which incorporates the DRE3 model and modern computational techniques [105]. Addressing the use-case specific requirements of the many domains which might have interest in monitoring tools has been considered elsewhere [81]. Instead, the focus here will be on the requirements for more general sensemaking about public narratives generated by image memes.

Narrative Intelligence

The general requirements for sensemaking common to all intelligent systems are the abilities to capture relevant data from the environment (sense), fit the data to expectations or adapt those expectations to fit the data (model), and use the expectations to consider or frame choices (policy) as a basis for informing action [87]. Various frameworks exist to convert these general requirements into formal processes and specific requirements for systems which facilitate sensemaking. These frameworks are often built for activities which require special consideration beyond the fundamental sense-model-policy framework, such as in militaries [106–108], teams [107–109], intimate relationships [110], machines and AI [111,112], and businesses [113]. Of the many sensemaking frameworks available, intelligence production may be the most appropriate for sensemaking related to digital discourse.

Intelligence production is an organizational sensemaking process which is intended to produce deliverables to inform policy that achieves or maintains the interests of an organization [114,115]. Formal intelligence production processes are particularly helpful for organizations that are large enough to make the natural emergence of synthetic intelligence or macrocognition unlikely or illusory, and for organizations which are interacting with systems of interest that are sufficiently complex to prevent existing synthetic intelligence from being able to manage available sense data appropriately [109,114,116–118]. The process of intelligence production was originally semi-formalized by the Roman military [118] and has been iteratively developed throughout history in response to situations where conditions complicating macrocognition arose or became exacerbated [114,119–123].

Intelligence production is a helpful way to frame the requirements of sensemaking in digital domains given that intelligence production was formalized to face similar challenges, such as voluminous collections across myriad surfaces, multimodal data [124,125], deception and intentional disruption of data collections (counterintelligence) [126], and difficulty of detecting, monitoring, and interpreting counterpublic membership and activity [50,127–129]. Since intelligence production is usually performed by high reliability organizations [50] and faces the aforementioned challenges, it has been iteratively developed over time to maintain reliability and cope with imperfect data and uncertainty. While various specifications exist for particular use-cases, such as in business and commercial intelligence [113], generally intelligence production is modeled using 5 distinct stages: 1) planning and direction (requirements setting), 2) collection, 3) processing and evaluation, 4) production and analysis, and 5) dissemination [113,125,130,131]. These 5 stages provide opportunities for separations of concern between categories of function and process, as well as between personnel and access to information [131,132] to limit the possibility of "having either the facts or the conclusions warped by the inevitable and even proper prejudices" of those involved [133]. However, it should be noted that the steps formalized in the intelligence production model are not necessarily implemented in discrete phases, and that even where separate steps are intended, they still occur in parallel with blurs between processes [134,135].

Ecological and rhetorical metaphors and methodologies may offer unique and valuable approaches to monitoring and analyzing digital discourse, but no metaphor is a perfect mapping [136]. Here we apply the intelligence production framework to facilitate practical considerations for "mapping the gap" between ecology- and rhetoric-inspired methodology and the needs of a meme analysis pipeline at each stage.

Planning and Direction

The first step of the intelligence production cycle is planning and requirements setting. This stage entails considering what kinds of intelligence products are needed and in what time frame, and translating these needs into technical and personnel requirements, scope, and expectations for the following steps [130–132]. In the case of a meme analysis pipeline, we suggest that the relevant products be broken into 5 broad categories:

> **Data Sets.** While raw datasets do not constitute a formal intelligence product, the data collected and used for projections and other features are nonetheless a product which should be made available both internally and externally, similar to the provision of Twitter's streaming API (application programming interface) and "Firehose" [137,138]. These releases are essential for 3 primary reasons. First, the analysis pipeline should never be considered entirely complete; data used and produced by various features should be available for both quality testing and use in the development of new features. Second, datasets of content with semantic annotations could be invaluable for the

development and training of AI. Finally, the capability to release data used allows for reproducibility and transparency in the case that outputs are considered partisan or questionable.

Research Intelligence. Research intelligence refers to information that may provide context or support for other intelligence products or help in further analysis or sensemaking, such as wikis, or "fact books" which might provide details about content and communities of interest in the context of digital discourse [114,139], field guides for providing education on common patterns and processes [98], exploratory search features for analysts and researchers, and research products such as academic articles or white papers.

Estimative Intelligence. Estimative intelligence refers to information regarding uncertain phenomena, such as the likelihood of an object impacting a particular hidden state, though some definitions place a larger emphasis on projection [140–143]. In the monitoring of digital discourse, helpful estimative intelligence might include metrics and projections regarding the state, rate of change, and impact, of beliefs, communities, patterns of activity, or content, informed by methodologies from ecology and rhetoric.

Warning intelligence. Warning intelligence refers to information about anomalous phenomena or rapid or unexpected changes to system state [139,144,145]. In the monitoring of digital discourse, useful examples of warning intelligence would include the detection of anomalous activity, the emergence of what may be coordinated, aggressive, and strategic activity associated with untracked or tracked objects or communities, notifications about other organized activity such as the censorship of content on a platform, or the presence of harassment, threats, or explicitly illegal activity.

Actionable Intelligence. Actionable intelligence suffers from a lack of consistent usage or a consistent definition, but generally refers to information which needs to be addressed urgently and informs or enables actions that might be or need to be taken [146]. In the monitoring of digital discourse, actionable intelligence would help inform interventions such as the removal of content, inform design of content or messaging based on current trends, and guide sensemaking by providing new routes to consider when presented with ambiguity or structurally complex information.

Collection

The second step is broadly referred to as "collection". This term is sometimes used to refer to the entirety of the intelligence production cycle [133,147]. However, in the context of the production cycle and its processes, it refers to the conversion of requirements set during planning and direction into tangible targeting, selection, and instrumentation choices in order to collect data [125,130,148]. At this stage, the focus is on the collection of "raw intelligence", or unanalyzed information, in accordance with requirements—as such, it is sometimes referred to as collation [132]. In the past, organization of raw intelligence was fairly disorganized [118–120,134,149]. But with the increase in volume, and the need to collect multimodal data from myriad surfaces, came a need for specialization not just in analysis but in the collection of raw intelligence as well, resulting in various formal categories of tradecraft, or types of intelligence collection and annotation methodologies [130,150].

There are a series of ethical and practical challenges to the development of collection requirements and procedure for image memes in the interest of developing an image meme analysis pipeline. A root problem, worth addressing first, is that even at the cutting edge of machine learning applications in analyzing memes, there are serious limitations imposed by the lack of existing annotated collections to use as training data [23]. Thus, the use of AI at this time for automated collections would likely be inappropriate given that even the ability to differentiate between an "image meme" and "just an image" is a difficult, semantic challenge—let alone the ability to analyze it. However, given the rate of change, complexity, and volume of image memes, collection would place too high a burden on researchers, experts, and analysts. Crowd-sourcing may therefore be the best avenue of approach. While crowd-sourcing approaches have come under criticism, recent successes indicate that more complex tasks may now be ready to be outsourced to crowds [95]. Choices in incentivization mechanisms and user experience design would need to be considered in depth elsewhere, but there is a rich history of crowd-sourcing data in ecology which could be of use in framing collection requirements. For example, millions of entries for bird sightings are generated by citizen bird watchers each month [151] and data from bird sighting submissions can be used by analysts for real-time monitoring of animal activity as well as for forecasting phenomena such as outbreaks of West Nile virus [152]. The frameworks used for crowd-sourcing in ecology may allow for a direct transfer to other domains, such as those which provide data management principles [153] and offer methods for improving information quality or "Crowd IQ" [154].

Among the approaches developed in ecology and ecology-adjacent fields from learning-by-doing in crowd-sourcing, three stand out as both valuable and immediately applicable. First, based on crowd-sourced classification of plants and birds, quality of collections can be greatly improved simply by improving the quality and scope of the class structures (schema) and data standards the crowd will interact with [154]. Second, the study of crowd-sourcing fish classifications and remote-sensing in hydro-ecology has shown that quality can be improved over time by segmenting users by expertise and using these segmentations to provide different levels of responsibility [155,156]. Third, work on crowd-sourcing biomedical annotations has revealed that expert contributions can be used to train and tune user contributions, particularly to detect anomalies and unexpected deviations from patterns. Similarly, user contributions can be used to train and tune automated systems and be assisted and guided by them in performing contribution tasks (see figure 10) [95]. These approaches could be directly applied to "field" collections of image memes. Given that collections are occurring online, most relevant information, such as where the object was collected, the object's file type, and reaction or "impact" data if it was collected from social media, could be automatically fit to pre-existing data standards with no need for experts involved in collections before being placed in a buffer for classification. The collected objects could then be used to train AI to determine what and what does not constitute a meme.

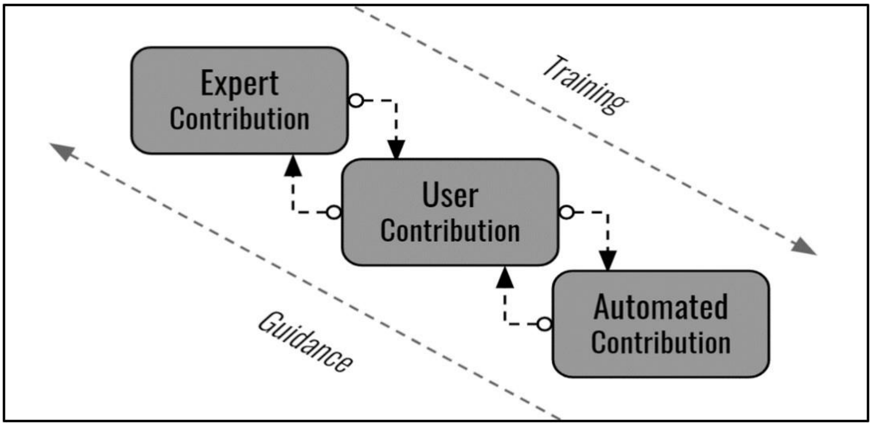

Figure 10. The flow of benefits offered between types of user contributions. Contributions by user segments with higher levels of competency in a task can be used as training data for those of a lower competency, while contributions from segments with lower levels of competency can be used to help provide guidance to those of a higher competency (e.g., suggested classifications).

While it might be reasonably assumed that data about the user who posted the collected object should be automatically parsed and collected as well, this may not be necessary. As noted elsewhere in this article, memes, particularly political memes, are often presented without attribution. Further, user data may need to be bypassed because creating or sharing political or even quasi-political memes or other content, especially within counter-publics where meme-activity is rich and of interest to researchers, is increasingly being accompanied by the expectation of potential consequences from peers [157], employers [158,159], and institutions [160,161], as well as by potential punitive consequences from media-sharing platforms [162–165] and governments [166,167]. The DRE3 model's focus on claims in memes informed by a rhetorical approach, and on relationships, placement, and change of that content informed by an ecological approach, as opposed to a focus on the identity of the poster, prevents misattribution or association inferred by posting history (e.g. a CDC official sharing an anti-vaccination meme for educational purposes), reduces the potential for harm by "outing" or "doxxing" internet users, especially in countries with higher potential for consequences for sharing political content, and reduces the potential for critical misuse of the analysis pipeline. For the purposes of understanding movement of memes specifically, the channel over which the meme travels is sufficient. If the collector of the meme in context with a particular platform constitutes a channel, then this channel can be considered a location—leaving no reason to deanonymize the collector and making the generation of an "identity" within the pipeline an opt-in exercise.

Processing and Evaluation

The third step of the cycle is often referred to as processing and evaluation and refers to a pre-analysis stage in which data is cleaned, refined [148], and filtered [130] and the reliability and credibility of sources of the information are considered [132,134,168]. The raw intelligence assembled in the collection phase is now altered or reassembled for usability, "coded data is decrypted, foreign languages [are] translated, and photographic material [is] interpreted" [148]. The importance of processing and filtering cannot be overlooked. Without comparable measures, accessible reference information, or compression into usable formats, much of the data could essentially become meaningless [169]. When this processing is done in concert with proper scope and orientation introduced in the planning and direction phase, it also reduces the potential for endless abstraction by making the means and intentions of the process clear [87,170].

It is at this stage in an image meme analysis pipeline that experts would be needed to begin classifying objects and improving information quality as the pipeline begins to move beyond syntax and metadata toward semantic annotations. Even with the use of crowd-sourced and automated collections, the load would still be far too great for experts and trained analysts to handle alone. This being the case, the same framework of training, guidance, and segmentation between the kinds of contributors described in the prior section would offer continued utility (see figure 10). Automated systems would be given responsibilities such as detecting quantitative features that are correlated with virality and longevity of the image meme, which can then be used to direct the attention of both experts and average users [23]. These systems would make use of data from the contributions of human users to train for more complex tasks. Expert users would have the primary responsibility of developing and detecting claim and argument patterns and applying these labels to content, which could then be used to train average users or even AI to do the same.

Claim identification presents the largest challenge to crowdsourcing the DRE3 model due to the subjectivity of the extraction whether it comes from rhetorical experts or average users. Image memes, as discussed in prior sections, tend to have an ambiguity which offers the poster plausible deniability about the assertion of claims. Therefore, simple automation of feature recognition cannot be relied on for extracting claims from images. However, this challenge may instead be seen as an opportunity. There are many viable methods for extracting and aggregating arguments from text [171–173], allowing for the substance of these common arguments in various phrasings to be aggregated and clustered. The remaining disparity between interpretations would not, and should not, be considered noise—but instead valuable data for producing metrics related to the subjectivity and complexity of the content and of diverse perspectives interpreting it. Average users would share responsibility for claim extraction, though their primary responsibility would be the extraction of relevant entities from the content.

Once experts have provided sufficient labeling of rhetorical pattern and structure, average users could be slowly trained. Segments of those users may even eventually be trusted with contributing rhetorical or other expert classifications, though the provision of greater responsibilities would likely require new tools or frameworks for managing trust in crowd-sourcing systems. Automated features however, would likely need to stay in a guidance role regarding most semantic analysis of image memes. Semantics on the internet are prone to rapid change and often require contextual knowledge. For example, triple brackets around an organization or person's name is now often considered an antisemitic symbol marking Jewish background or influence. But obviously, not all uses of triple brackets indicate this—and worse, prior to this association, the same triple brackets were used to indicate a "cyberhug". This does not mean that automated features would be useless. For example, the ability to note that some typographical feature may mean something to specific audiences and to direct a user's attention to that symbol is a valuable guidance feature.

Production and Analysis

The fourth stage of the cycle is referred to as production and analysis, wherein experts begin to produce the intelligence products requested, given the collected, processed, and evaluated information available and relevant to them [148]. At this stage in a meme analysis pipeline, data and content cataloged throughout the collection and processing stages can now be structured into data sets for developing, improving, and replicating automated features at all stages in the pipeline and for more specific exploratory analysis by experts. More importantly, it is also at this stage in the meme-analysis pipeline that rhetorical and ecological framing and techniques begin to have their most valuable contributions.

> **Research Intelligence.** The content labels, entity extractions, and identified claims informed by rhetoric now have a role in enabling semantics-driven exploratory search. The bottom-up detection of patterns and topological motifs allow analysts to view single pieces of content as a part of memetic clusters, not just of other pieces of content, but of entities, claims, and subclaims expressed in that content, and

of the hidden states that may be signaled by them. With the metrics and features which accompany the objects labeled within these memetic clusters, the analyst is able to monitor a semantic field, or rhetorical ecosystem, as described in previous sections, before analysis has even been performed. The data is now available to enable methods of analysis from ecology discussed elsewhere in this document. In addition, the content, patterns, and aforementioned ecological motifs can now be structured into coherent and navigable wikis, field guides, and fact books, modeled after the large, robust identification systems and guides found in ecology—helping improve methods and standards at all stages of the pipeline and increasing the likelihood of novel genres or features being detected.

Estimative Intelligence. The use of ecological frameworks and methods for identifying and communicating state features of content and claims, and considering the relationships between entities, memes, and claims, as discussed previously, could be of great value. The ability to classify and quantify state features implies the ability to consider potential for impact and spread, as well as the ability to measure rate. The provision of data regarding these changes to content and claims and related rates of changes may allow analysts to not only communicate current state, but also project future state of both claims and associated hidden states. This information can be leveraged in order to generate reports regarding underlying ecosystem hidden state features and their potential for change.

Warning Intelligence. The ability to classify and quantify state features, and project future states, further implies the ability to use those projections in the production of warning intelligence or general alerts. First, with the presence of patterns of spread, rhetorical structure, and state changes, comes the ability to detect breaks from expected patterns, or anomaly signaling. These anomalies can be prioritized and reviewed in ex post analysis to reveal and catalog new patterns, allowing for indications of phenomena which urgently require attention, such as swarm-behavior in political happenings, communications, harassment, censorship events, or organized activity. In addition, the ability to simply index content paired with the ability to classify and quantify state features means an ability to tag or "track" content. Ecology already has robust methods for the tagging of animals, some of which are used to enable early warning and risk alert systems. Similar methods could help inform the translation of changes to state into relevant notifications and warnings [174].

Actionable Intelligence. State features and context provided by hidden state analysis could generate intelligence products to improve decision-making around digital discourse in a number of ways. First, design and timing of content could be informed by the hidden states behind the claims dominating the environments they are intended to be deployed in. Second, if certain activities presented in warning intelligence require action, state features and hidden states can inform interventions. Finally, organizations whose decisions are meant to be informed by the interests of their constituencies can learn, through the tracking of claims, what those interests are, to increase the relevance of, and avoid negative externalities in, content deployments.

Dissemination

The final step of the cycle is the dissemination of intelligence products to stakeholders and decision-makers [102,104,113,119] and integration of those products into existing knowledge-bases for future use [96,119]. The various categories of individuals who would receive these intelligence products are often broadly referred to as "consumers" or "users" [104]. These intelligence products are traditionally written or oral reports intended to be periodically disseminated [148]. However, an insight which may be gleaned from ecological and ecology-adjacent forecasting is that when threats tend to be fast-moving or ongoing, and cannot be solved, only managed, intelligence needs to be consistently available, updated in real-time, and automatically disseminated and tailored based on expected need or upon request [59,175]. While the release of both periodical and non-periodical publications, newsletters, and briefings would be of value, they could not be relied on as the only method of dissemination to stakeholders.

In addition to these static disseminations, intelligence products would have to be tailored and presented in several ways. First and foremost, would be automated and other on-demand reports, that could be made available when requested, on particular claims, clusters, or other queryable objects. The ability to have dissemination via notification would be significant as well, given that warning intelligence is, by its nature, emergent and non-periodic, and is therefore in need of a channel over which it can be provided to those to whom it would be most relevant. Further, who may need this warning intelligence can change greatly with context. For example, warning intelligence regarding purported foreign influence of memetic content would only become relevant to some users of pipeline outputs upon their viewing of that content. Thus, intelligence would also have to be made available upon encounter. On-encounter dissemination could also be useful in terms of actionable intelligence, to help facilitate interventions, or, in terms of estimative intelligence and research intelligence, to allow analysts to use the content in front of them to direct the exploratory search of the existing corpus in developing new intelligence products, or to allow contributors during the processing and evaluation phase to better understand how to perform classification. Finally, given the rate of change in digital discourse, the ability to watch intelligence update in real time becomes essential. This type of real-time analysis of large volumes of digital discourse would be useful for a range of individuals, for example, public health officials observing the dynamics of public sentiment and impact of government messaging [81].

Toward a Meme SCADA

With these requirements in mind, there is one approach in particular which presents the affordances and flexibility necessary to handle all of the challenges posed by the production cycle discussed above: the use of dashboard-based SCADA (Supervisory, Control, and Data Acquisition) systems. SCADAs are used to supervise state, acquire data from remote sensors, and control operations in real time [176]. While SCADA systems were traditionally intended for use in industrial operations, approaches from this area of research and application have recently gained traction in ecology [177,178]. Framing image meme analysis pipeline as part of a SCADA infrastructure is potentially the most practical approach for two primary reasons. First, SCADA infrastructure is built with real-time use in mind and designed to facilitate the production of dashboard-like presentations of multimodal data and hidden states which are often difficult to communicate. Second, SCADA infrastructure design methodologies assume the need to collect and aggregate data from myriad sensors, and help inform information fusion protocols needed to generate forecasts, estimates, and current state features in real-time. In the case of the meme-analysis pipeline, supervisory and data acquisition features would be most prominent, though control features might be expressed in the form of prioritizations for users performing classifications and collections (such as during political happenings or swarm-behavior events), and in the form of explicit direction of automated collections and classifications. Here we present the rough blueprint of a meme analysis pipeline built in the style of an ecological or industrial SCADA system, from the requirements and outputs discussed within the previous section (see Figures 11 and 12).

Figure 11 shows the process by which artifacts (image memes) are collected, processed, analyzed, and disseminated. It begins with automated and manual collections of artifacts being given standardized annotations related to the location, structure (data type), and impact of the item. Next, these yet-to-be-processed artifacts are placed into a buffer; experts, average users, and automated features select artifacts from this buffer to identify their (i) statistically or quantitatively derived attributes and classifications, (ii) featured entities, (iii) claims, and rhetorical structure. The artifacts are annotated with these classifications using rhetorical and format annotation standards before being placed into an indexed and queryable catalog. Automated features and experts can draw from this catalog to perform analyses offered through a dashboard system for dissemination and monitoring. In addition, developers could use the catalog for training and test data in the development of new automated features. Finally, experts can make requests through the dashboard for prioritizations on manual collections and could direct the prioritization of automated collections (e.g., on certain kinds of content or from specific communities). Figure 12 shows the various forms of analysis and products which should be made available both through the dashboard and otherwise.

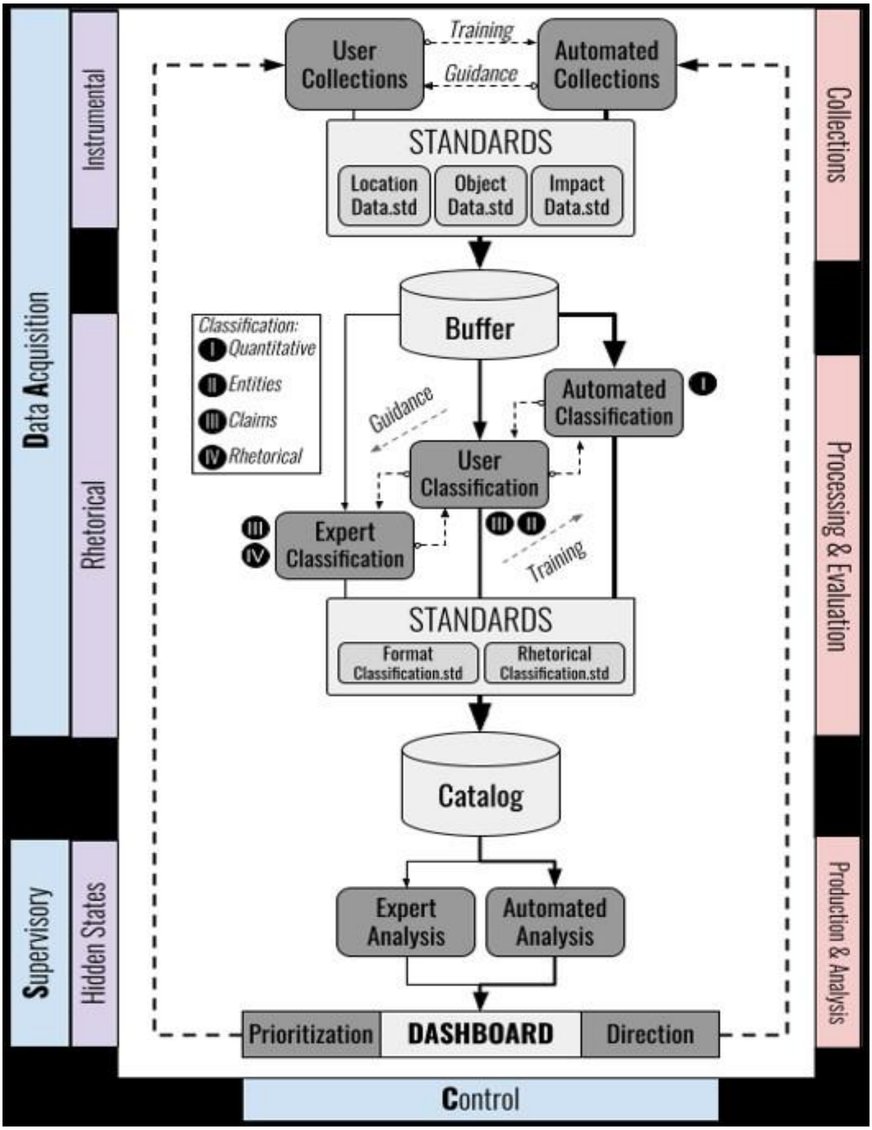

Figure 11. A rough blueprint of a meme-analysis pipeline. Color is used to indicate areas of the pipeline related to specific aspects of SCADA systems (blue), DRE3 analysis layers (purple), and intelligence analysis stages (red). The blueprint shows the various steps of content collection, processing, and analysis leading to the management of final intelligence products within a dashboard.

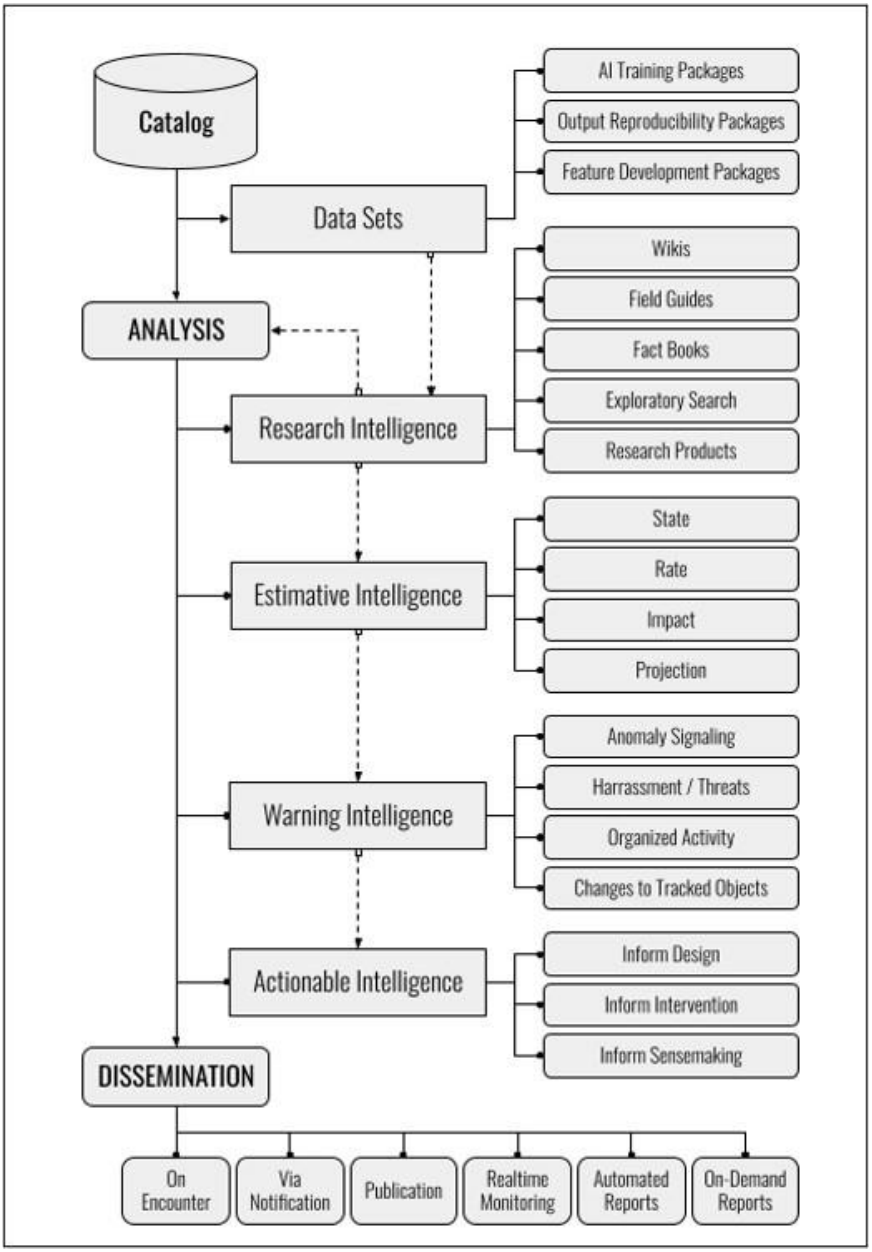

Figure 12. A map of desired outputs from a meme-analysis pipeline.

Discussion

In this paper, we have reviewed the relevance of rhetorical and ecological approaches for analyzing multimedia digital discourse, such as shareable image memes. While rhetorical analysis captures the nuanced relationships between artifacts and audiences, ecological analysis captures the complex relationships among organisms and their niche. Others have explored similarities between the fields of ecology and rhetoric [37,179]. We have elaborated this connection through three key themes from modern ecology: the multilevel systems perspective, antifragility, and ecosystem services. These key themes integrated into the Digital Rhetorical Ecosystem three-tier (DRE3) model, providing a framework for incorporating rhetoric into computational pipelines for analyzing digital discourse, with ecological toolkits and frameworks as intermediaries. In addition to the transfer of concepts used in ecology into the digital discourse space and specific implications for SCADA design, here we conclude by exploring some broader implications.

We go so far as to hypothesize that a disruption or correction of narratives forged through memetic circulation needs to adopt the memetic form itself, sometimes known as a counter-meme [180]. We advocate re-deploying the memetic form to interrupt the credibility of a specific meme argument by illustrating why the claim advanced by the original meme does not rest soundly on the evidence or the warrants (assumptions) signaled explicitly or implicitly within the meme. Current efforts to fact-check memes address memes with a different genre of rebuttal discourse (e.g., the Facebook fact-check box that often links to news articles of official credibility). Digital audiences that have become vulnerable to the influence of memetic argument have also grown a staunch resistance to this particular form of fact-checking. Therefore, we argue that any attempt to neutralize memetically constructed narratives needs to understand the rhetorical power encoded within the memetic form and to use that form strategically to restructure public discourse. We urge, however, that counter-memetic efforts acknowledge the conditions of cognitive complexity endemic to digital knowledge environments and avoid the pitfalls of easy fact/fiction dichotomy for issues that are murky, complex, or ambiguous. Counter-memetic strategy should expose how memes mistakenly create narratives of certainty in the face of situational ambiguity and complexity. That is, counter memes should avoid making new issue-based arguments themselves, and instead reveal the argument weaknesses in memes deployed to advance public argument. Simply put, memes can be used to demonstrate the argument weaknesses of memes. The repeated circulation of rebuttal memes to demonstrate the inferiority of memetic argument has potential to eventually decelerate reliance on the memetic form in public discourse. In addition, asking users to identify claims embedded within image memes during the stage of data processing and evaluation (Figure 11), could induce a more critical or meta-cognitive engagement with the memetic content and its deficits.

Rhetorical analysis has traditionally focused on single cases. Advances in computational technology provide the possibility of scaling up rhetorical analysis, for at least certain kinds of artifacts, such as image memes. Such high-throughput automated possibilities are evident in AI software such as Project Debater [181] and SwarmCheck [182] which can make sense of voluminous amounts of argument data using argumentation principles. The integration of rhetorical analysis with ecosystem tracking into a SCADA can enrich the field of rhetorical study by growing data-driven rhetorical theory. In 1969, Chaim Perelman and Lucy Olbrechts Tyteca published the influential New Rhetoric—a comprehensive compendium of argument strategies that relied not on formal logic but on everyday rhetorical practices [183]. Their catalog was built upon meticulous collection and analysis of real specimens of persuasion. Likewise, with the building of the proposed SCADA, we have the possibility of identifying and cataloging argument patterns across large amounts of image meme data, in a partially-automated fashion. The incidental value to argumentation theory of tracking the emergence, interaction, proliferation, and demise of image memes through discursive ecosystems is significant. We can determine whether argument patterns in image memes replicate documented argument patterns or assemble new ones. We can assess whether the unique genre of the image meme privileges certain argument patterns over others. An over-reliance on certain argument patterns (like argument by exposing hypocrisy [17]) may signal epistemic trends that are being exploited in the digital public sphere because they make minimal attention demands. When audiences are conditioned to argue in certain ways, their receptivity to other argument patterns that demand more central processing may diminish. We may observe at scale, with the intelligence that emerges from the SCADA, that one significant answer to the epistemic crisis we are currently battling is to understand the problem not just through a content framework (e.g., the fake news-real news dichotomy) but rather to problematize the medium, in this case the rhetorical form of the image meme, as one of the primary drivers of the crisis.

Another way to address the crisis is by examining ethical frameworks for managing a resource commons. In ecological philosophy, the "land ethic" [184] captures a sense of duty and responsibility towards ecosystem interactions. In the eponymous book, Aldo Leopold contrasted the land ethic with alternative frameworks that might be used to guide decisions around resource use, such as economic valuation, pragmatic use, and libertarian or egalitarian ideology. The land ethic serves as a conceptual nexus that integrates actors with different interests, and bridges world knowledge traditions. The application of a land ethic to online spaces might help ground otherwise-abstract digital communities and give a framework for service through deep time to these spaces. The ecological land ethic begins from a scientific foundation, then introduces insights from psychology and philosophy to characterize the nature of proper human-ecosystem relationships. In the case of a digital commons ethic, the system is physically grounded in the software and hardware that are the enabling architecture of the online platform. Framing an empirical (computational) basis as a starting point for studying online discourse could allow a "rhetorical commons" ethic to emerge, as driven and structured by psychological and ethical preferences.

Approaches to collective governance of ecological and resource commons have also integrated the economic insights of Elinor Ostrom and others [185]. As with these ecological commons, digital governance and economic systems could be designed with specified functions, performance metrics, and a stated collective purpose [186]. This model of "digital commons as public good" has already been applied to online communities [187,188]. Connecting the notion of "rhetorical commons" to the economic game theoretic setting of the "tragedy of the commons" helps connect the behavior of users, to outcomes at the level of the commons [189].

Conclusions and Recommendations

Can an ecological framework layered on rhetorical analysis help bridge the world of meaning and the capacities of computational pipelines? The ongoing and changing nature of the epistemic crisis requires new technological approaches towards scaling the modeling and understanding of our rhetorical commons. Here we expanded on previous appeals to rhetorical ecology and observations of the fundamental similarities between these fields [37], to posit the foundation for a type of system which might be able to infer, model, and intervene in multimedia digital discourse. With such a system, it could be possible to move beyond syntactic and user-driven understandings of digital discourse, to better observe and codify cycles and patterns within it, and to make progress towards ecologically-framed platform policies which can be more clearly informed by social preferences and values.

Recommendations

- Review best practices in improving information quality of crowdsourced subject-matter tagging in physical, digital, and rhetorical ecosystem contexts.
- Review and synthesize research on argument mining methodologies using crowdsourced annotations.

- Research the implementation and limitations of applications and web extensions for providing lenses (e.g., enriched augmented views of an object) on content displayed on various electronic devices.
- Curate a list of qualitative and quantitative patterns in the rhetorical structure and use of image memes.
- Consider users a part of an information commons rather than simply affected by an information system in future work on misinformation dynamics.
- Ensure that the identity, privacy, and preferences of users are protected in rhetorical cataloging schemes.

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CHAPTER III

The Knowledge Management Archipelago

Daniel A. Friedman & Richard J. Cordes

ABSTRACT

The theory and practice of knowledge management shares concerns and approaches with a number of other areas of research, some of which preceded its formalization as a field. In the age of the internet, the challenges that the field of knowledge management addresses, such as the difficulty of synthesizing, interpreting, and managing large streams of information, are no longer confined to professional disciplines and are present in everyday life. The commonality and timelessness of these concerns presents a potential problem for the field of knowledge management that, ironically, the field itself often seeks to address: the creation of silos, sometimes referred to as "islands", in the knowledge base. The purpose of this paper is to present an exploratory bibliometric analysis of the various areas of research which share concerns, approach, and scope in common with knowledge management. Search-strings associated with selected areas of research were used to query Google Scholar in various combinations in search of co-occurrence, results were quantified and visualized. The results show variable couplings and differential prevalence of keywords, and serve as a starting point for targeted analyses and next steps.

Introduction

Knowledge management has had the distinction of being a formally-defined field of research for at least three decades [1–3]. However today, knowledge management and a number of related fields still suffer from a lack of consensus on definitions and scope [2,3]. When considering the source of this lack of consensus, there are two features in particular that are worth noting. First is the fact that the challenges addressed by knowledge management are not novel but simply more pronounced due to the advent of digital technology and the internet [2]. Second, many challenges that knowledge management is concerned with are not specific to any particular class of organization. For example, effective allocation of intellectual capital and content [3–9], facilitation of research, situational awareness, the creation of intelligence products [3,9], and efficient use of human expertise [3,9,10] are challenges faced by organizations such as research and education institutes, intelligence agencies, industrial and manufacturing companies, militaries, law firms [3,9], and even citizens [11,12]. Thus many domains are in need of support in overcoming technical and cognitive challenges in making sense of the world [2,13].

This lack of novelty in concerns and their being so widely shared presents a potential problem for the field of knowledge management that, ironically, the field itself often seeks to address: the creation of silos (sometimes referred to as "islands" [14–18]) in the knowledge base due to differences in ontology and the lack of network connections between knowledge workers working on common issues [3,9,13]. In other words, there is disorder and disarray in the management of knowledge related to knowledge management itself—potentially leading to unrecognized solutions, redundant efforts, and incompatible or contradicting research, frameworks, and products. With the potential value of solving this problem in mind, an exploration of the literature, and even of the myriad definitions of knowledge management itself, reveals a number of distinct, formally-defined fields that are also addressing this common set of challenges, often with the same or similar approaches—chief among them are information management and library science.

Knowledge management, library science, and information management are difficult to separate, even at high levels of expertise, due to underlying confusion "around the concepts of knowledge and information" [19,20]. Even when clarifications are made however, those clarifications are accompanied by a lack of consensus regarding knowledge management being its own field rather than being either a modern update to information management [3,21,22] or an extension of library science and information management [1,3,19,23]. Further, the deep interconnectedness between information management, library science, and knowledge management theory and practice often causes attempts to define the differences between these disciplines to result in them being only more difficult to tell apart [24–29].

The practices most commonly associated with library science, information management, and knowledge management at least afford a common audience and base of stakeholders [3], but other fields with common concerns and research interest might not. For example, command and control or C2 systems, supervisory control and data acquisition or SCADA systems, intellectual capital management, and data, information, and sensor fusion are all areas which share challenges, requirements, and approaches in common with knowledge management. Worse still, many of these areas of research, including knowledge management and information management, are of interest, as stated earlier, to governments, militaries, intelligence agencies, and commercial organizations and therefore it stands to reason that an unknown fraction of research products are classified or otherwise uncirculated due to concerns regarding trade secrets and national security [3,9]. This problem isn't specific to government and industry research products—even within the domain of peer-reviewed academic research, publications are often only legally accessible to those with institutional affiliations. Today, even in cases where a team has the resources to make a deep search into all publicly available research regarding these disciplines, there may still be difficulty in performing comprehensive searches because of the aforementioned divergent ontologies. Thus a variety of challenges beset the area of knowledge management, with serious implications for workers and projects of many different kinds.

We hypothesized that an exploratory bibliometric analysis of targeted domains would characterize the structure of connection or fragmentation of different bodies of literature published by various sectors related to knowledge management. Our assessment of the literature connectivity was among the targeted areas defined individually in the following paragraphs.

Command and Control Systems. A command and control system can be defined as the set of "procedures and techniques" which "synchronize battles and engagements and which contribute toward the decisive application of combat power" [30] and facilitate "planning, directing, coordinating, and controlling" operations [31]. In practice, a command and control (C2), command, control, and communications (C3), or command, control, communications, and computer (C4) system generally takes the form of a distributed digital system that synthesizes and facilitates the generation of intelligence products and situation assessments, supports decision making, and provides situational awareness and opportunities to monitor, coordinate, and control operations in real-time [32,33].

SCADA Systems. Supervisory control and data acquisition (SCADA) systems provide features such as credential and role management, generation of and access to assessments, reports, and other intelligence products, real-time monitoring and surveillance, and control over physical systems. [34,35]. The development of SCADA systems began with the need for "increased knowledge of real-time status" or situational awareness of industrial infrastructure [35], and while this area of research is traditionally focused on monitoring and control of critical infrastructure, interests and concerns within this domain have a notable crossover with those within command and control systems and knowledge management research [36–39].

Knowledge Management. While hundreds of definitions for knowledge management have been generated as a result of sustained academic interest and use in a variety of fields, a potentially comprehensive, albeit general, definition is as follows: "Knowledge Management is the process of creating, sharing, using and managing the knowledge and information of an organization" [3]. Knowledge management, depending on its implementation, may also have within its scope areas such as intellectual capital attribution and governance (intellectual capital management), human and cultural dynamics, situational awareness facilitation, and learning management [3,9,20,39,40].

Data, Information, and Sensor Fusion Systems. Data Fusion is the domain, as the name suggests, of combining disparate types of data, be they from sensors or databases. Similar in some ways to the relationship between knowledge management, library science, and information management—data fusion, information fusion, and sensor or multi-sensor fusion systems are difficult to separate, have many definitions, and are often used interchangeably or fused together (e.g., "multisensor data fusion") [41,42]. Most definitions, however disparate, tend to have consensus that these terms refer to systems or aspects of systems which combine, consolidate, and otherwise synthesize information from various sources in order to provide situational awareness and create new value or deliverables, regardless of the fusion prefix used (e.g., data, information, sensor) [41]. In some cases, these definitions place emphasis on knowledge, information, intellectual capital, and document management as a part of such a process or system [41].

Information Management. Information management, separate from its blurred boundaries with library science and knowledge management, also has both internal and other external confusions regarding definition, scope, and ontology [23]. For example, information management is sometimes difficult to separate from information engineering, information systems management, management information systems, executive information systems, decision support systems, information resources management, and information science [23]. A general definition of information management might see it as concerned with the creating, sharing, using, retrieving, searching for, curating, recognizing, and managing content, data, and information within an organizational context [23,43,44]. However, definitions of the scope of information management generally also include concerns for elements such as knowledge management, supporting decision making, maintaining situational awareness, commoditizing information as intellectual capital, increasing knowledge creation, and synthesizing information from numerous sources [23,43,44].

Intellectual Capital Management. Intellectual capital management is an area of research that frames knowledge products, intelligence products, and formal intellectual property as intangible assets which can be invested, synthesized, and allocated in order to fuel the generation of new intangible or tangible assets [8,45]. Intellectual capital management is sometimes seen as either an aspect of knowledge management or as its own field which shares overlap with knowledge management [8]. Further, intellectual capital management often includes consideration for human and cultural dynamics such as the intellectual capital which has not yet been extracted from the minds of employees or has not yet been generated due to knowledge gaps—intellectual capital management thus shares a common set of concerns with research interests associated with human resources, serious games, communities of practice, and learning management systems [46].

Library Science. Library science is perhaps the earliest field to mature among the disciplines discussed here [47,48], and much like information management, separate from its relationship with knowledge management it has had both internal and external confusions regarding scope and ontology [29,47]. As of the 1970s, library science was roughly defined as the theory and practice of information selection, acquisition, organization, storage, and curation for "all-types of information-handling organizations" [47]. Due to the development of numerous other fields which have similar concerns, and the changing function of the library building in modern society, library science may be becoming an "island" in the knowledge base, evidenced by its lower degree of interdisciplinarity with other fields when compared with adjacent domains [29].

Term	2-Character Abbreviation	Inclusion Search-String	Exclusion Search-String
Command & Control	C2	(("C2" OR "C3" OR "C4") "Command and Control")	-"c2" -"c3" -"c4" -"Command and Control"
Supervisory Control and Data Acquisition	SC	"Supervisory control and data acquisition"	-"Supervisory control and data acquisition"
Knowledge Management	KM	"Knowledge Management"	-"Knowledge Management"
Data Fusion, Sensor Fusion, and Information Fusion	DF	("Data Fusion" OR "Sensor Fusion" OR "Information Fusion")	-"Data Fusion" -"Sensor Fusion", -"Information Fusion"
Information Management	IM	"Information Management"	-"Information Management"
Intellectual Capital Management	IC	"Library Science"	-"Library Science"

Table 1. Areas of research included in the bibliometric analysis, along with exact search-strings utilized.

Methods

This study was conducted in three parts: (i) collection preparation, (ii) data collection, and (iii) data analysis and visualization.

Collection Preparation

A list of domains with similar focus on and approaches to the production, management, allocation, routing, and synthesis of meaning and information was generated by considering co-occurrence of references to other domains within disparate definitions of knowledge and information management in relevant literature reviews, meta-analyses, and encyclopedias (see Table 1) [3,10,19,24–27,49,50]. Given that these areas are frequently discussed across both professional and academic disciplines [3], there was an expectation that much of the material would be contained in conference, working, and white papers, Google Scholar was chosen over Web of Science for this analysis as it has "far more comprehensive coverage" of these kinds of documents [51]. Due to Google Scholar's limitations on search-string size [52], this initial list and associated search commands had to be prioritized and pruned. The removed domains and the basis for their removal are described in the paragraphs below.

Records Management

Records management was a very good candidate for inclusion given both its subject matter focus [27] and an initial exploratory search indicating that over 62% of the records management literature was found to have keyword co-occurrence with other chosen domains (see Supplemental Files A-1). However, it was removed on the basis that the aspects of records management that would place it as a domain of interest are often acknowledged to be part of the information management discipline [53–56].

Situation Awareness System

While the "situation awareness system" market was valued at over 18 billion USD as of 2019, it is primarily a market-research term that describes SCADA, intelligence fusion systems, command and control systems [57]. It was not included on the basis that exploratory searches indicated that it was of limited use in academic literature and that where it was used, it shared a reasonable overlap with larger and more impactful domains (see Supplemental Files A-1).

ISR Systems

ISR (Intelligence, Surveillance, and Reconnaissance) systems also fall under this umbrella of common systems and was considered for inclusion, however, it was removed on the basis that less than 25% of the retrieved ISR literature was separated from the context of command and control systems and features of the command and control ecosystem [58,59] and that the total results associated with ISR systems only constituted 165 documents (see Supplemental Files A-1).

Intelligence Fusion Systems

Intelligence fusion systems were removed on the basis that only 77 documents were retrieved via an initial exploratory search and thus not impactful enough to be included despite a high rate of co-occurrence with other domains (see Supplemental Files A-1).

Bibliometrics, Scientometrics, and Informetrics

We did not include bibliometrics, scientometrics, or informetrics as a part of the study on the basis that they are more specifically concerned with metrics about the use of intellectual capital and knowledge products, rather than the facilitation of their use [60].

Creation of Search-Strings

Individual searches of every combination of domain-associated "Include" and "Exclude" search-strings (see Table 1) were found to be necessary due to limitations of Google Scholar search features and the potential for false positives and unintended overlap [52]. The inclusion or exclusion of each search-string set constitutes 27 - 1 permutations, as there was no reason to include an "all-excluded" query. A Python script was developed (see Supplemental Files A-2) to produce the set of search-strings (see Supplemental Files A-3).

Data Collection

Searches were implemented in Google Scholar using manual search based upon generated search-strings (see Supplemental Files A-3). After each search, the number of total Google Scholar results for the search-string was noted.

Data Analysis and Visualization

Data analysis was performed using Google Sheets and Python and visualizations were done using Google Sheets and Gephi.

Visualization

Given past successes in the use of graph visualizations for communicating cross-domain collaboration and other relationships in past bibliometric analyses [61–63], the graph visualization and analysis tool Gephi was chosen as a basis for rendering and analyzing the relationships between Google Scholar search results. A Python script was developed (see Supplemental Files A-2) to take the results of the data collection and convert it into "node" and "edge" files compatible with Gephi (see Supplemental Files A 4-5). In the interest of making the network renderings presentable, the domains were each given 2-letter abbreviations (see Table 1). These node and edge files were used to generate additional versions of node and edge file pairings and imported into Gephi to render network visualizations (see Supplemental Files 7-9 and Supplementary Figures 1-3).

Numerical Analysis

Google Sheets was used to perform a regression analysis of the number of results, comparing linear, exponential, and logarithmic regressions with number of domains included as the independent variable (X-axis, from 1 to 6) and number of results as the dependent variable (Y-axis). Conditional formatting was used to generate a heatmap of one- and two-term search results (see Figure 2).

Results

A total of 127 searches were performed on Google Scholar on June 10th, 2021 (see Supplemental Files A-6), covering all include and exclude combinations of the 7 domains and their search-strings described in Table 1. These domains are abbreviated to their respective 2-character abbreviations assigned in Table 1 within this section.

There were 57 queries, all with 2 or more include search-strings, that had zero results. Of the 69 queries with one or more result, 46 queries returned ten or more results. The search with the largest number of results was for IM alone (962,000).

In descending order of total citations, the domains were: IM, KM, LS, SC, C2, DF, and IC. In order of highest proportion of co-occurrence with other keywords (reflecting degree of integration across fields) to least, the domains were: IC (76%), DF (71%), KM (32%), C2 (30%), IM (28%), LS (29%), and SC (15%) (see Figures 3-9). Thus at least in this keyword-based search among areas, there is an indication that DF and IC have the fewest number of overall citations, but demonstrate the highest rate of co-occurrence with other keywords. In contrast, the relatively large body of literature related to IM and KM demonstrates an intermediate degree of co-occurrence with other domains, while the mid-sized body of literature related to SC demonstrates the lowest level of overall co-occurrence.

Among searches which included 3 domains, the highest-volume domain crossovers were KM-IM-LS (11,800 results), KM-DF-IM

(1,820 results), KM-IM-ICM (1,560 results), C2-DF-IM (887 results), and C2-KM-IM (819 results). Among searches which included 4 domains, the highest-volume domain crossovers were C2-KM-DF-IM (273 results), KM-DF-IM-LS (89 results), KM-IM-IC-LS (78 results), and SC-KM-DF-IM (48 results). Among searches which included 5 domains, only 4 searches produced results: C2-SC-KM-DF-IM (6 results), SC-KM-DF-IM-LS (1 result), C2-KM-IM-IC-LS (1 result), and C2-KM-DF-IM-LS (1 result). No searches which included 6 or all 7 domains returned any results.

Figure 1 shows the distribution of the number of search hits (Y-axis) as a function of the number of included domains (X-axis). As expected, there was a monotonically decreasing number of returned searches as a function of the number of search-strings used. The drop-off in search results was more consistent with an exponential regression with negative exponent (R2=0.324) than a logarithmic regression (R2=0.177) or a linear regression (R2=0.096). Notably, the KM-IM co-occurrence edge is above the trend line of the overall regression (Figure 1), suggesting that these two keywords are deployed in main texts and bibliographies at a rate higher than expected. Anecdotally, the areas of KMS and IM are largely overlapping in scope, including many works explicitly linking, contrasting, or juxtaposing the two approaches (e.g., [64]).

Figure 2a shows a heatmap of the number of results for each domain searched alone excluding all other domains using their respective exclude search-strings (on the diagonal), and their co-usage (in the bottom triangle of the matrix) for each pair of domains, where darker cells reflect a larger number of total results per query. Figure 2b shows the proportion of citations from each target domain (row) that additionally reference another domain (column), where darker cells reflect a higher proportion of keyword co-occurrence. There was a significant degree of variation among terms in total number of solitary and co-occurrence, as well as the proportion of directed co-occurrence between the keywords of pairs of domains. The only domain pairing that was absent entirely was IC-SC, suggesting that these two are the most diverged or isolated from each other in terms of approaches, concerns, and ontology. In contrast, the large fields of IM and KM had a relatively high proportion of co-occurrence with other keywords, while among the smaller fields, DF-C2 displayed a higher proportion of co-occurrence than other pairings. In terms of directional co-occurrence, IC-KM had a higher rate of co-occurrence than any other field pairing, with nearly 60 percent of results associated with IC also being associated with KM.

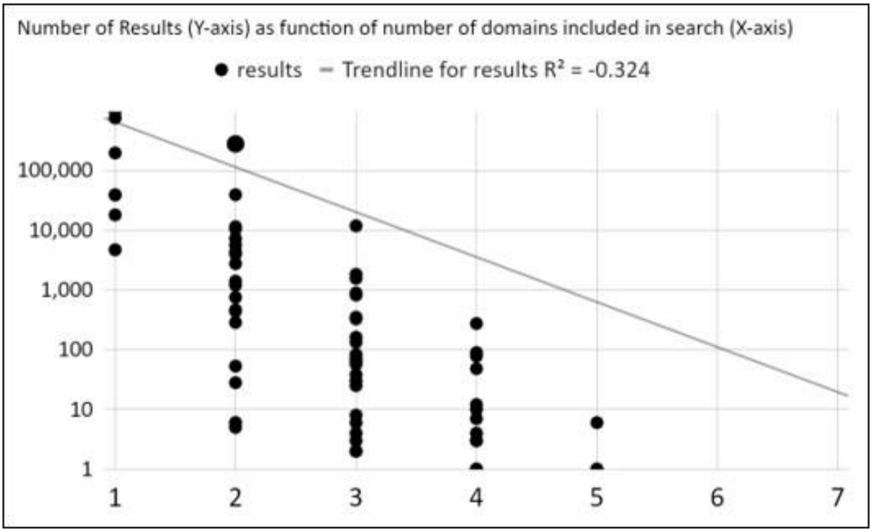


Figure 1. Relationship between number of domains included in search and number of Google Scholar results.

Figures 3-9 show targeted analyses centering each domain, with summary statistics and visual representations of the patterns of co-occurrence of keywords with other domains. Within Figures 3-9, subpanel A represents the proportion of co-occurrence and no co-occurrence with other domains within results associated with the subject domain broadly. Subpanel B represents the proportions of total results which had co-occurrence with specific other domains (so numbers will not sum to 100%). Subpanel C shows a weighted directed graph of the neighborhood around each keyword, in terms of the relative proportion of co-occurrences to and from each of the included keywords.

Broadly speaking, IM, KM, and LS were the most common domains overall, and appeared deeply intertwined. DF seems to be a bridge between these keywords (Figure 10), potentially because the practices and theories associated with it both support and draw support from a common class of systems of which LS, IM, and KM systems are a part. Visualization of the nominal (absolute) and relative percentage of co-occurrence among keywords (Figures 2-10 and Supplemental Figures 1-3) supported the trends broadly outlined above.

	IM	KM	LS	SCADA	C2	DF	ICM
IM	962,000						
KM	294,849	754,000					
LS	51,358	22,612	196,000				
SCADA	3,378	1,230	36	39,100			
C2	6,428	2,908	108	628	38,700		
DF	14,836	9,973	777	1,558	5,577	18,000	
ICM	1,936	7,295	128	0	14	17	4,690

a

	IM	*KMS*	*LS*	*SCADA*	*C2*	*DF*	*ICM*
IM		22.40%	3.90%	0.26%	0.49%	1.13%	0.15%
KMS	27.43%		2.10%	0.11%	0.27%	0.93%	0.68%
LS	19.86%	8.75%		0.01%	0.04%	0.30%	0.05%
SCADA	7.50%	2.73%	0.08%		1.39%	3.46%	
C2	12.49%	5.65%	0.21%	1.22%		10.84%	0.03%
DF	32.06%	21.55%	1.68%	3.37%	12.05%		0.04%
ICM	15.75%	59.34%	1.04%		0.11%	0.14%	

b

Figure 2. Heatmaps of (a) the total results associated with pairings of domains and (b) the percentage of total literature results associated with one domain (y axis) which had co-occurrence with another (x axis).

The bulk patterns discussed above and represented in the heatmaps in Figure 2 motivated a deeper analysis into whether the different domain keywords had distinct patterns of solitary and joint usage, potentially revealing patterns of disciplinary connectedness or isolation. A total of three Gephi files were generated from these initial files. The first, titled "Nominal Co-Occurrence", was an undirected graph of 7 nodes and 27 weighted edges, where nodes represented the target domains, and edge weights represented the number of retrieved documents which included both terms (see Supplemental Figure 1). The second, titled "Percentage Co-Occurrence", was a directed graph of 7 nodes and 40 weighted edges, where nodes represented the chosen domains, and edge weights represented the percentage of total documents associated with one domain that referenced another (see Supplemental Figure 2). The third, titled "Search-Strings as Nodes", was a directed multigraph of 65 nodes and 180 weighted edges, where nodes represented either chosen domains or the search-strings that were used to conduct searches (see Supplemental Files A-3), and edge weights represented the number of documents associated with a domain and a search-string (see Figure 10 and Supplemental Figure 3). The search-strings for (i) KM-IM, (ii) IM-LS, and (iii) KM-IM-LS were removed from the "Search-Strings as Nodes" multigraph in the interest of visualization (see Figure 10). A histogram of this directed graph showed a range of edge weights representing the proportion of directed co-occurrence between pairs of domains, from almost 60% (IC->KM), to zero (see Figure 11).

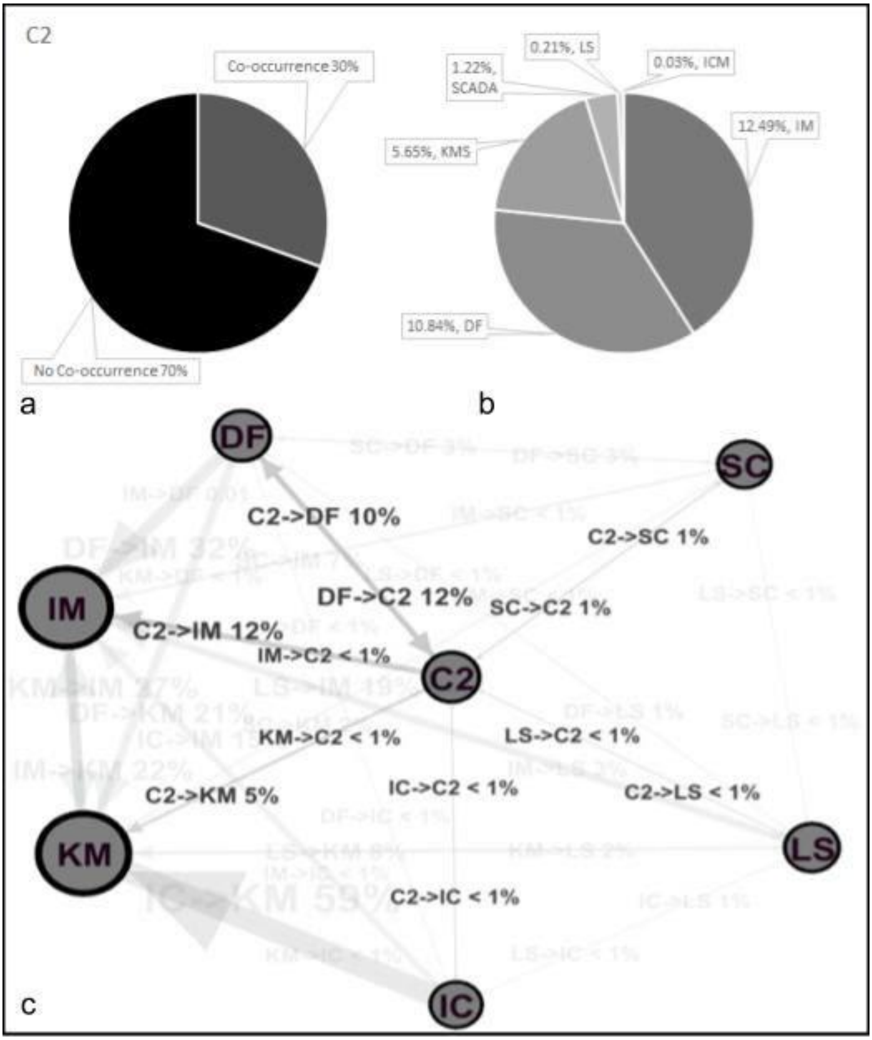


Figure 3. C2 (Command and Control)

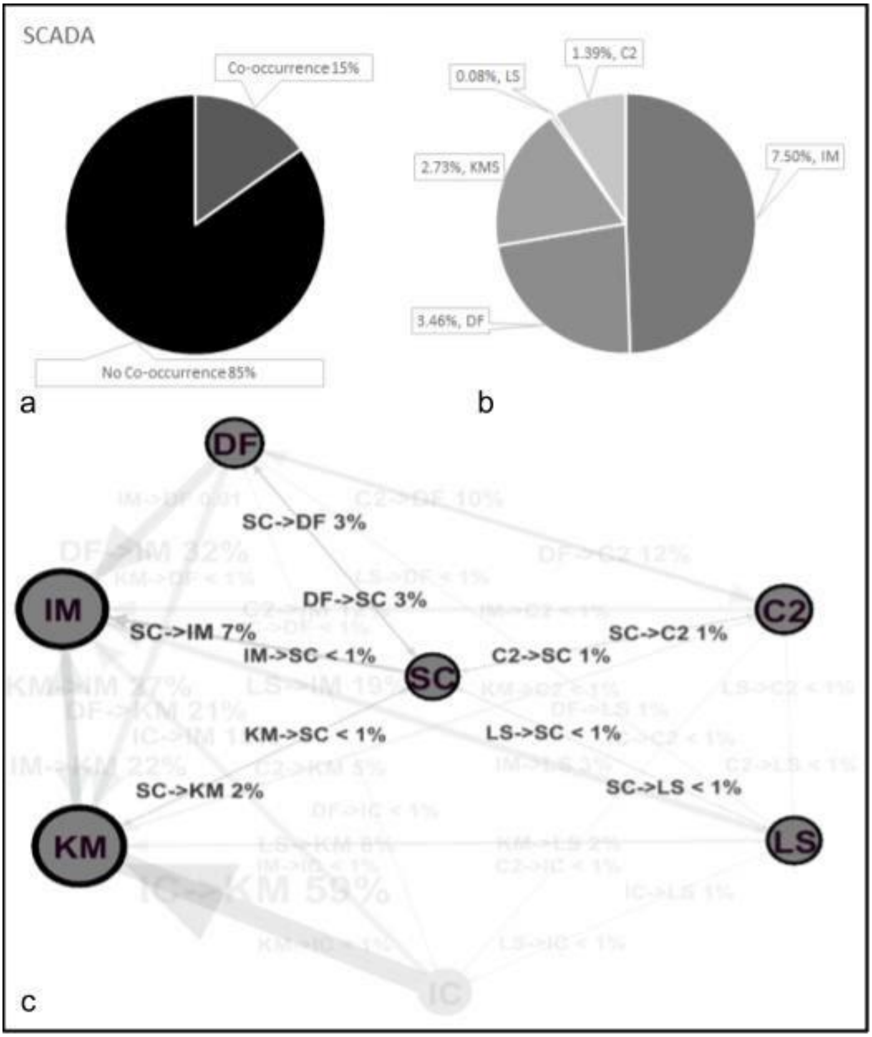


Figure 4. SC (SCADA)

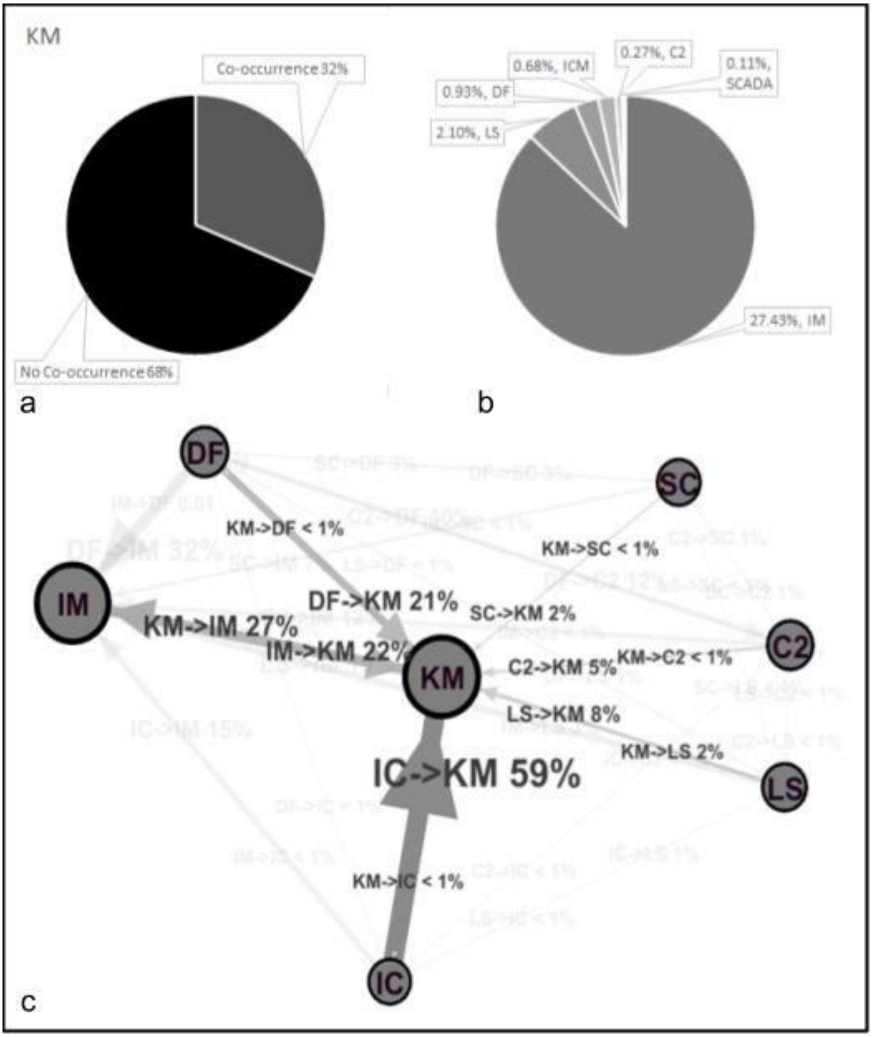


Figure 5. KM (Knowledge Management)

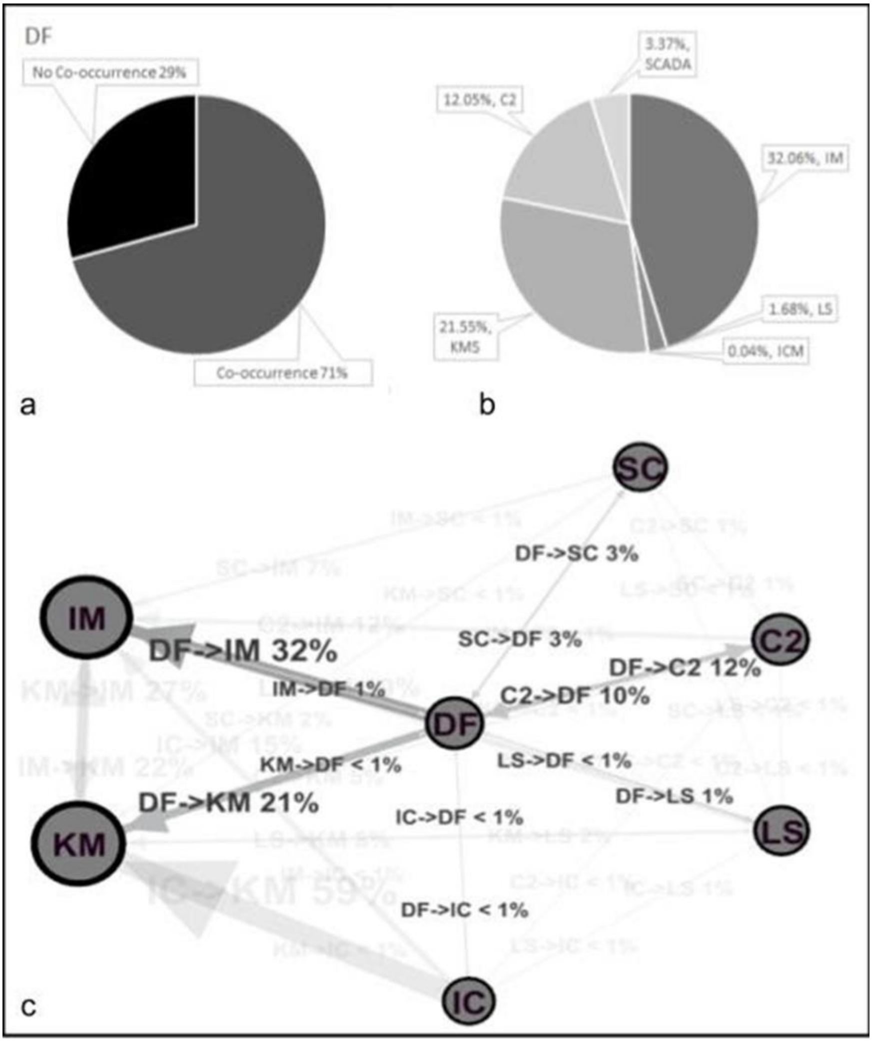


Figure 6. DF (Data, Information, and Sensor Fusion)

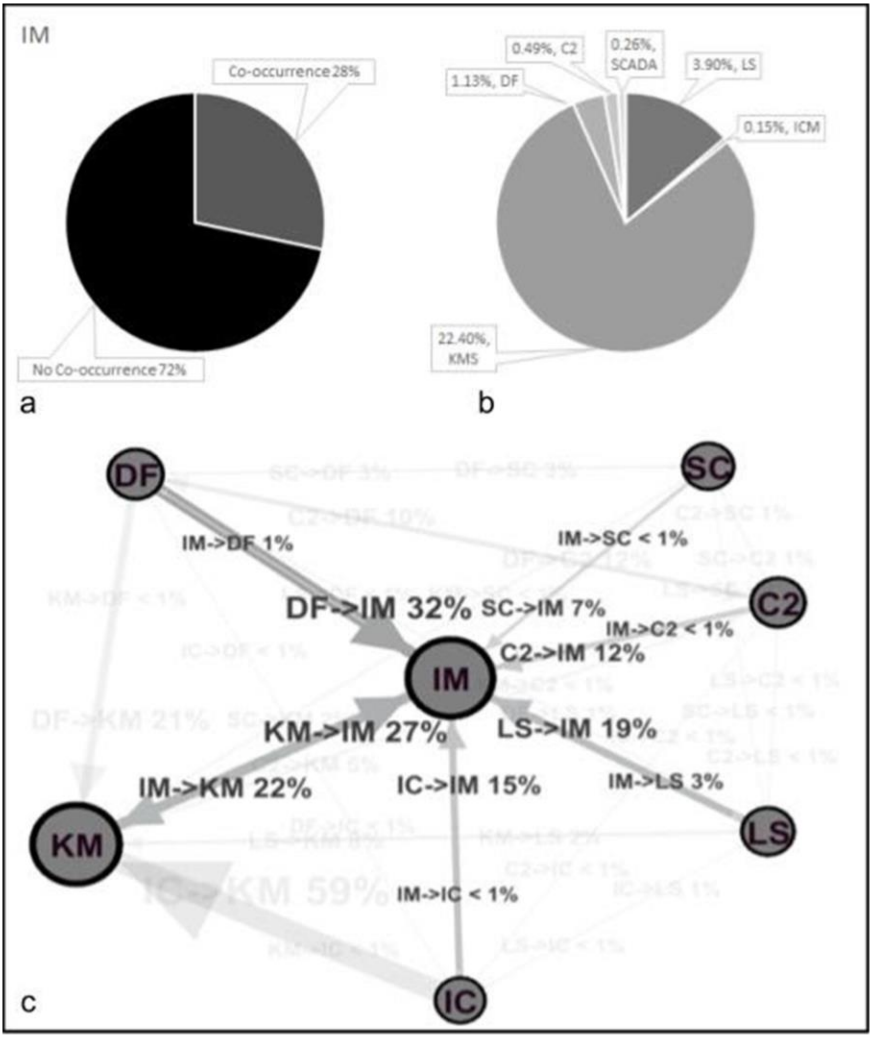


Figure 7. IM (Information Management)

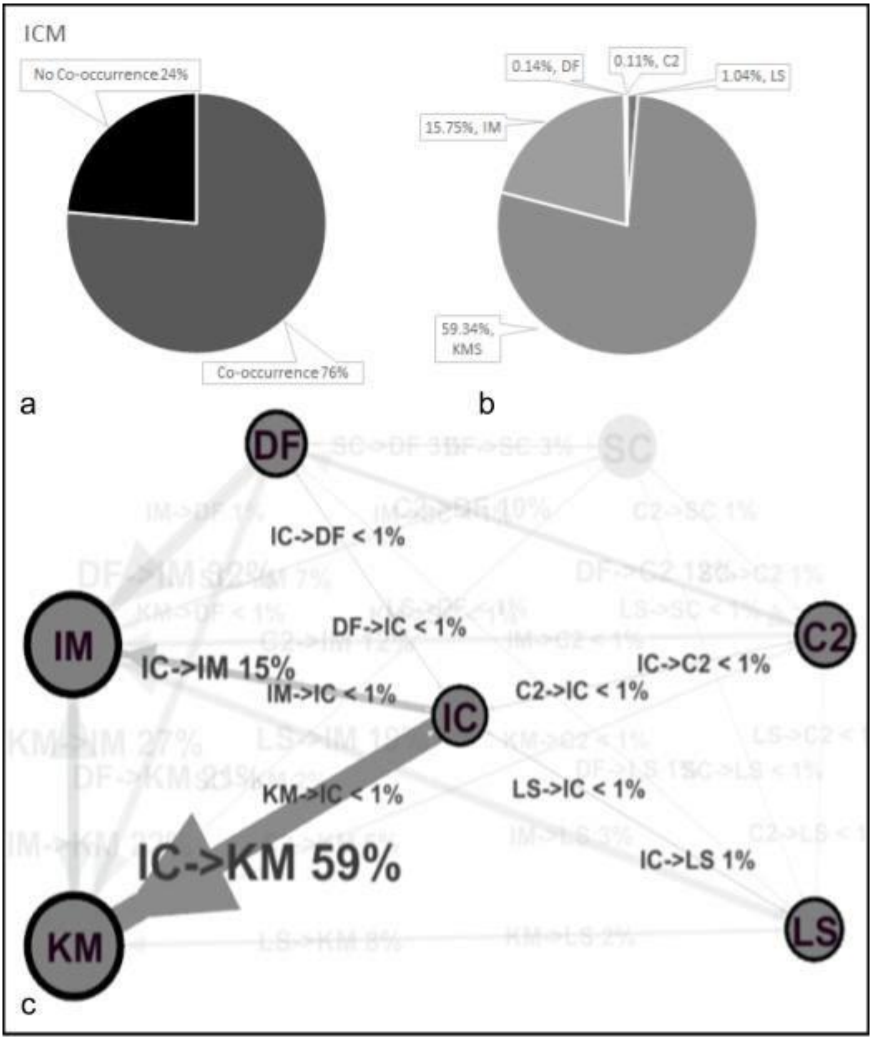


Figure 8. IC (Intellectual Capital Management)

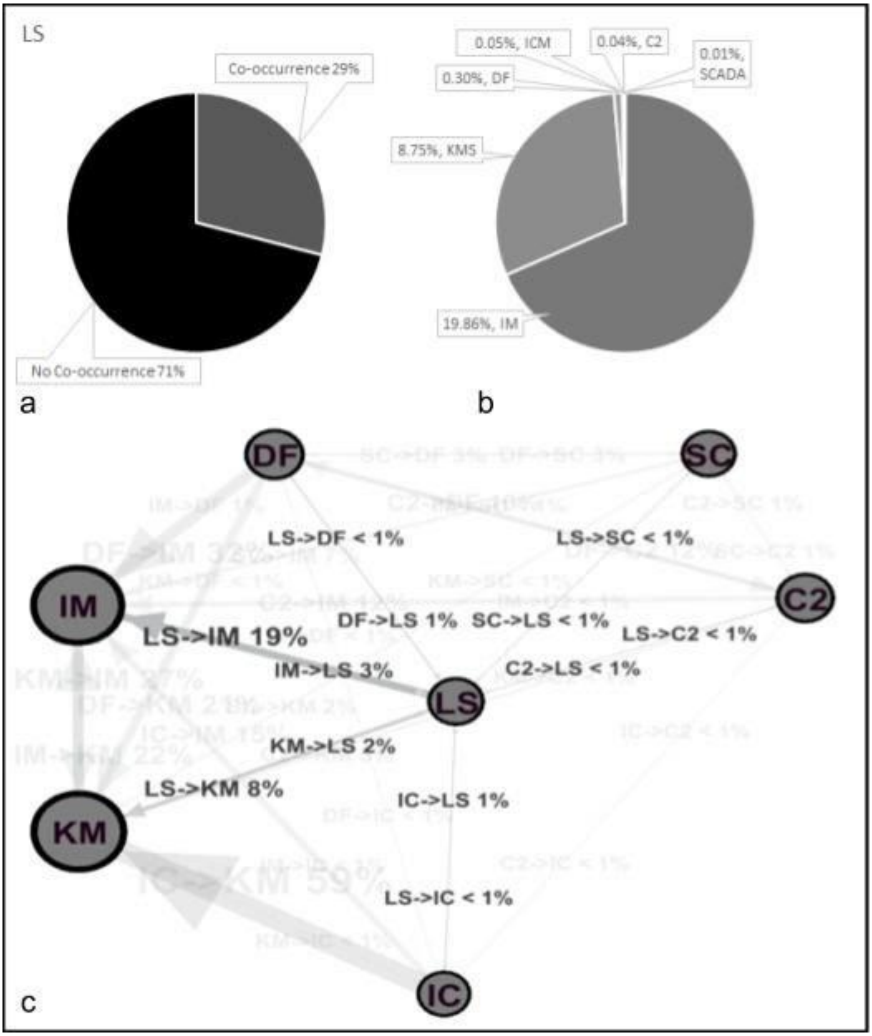


Figure 9. LS (Library Science)

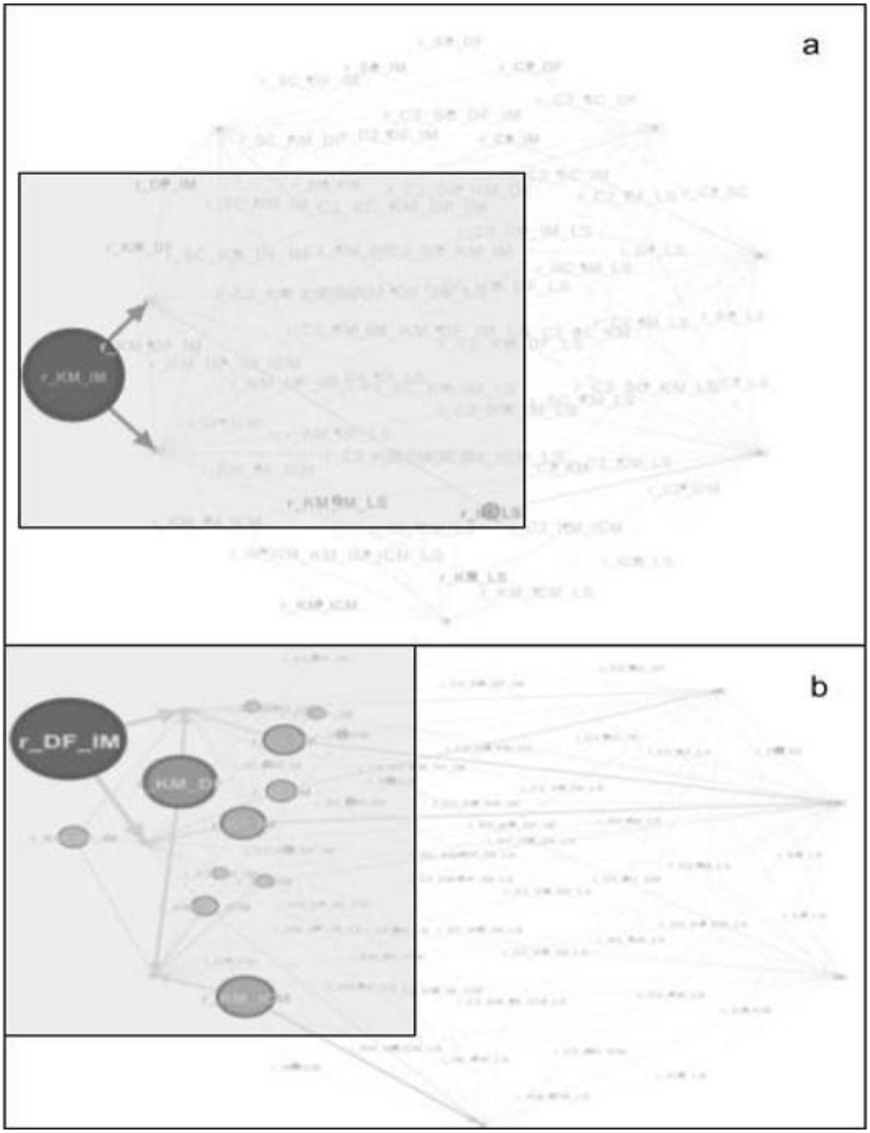


Figure 10. Gephi rendering of the "Search-Strings as Nodes" graph (see Supplemental Figure 3) before and after removing KM-IM, IM-LS, and KM-IM-LS search-string nodes for visualization purposes.

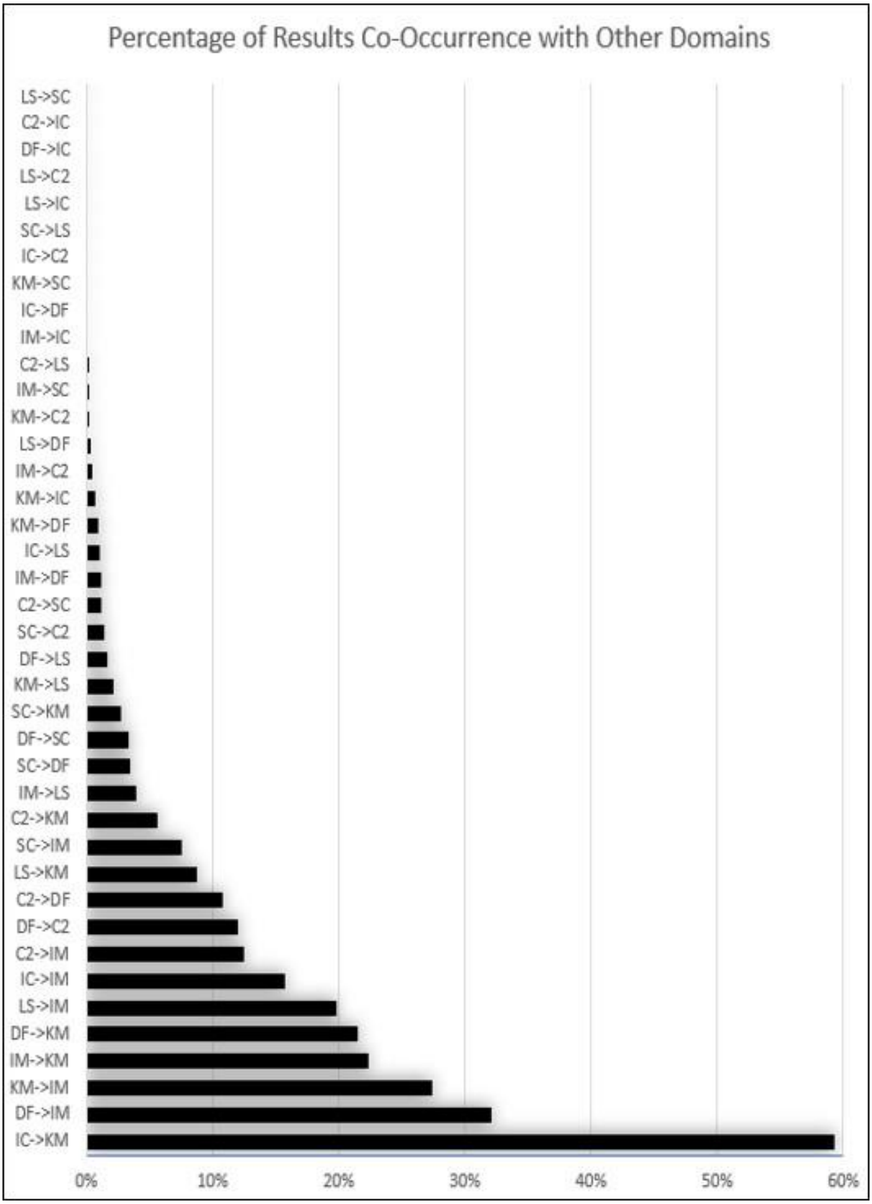


Figure 11. Percentage of results associated with one domain which had a co-occurrence of keywords with another domain.

Discussion

Here we performed keyword-driven searches on the Google Scholar database to assess the fragmentation and connection within the literature related to knowledge management (Table 1). We traced out broad trends in keyword occurrence, and co-occurrence, and used graph visualization to investigate the relationships among domains.

As a result of this exploratory analysis, an interesting pattern was found. Namely, that many papers directly motivated the transition between the use of one included area and another (see Table 1), or between included areas and other areas not initially considered or known. For example, from business intelligence to information management [65], information technology to information management [66], information management to knowledge management [21,67], knowledge management to “interaction management” [68], knowledge management to “knowledge services" [69], knowledge management to “learning management” [70,71], “information resources management” to knowledge management [67], and knowledge management to records management [72].

Other relevant areas were discovered during searches that were not included or considered for inclusion in the target keywords in Table 1. Several significant areas are described in the paragraphs below.

Decision Support Systems

“Decision support systems” were found to be discussed alongside or as a feature of, adjacent to, or a complement to knowledge management and C2 systems [33,73,74]. Decision support systems are generally defined as a system which increases the quality of decision making and related processes primarily by aiding in the curation, synthesis, creation, and sharing of information with consideration for user and organizational dynamics [75]. Decision support systems had not been initially considered as a candidate for inclusion but should be in similar research in the future. The volume of decision support systems literature was comparable to that of knowledge management, information management, or library science and only ~6% of decision support systems results had co-occurrence of keywords with areas included in this study (see Supplemental Files A-1).

Learning Management Systems

"Learning management systems" were found to be discussed alongside or as a feature of, adjacent to, or a complement to knowledge management [71,76,77], SCADA systems [78,79], and intellectual capital management [70,77,80]. Learning management systems are generally expected to assist in learning, knowledge gap handling, and management of learner data and include features such as personalized search and curriculum, rapid assessment of the state of the knowledge and progress of users, intellectual capital management features such as attribution and plagiarism detection within resources and generated content, curation and recommendation of resources and relevant problem scenarios, and reference management [81]. An exploratory search showed that 13% of the returned learning management results had a co-occurrence of keywords with this study's selected domains (see Supplemental Files A-1), and many of the top resources (sorted by relevance) returned on this search were concerned specifically with the similarity and opportunity for synergy between learning management and these other domains [40,70,76].

Business Intelligence Systems

"Business intelligence systems" were found to be discussed alongside or as a feature of, adjacent to, or a complement to SCADA [82,83], knowledge management and information management [84–88], and decision support systems [88]. Business intelligence systems are defined as systems which help reduce the impact of cognitive overload and increase the quality of business decisions by providing situational awareness and curation, access, and synthesis of relevant intelligence products [89,90]. An exploratory search showed that the volume of business intelligence literature is comparable with that of knowledge management, information management, and literature management and an exploratory search showed only ~6% of business intelligence results having a co-occurrence of keywords with this study's selected domains (see Supplemental Files A-1).

Information resources management

"Information resources management" was found to be discussed alongside or as a feature of, adjacent to, or a complement to knowledge management [67,91,92], information management [67], intellectual capital management [93], and SCADA systems [94], as well as other areas that are related but not included in this study, such as records management [95] and document management [92]. Information resource management was originally coined as a term by a US Presidential commission and intended to be an area concerned with the design, creation, collection, analysis, use, sharing and curation, storage, and retrieval of information, records, and knowledge. An exploratory search showed ~60% of information resources management results having a co-occurrence of keywords with this study's selected domains (see Supplemental Files A-1).

Document management

"Document management" was found to be discussed alongside or as a feature of, adjacent to, or a complement to knowledge management [24], information management [24], learning management [96,97], information fusion [98,99], intellectual capital management [100], library science [101], and SCADA systems [102–105]. Document management is generally concerned with the collection, use, sharing, retention and storage, security and governance, retrieval, and identification of attributes associated with documents and records [106,107]. An exploratory search showed ~18% of document management results having a co-occurrence with keywords within this study's selected domains (see Supplemental Files A-1). Surprisingly, despite having a nearly identical definition and scope to the area of records management, only ~8% of the results associated with document management had keyword co-occurrence with records management (see Supplemental Files A-1).

Limitations

There were several limitations to this study. As stated in the Introduction, an unknown amount of relevant literature may be unavailable due to it being classified by a government, or regarded as proprietary information by industry. Other limitations were related to the use of Google Scholar for performing searches. First, Google Scholar may provide results based on false positives and false negatives in keyword recognition, sometimes due to problems associated with the digitization or indexing of the document (e.g., spaces within a keyword or keywords being separated by line or page) [108]. Second, the keyword proportion in any database at any single time may not be reflective of the relative accessibility of this information to any specific researcher from the past or now [51,52,108]. Third, Google Scholar does not provide affordances to separate a positive recognition of the keyword in a text from a positive recognition of the keyword in the titles within cited works in a text—the ability to do so would have allowed for a more nuanced picture of the fragmentation and connection between various domains. Fourth, Google Scholar search results can vary, sometimes significantly, based on a variety of both known and unknown factors [108]. Fifth, temporality of results was not considered given that affordances for considering time of publication in conducting searches were restrictive for a manual search, that it is "not an infrequent occurrence" for Google Scholar to index dates incorrectly [109], and that Google Scholar provides no affordance for downloading the results of a search. Therefore, our estimates of usage and co-occurrence may not capture recent or contemporary trends in each area.

Conclusion

There appears to be an archipelago of partially-connected "islands" in the knowledge management space. The state of the literature indicated by the exploratory analysis conducted suggests a need for synthesis across these domains and areas of expertise so that each domain can benefit from research in others and reduce the likelihood of redundant work. However, the path towards this synthesis is unclear. In the face of this uncertainty, we conclude not with a single answer, but a set of potential avenues of synthesis and driving questions. Several approaches for this synthesis present themselves, some of which we present below as the beginning steps.

Recommendations

Restoring prominence of an existing keyword

Rehabilitation of an appropriate extant keyword could be attempted. knowledge management or information management for example could be restored as a central keyword around which all others could be reorganized. A conference or working group could be assembled to facilitate synthesis of the existing literature and wider adoption of the new framing. A compendium detailing the use and scope of these many terms could be written to serve as a common resource.

Creation of a new keyword

A new keyword or search-string could be generated to tag works related to information storage, search, and presentation. This keyword could be used within documents, or applied as an annotation to existing documents, reflecting the relevance of the document for knowledge management. A new synthetic keyword or string might be proposed as a tag for any kind of work broadly in the domains of Table 1, such as a novel emoji or hashtag such as #9jt05kw690j ("information" with each key shifted up and to the right one position on a QWERTY keyboard). Alternatively, a new term could be generated that describes or scopes the common set of challenges, approaches, and concerns of these various fields without necessarily intending to replace any of the extant ontologies. However, any of these approaches would have to be done with consideration for achieving wide adoption in order for them to be useful rather than further contribute to divergence among fields.

Encourage interdisciplinary communities of practice

A longer-term approach may be to socially connect various domains of expertise with broader communities of practice and encourage interdisciplinary collaboration. This would connect networks and projects across silos and allow for synthesis and integration of terms and resources in a sustainable and organic manner.

New tools

Computable documents, computable ontologies, and low-cost distributed knowledge management tools could enable next generation indexing, annotation, and semantic tagging of digital artefacts that would allow users to search not just for syntax but for meaning and use of syntax, and could do so across languages [110–113]. This kind of search would reduce the impact of diverging ontologies and increase situational awareness of the literature. Further, tools of this kind would help index non-academic resources and have value in handling challenges outside of the academic space, such as cognitive security in civil society, education, and journalism [12,114].

Awareness

Increased recognition of the similarity of challenges, approaches, and concerns across fields on its own could set the stage for synthesis and integration across fields. At this time, no results are provided for any search including all of the included domains within this study, let alone all of the other similar domains found during exploratory searches.

Driving Questions for Ongoing Research

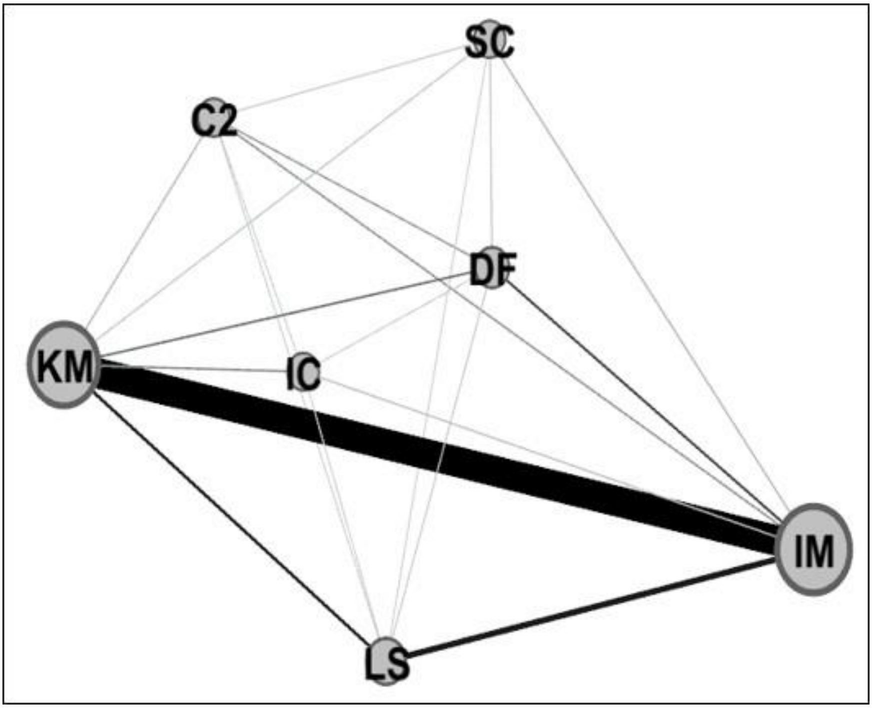
- How can we search, read, and cite across fields to make better knowledge management decisions?
- How can connecting communities, skill sets, and understandings across fields lead to better performing systems?
- How can uncirculated or currently unindexed literature resources from industry and government be safely and respectfully indexed, queried, and quantified?
- How can we synthesize the requirements of systems associated with the many domains concerned with creating, sharing, integrating, storing, attributing, accessing, searching, and curating digital information?
- How can systems with heterogeneous datasets and domain-specific information be provided for users from different backgrounds and areas of expertise, without cognitive overload?

Chapter III
Supplemental Files

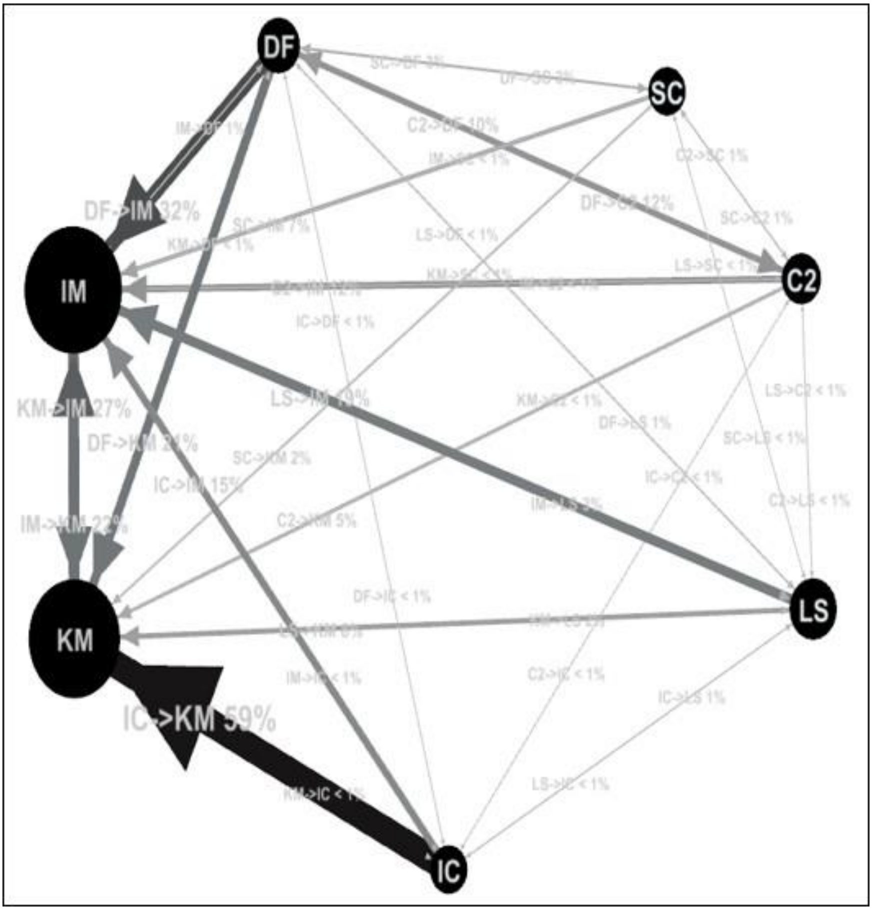
All files available at https://github.com/Cordes-RJ/KMA

ID	Name
A-1	Additional Searches
A-2	Python Script
A-3	Python Outputs - Search-Strings
A-4	Python Outputs - Edges
A-5	Python Outputs - Nodes
A-6	Results
A-7	Folder - Gephi - Nominal Co-occurrence
A-8	Folder - Gephi - Percentage Co-occurrence
A-9	Folder - Gephi - Search-Strings as Nodes

Chapter III
Supplemental Figures



Supplemental Figure 1. Gephi Rendering: Nominal Co-Occurrence



Supplemental Figure 2. Gephi Rendering: Percentage Co-Occurrence

Supplemental Figure 3. Gephi Rendering: Search-Strings as Nodes (KMS-IM-LS connections removed for visualization)

CHAPTER IV

Active Inference in Modeling Conflict

Scott David, Richard J. Cordes, & Daniel A. Friedman

ABSTRACT

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.

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"

[24]

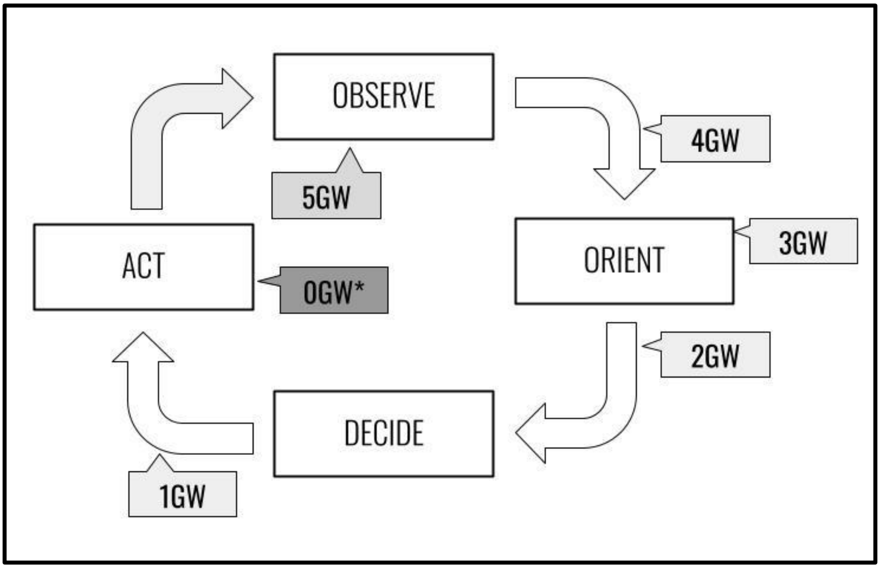


Figure 1. Abbott's Gradients of Warfare projected onto John Boyd's OODA loop. Adapted from [25]. 0GW not included in original figure.

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].

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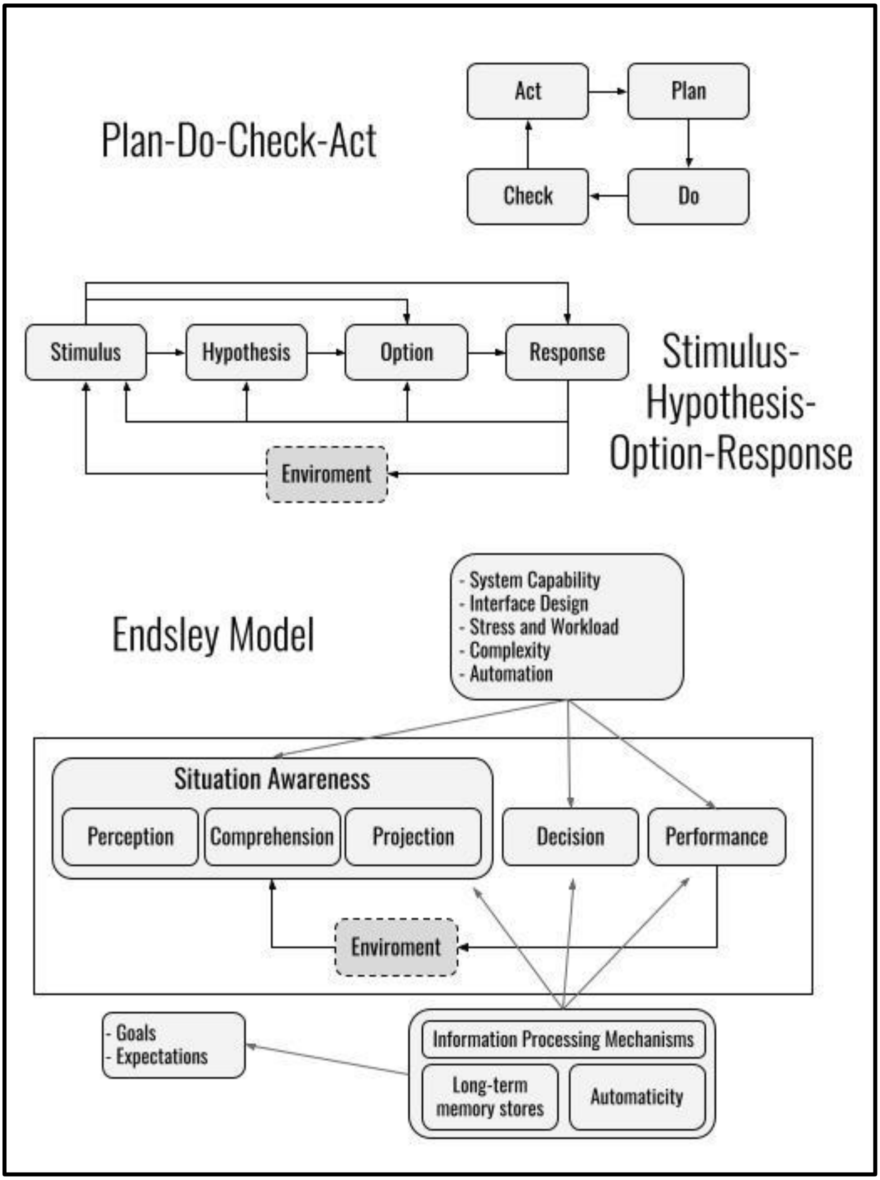

Figure 2. Various Decision-Making Models. Plan-Do-Check-Act Model from [43], Stimulus-Hypothesis-Option-Response from [44], Endsley Model from [45].

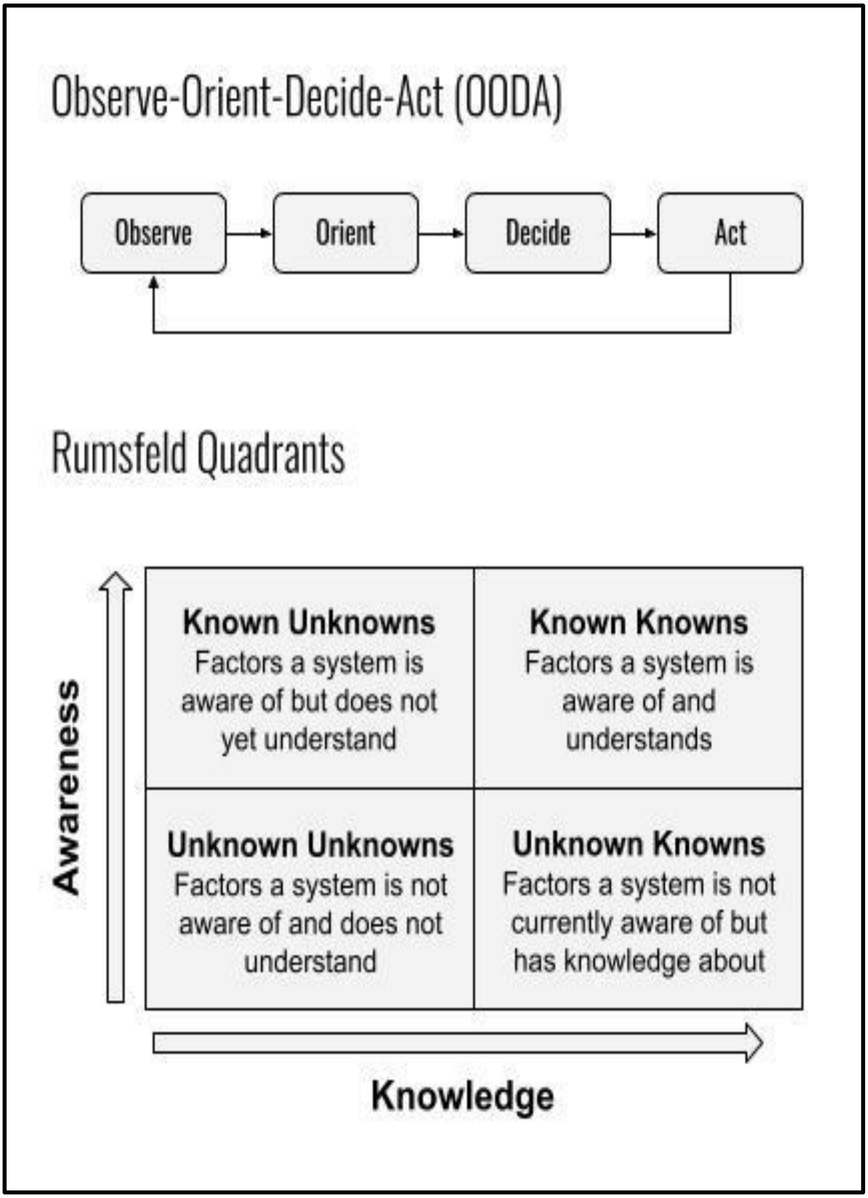

Figure 3. OODA and Rumsfeld Quadrants.

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.

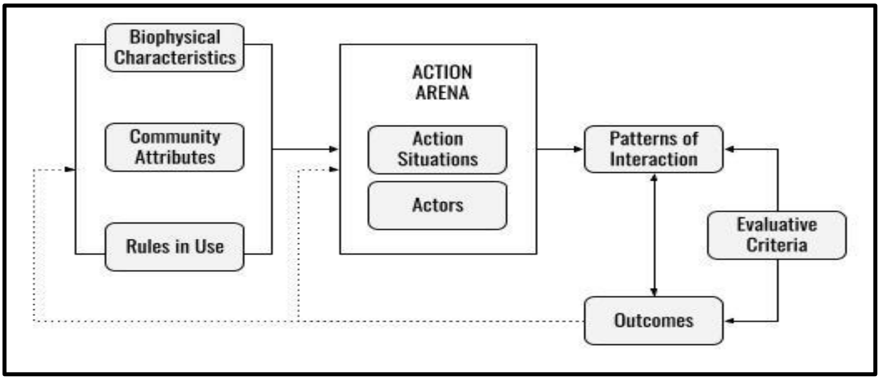

Figure 4. Institutional Analysis and Development Framework, modified from [79]. Biophysical characteristics refer to ideas, artifacts, and facilities, the relevant factors which relate to the physical or quasi-physical affordances, boundaries, capacities, and limitations of a particular commons. The 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).

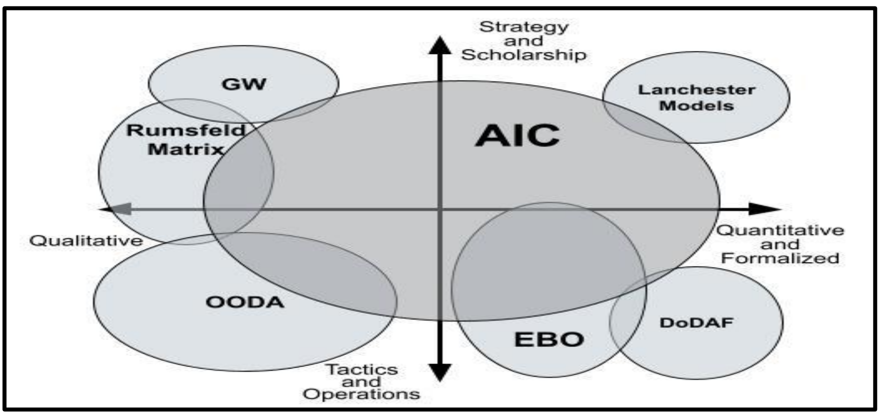

Figure 5. Scope of Active Inference Conflict (AIC) model along the dimensions of qualitative to quantitative (X-axis) and tactical to strategic scale (Y-axis). From the top-right and going clockwise: Lanchester models, DoDAF (Department of Defense Architecture Framework), EBO (Effects Based Operations), 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) and their usage in AIC (right 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.

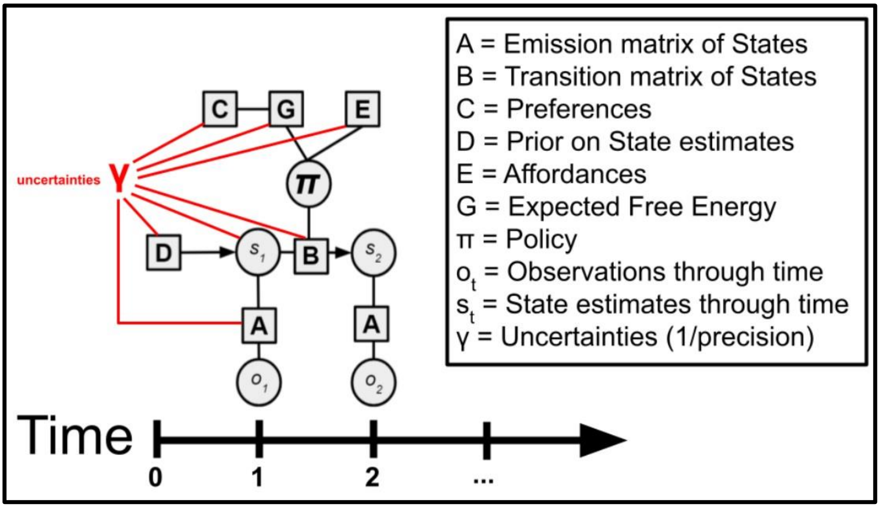

Figure 6. Partially Observable Markov Decision Process (POMDP) model of an ActInf entity.

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 (ot) 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].

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].

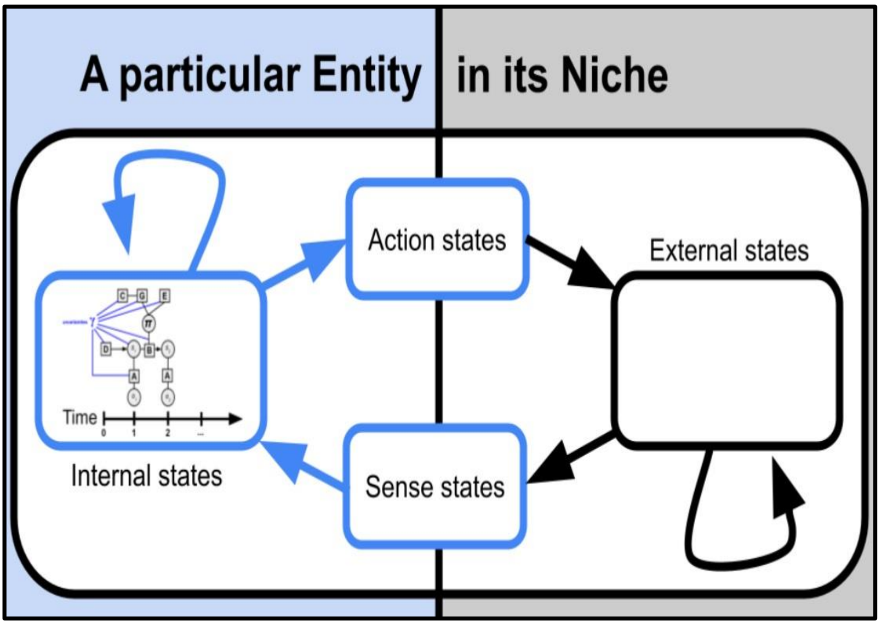

Figure 7. ActInf entity interfacing with external states. At right, external states are influenced by entity action states, and also external states may have endogenous dynamics. External states pass observations to internal states via entity sense states. Uncertainty in the flow of incoming sensory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

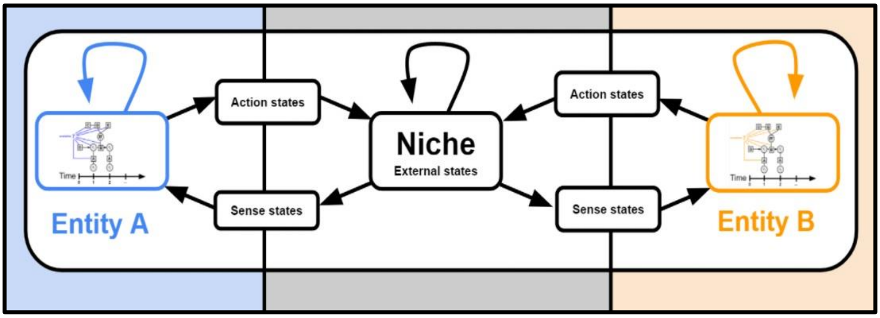

Figure 8. Two ActInf entities A and B, interacting via a shared niche (ecological, informational, or otherwise). The generative process of the niche is influenced by endogenous dynamics as well as actions from both entities.

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.

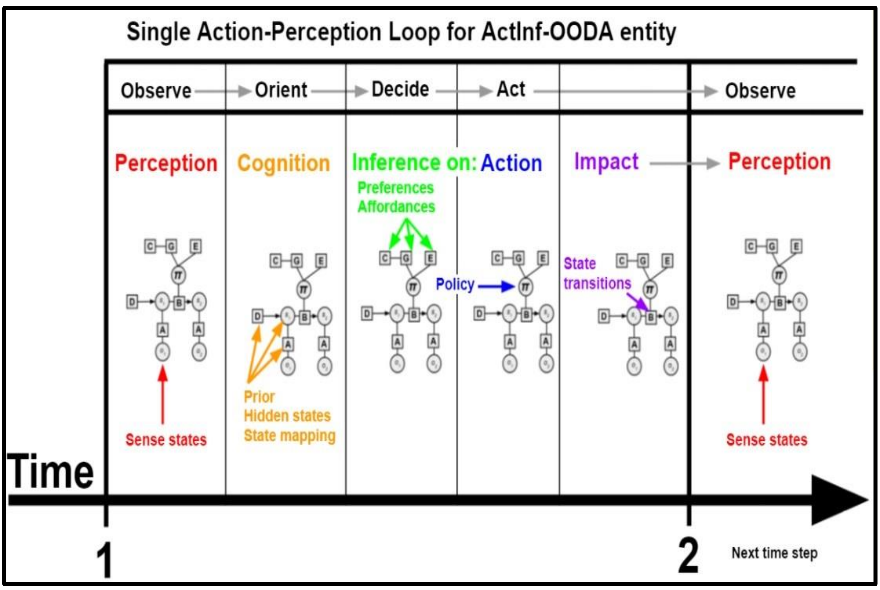

Figure 9. Comparison of Action-Perception loops for ActInf and OODA entities

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.

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 systems. We distill these insights in order to offer recommendations 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:

Recommendations

- 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: Richard J. Cordes

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Chapter I
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Chapter II
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Chapter III
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Appendices

Appendix A
Narrative Information Management Project Catechism

Milestones and Administration, Logistics, and Communications Sections redacted. Contact information and links redacted.

Project Callsign: NIM21
Facilitator: R.J. Cordes
Date of Announcement: 03/22/2021
Call for Collaboration Ends: 04/2/2021
Intended Date of Completion: 09/09/21 - 09/15/2021

Completed: 09/24/2021
Link to Finished Product: https://zenodo.org/record/5573287

Situation

What is the nature of the situation or problem the team is being formed to address? Are there known causes? Is the situation novel? If so, if there are traditional methods which would normally be used to address similar situations or problems, what are their limitations and why are they inadequate? What will happen if this situation is not addressed?

When the brain cannot reduce the complexity of the environment, it reduces the complexity of the strategy used to make sense of it [1–6]. This difficulty in reducing the complexity of a given information environment is often referred to as either data overload [7,8], information overload [5,8,9], reference overload [3], or, more broadly, as cognitive overload [2,10,11]. When an individual is exposed to potentially relevant, contradicting information at a rate inconsistent with the time and effort required to integrate and does not have access to appropriate tools, a trusted network of experts, or domain-specific training, they may withdraw from their role in the environment or experience anxiety and reduction in ability to manage stress, set priorities, make decisions, and detect logical inconsistency. To circumvent the stress of cognitive overload, the brain relies on heuristic approaches such as:

- compressing and filtering with an inappropriate emphasis on and abstraction of threat detection, resulting in paranoia and vulnerability to conspiracy theories [4,7]
- maintaining continuous partial attention, preventing integration of information and maintenance of focus, [3]
- or compressing and filtering on a basis of narrative identity, resulting in tribalism and vulnerability to extremist ideology and cults of personality. [4,7,12–16]

At best, these strategies create the potential for redundant analysis, wasted time, reduced work performance, "role withdrawal", or apathy. At worst, they contribute to a reduction in cognitive security: creating a false-sense of knowing, vulnerability to information warfare and social engineering--contributing to a free-fall in the institutional trust required to maintain social cohesion, and increasing the potential for failure in high-reliability domains such as cybersecurity, infrastructure and power management, military operations, health care, law enforcement, counterterrorism, and air-traffic control.

Data fusion, knowledge management, C4 (command, control, communications, and computer), and SCADA (Supervisory control and data acquisition) systems are often used to assist in the prevention of cognitive overload, maintenance of cognitive security, and maintenance of situational awareness, by facilitating reduction of information complexity, production of estimative and actionable intelligence, and navigation of users toward action [17–21]. As the volume and structural complexity of the information increases, information systems in this category shift from just a facilitating role to an enabling one and the usefulness of a given system becomes notably more tied to its efficiency in helping users meaningfully aggregate data, develop understanding, and navigate toward action as opposed to simply being tied to the provision and access of information [4,17,22–24]. Contemporary information systems still face challenges in meeting requirements when faced with large amounts of information [24].

Nearly 60 zettabytes (60 trillion gigabytes) of data were created in 2020 and the expectation is that the amount of digital data created between 2021 and 2025 will greatly exceed the amount created since the advent of digital storage [25,26]. Further, even small amounts of data can overwhelm analysts if they require specialized analysis or are structurally complex. For example, with over 7,000 peer-reviewed scientific and engineering articles and countless preprints, datasets, and other relevant materials being published each day, academics and researchers are prone to a state of information overload without the presence of big data dilemmas [27–30]. To both take advantage of opportunities and reduce potential for failure in contending with complex threat surfaces in this information-rich environment, the challenges faced by contemporary intelligence-oriented information systems will need to be addressed [12,24].

Some fields have addressed various aspects of challenges to facilitating sensemaking in information-rich environments (e.g. cybersecurity, logistics analysis, food security analysis), but methods discovered may be siloed and, consequently, may not be discoverable by others or have not yet been generalized to solve problems in other fields. Given that (a) the knowledge management requirements of many domains can be reduced to the facilitating or enabling of:

- Reduction of information complexity
- Production of estimative and actionable intelligence
- Navigation of users toward action

and that (b) the underlying intent of all of these requirements is to allow users to rapidly develop a plausible, explanatory, predictive story about some given system, then there is potential for the challenges to be framed and solutions to be generalized under the umbrella of "narrative information management", which is concerned with how we interpret, develop, compress, store, and present information related to narrative content.

Mission

Given the situation, what are the team's explicit objectives?

To generalize data fusion, knowledge management, C4, and SCADA system requirements, practices, and challenges under the concept of "Narrative Information Management" (NIM) in order to develop and present research and development recommendations for the next generation of these systems.

Current Avenue of Approach

Given the situation and mission, what are the potential or current avenues of approach? For each potential or for the current approach: What tools, techniques, or expertise, alone or in combination, would be required or provide opportunities? What are the risks? What are the potential limitations?

The current approach is to write a paper via asynchronous, remote collaboration with multiple contributors, each representing various NIM challenge spaces, including but not limited to:

- Cybersecurity
- Logistics analytics
- Food Security
- Power and Infrastructure Vulnerability Monitoring
- Intelligence Analysis
- Law Enforcement

- Human Trafficking
- Multi-sensor Fusion Systems
- Genomics
- Astronomy
- Finance
- Law

Each section will discuss the information load and relevant sensemaking challenges, designed, emergent/ad hoc, and borrowed solutions to these challenges, and potential future challenges of its respective space.

In order to circumvent difficulties which often arise when more than 3 individuals engage in synchronous collaboration on shared sections, the paper will be written using a "partition" approach and each partition will be expected to follow the section guide found here: [redacted]

Implications of Outcome

If all or some milestones were achieved what does the success mean to stakeholders, the situation, and to team members? What else might be affected? What work will come next?

Generalizing the problem and solution space under a single domain would allow large communities of researchers which are currently siloed in their respective technology spaces to begin sharing information and collaborating on common frameworks.

Appendix B
Digital Rhetorical Ecosystem Analysis Project Catechism

Milestones and Administration, Logistics, and Communications Sections redacted. Contact information and links redacted.

Project Callsign: ECOMEME
Facilitator: Daniel Friedman
Date of Announcement: 02/12/2021
Intended Date of Completion: *Mid 2021*

Completed: 10/16/2021
Link to Finished Product: https://zenodo.org/record/5573947

Situation

What is the nature of the situation or problem the team is being formed to address? Are there known causes? Is the situation novel? If so, if there are traditional methods which would normally be used to address similar situations or problems, what are their limitations and why are they inadequate? What will happen if this situation is not addressed?

Much of the narratives present online are being exchanged and co-constructed through image-macro "memes", as well as memes that cross single media formats (text in image, words in audio). These memes communicate narrative that is currently very difficult to rigorously model, leading to operational uncertainty in areas where memes and narratives can have influence (everywhere). Recent events, such as the 2020 Election and the Reddit-GameStop event evidence both the impact memes can have, as well as the need for monitoring and predictive analytics of distributed meme ecosystems.

Images memes exist at the intersection of several kinds of systems: Narrative, Informational, and Socio-technological. Recent research has also considered image memes from the perspective of Rhetoric ("Memes as Quasi-Argument", M. Mascarenhas) and evolutionary ecology ("Memes and the Ecological Niche", Hardisty & Cassill 2015).

In the modern operating environment, various kinds of teams and organizations have a need for realtime, flexible, scalable analysis of heterogeneous memetic data (text, audio, video, and image). What is needed for this kind of tool to exist, is the integration of deep metaphors (ecology), qualitative frameworks (rhetoric), and modern computational affordances (e.g. automated annotation of symbols or narrative).

In this EcoMeme project, we specifically bridge the areas of ecology and rhetoric, with an eye toward incorporation into future meme systems that are powerful and also center the individual human.

Mission

Given the situation, what are the team's explicit objectives?

To provide a rhetorical and ecological grounding for the development of future integrated systems involved in analytic and operational capabilities of the cyber information environment (affordances in the niche).

Potential Avenues of Approach

Given the situation and mission, what are the potential avenues of approach? For each potential approach: What tools, techniques, or expertise, alone or in combination, may provide opportunities for an approach to the situation? What are the risks? What are the potential limitations?

Write a paper (for preprint &/or submission to journal/conference, also for inclusion in COGSEC 2021 book) which:

- Considers Rhetoric (devices, technique, quasi-argument & narratives) to memes as a key basis for meme classification
- Uses ecological and evolutionary metaphors (and Complexity as a guiding approach) to frame the rhetorical & computational dimensions of SCADA/KMS.
- Considers the requirements of knowledge management and supervisory control and data acquisition systems (KMS and SCADA), to frame the requirements of a MEME SCADA/KMS and the standards and classifications of Meme-data in order to construct such a system (e.g. metadata standards and classifications required to make it operational)
- Provides agenda-setting and actionable recommendations that take into stock the narrative-rhetorical landscape (Part 1) and potentially productive path of taking ecological modeling seriously (Part 2) given the specifications of a MEME SCADA/KMS (Part 3).

Implications of Outcome

If all or some milestones were achieved what does the success mean to stakeholders, the situation, and to team members? What else might be affected? What work will come next?

Providing a foundation built on ecological, evolutionary, and rhetorical metaphor could have profound impact on future research on knowledge management, OSINT, and SCADA methodology and on complementary methodology for predictive, monitoring, and argument-mining analytics by making the cyber information environment more observable and machine-readable.

By incorporating biological and rhetorical considerations into the early design stages of such systems, we can retain a user- and human-centric understanding of how we use & modify meme ecosystems (just as the case is with landscape ecosystems).

Appendix C
Knowledge Management Archipelago Project Catechism

Contact information and links redacted.

Project Callsign: KMA
Facilitator: R.J. Cordes
Date of Announcement: 06/14/2021
Intended Date of Completion: 06/25/2021

Completed: 06/25/2021
Link to Finished Product: https://zenodo.org/record/5034809

Situation

What is the nature of the situation or problem the team is being formed to address? Are there known causes? Is the situation novel? If so, if there are traditional methods which would normally be used to address similar situations or problems, what are their limitations and why are they inadequate? What will happen if this situation is not addressed?

Knowledge Management, C2, SCADA, and Data/Information Fusion Systems research appeared to be siloed, but there was no clear citable reference or non-anecdotal evidence for this being the case. Light bibliometric analysis was performed and now needs to be developed into a short article for citation in NIM21, an ongoing project which would otherwise require an additional section to demonstrate evidence of this claim.

Mission

Given the situation, what are the team's explicit objectives?

To write a short article describing the fractured state of knowledge transfer between knowledge management and adjacent disciplines.

Avenue of Approach

Given the situation and mission, what are the potential or current avenues of approach? For each potential or for the current approach: What tools, techniques, or expertise, alone or in combination, would be required or provide opportunities? What are the risks? What are the potential limitations?

Sprint-based, classic-dyad writing collab.

Appendix D
Active Inference in Modeling Conflict
Project Catechism

Milestones and Administration, Logistics, and Communications Sections redacted. Contact information and links redacted.

Project Callsign: AIC-21
Facilitator: R.J. Cordes
Date of Announcement: 8/12/2021
Intended Date of Completion: 11/01/2021

Completed: 12/02/2021
Link to Finished Product: https://zenodo.org/record/5759807

Situation

What is the nature of the situation or problem the team is being formed to address? Are there known causes? Is the situation novel? If so, if there are traditional methods which would normally be used to address similar situations or problems, what are their limitations and why are they inadequate? What will happen if this situation is not addressed?

The "generations of warfare" (GW) highlights and simplifies certain features of aggression among groups, for example the usage of different physical tactics in the interest of helping military leaders set or rethink priorities [1,2]. However, the GW model may not be applicable for modeling various forms of modern threats (and vulnerabilities) and may oversimplify. First, the use of the term "generations" implies a chronological relationship that does not hold, and even where such generational classifications can be found they may not be actionable [3]. Second, "warfare" may no longer be the most appropriate term for the conflicts and threat surfaces most relevant to modern nations.

While multiple frameworks for understanding GW exist and have been described recently [4], they may fail to properly describe or even account for an increasing variety of conflict settings that are a result of the ongoing exponential increase in interactions and interaction types. Clausewitz called war "the continuation of politics by other means." The vast range of interactions and relationships that constitute the modern "nation state" creates a setting in which conflict has become bureaucratized into "the continuation of policy by other means" (with apologies to Clausewitz). The result is a vast and increasing "gray zone" of interaction conflicts, such as those concerning civilian supply chains, hostile and strategic trade and legal practices, media manipulation, biological warfare, election interference, and proxy warfare. The metrics for identifying and evaluating threats and vulnerabilities associated with these "gray zone" conflicts are insufficiently developed, and in particular have yet to be fully realized at the national security level.

Recent and ongoing changes to the operating environment include globalization and an explosion in interaction volume and consequent information complexity. The resulting complexity creates structural hurdles to individual and institutional situational awareness, and the lack of awareness can itself be perceived as threat and vulnerability. In this regard, it might be said that complexity itself is a common enemy. What might be done among adverse parties in a conflict to mitigate the aggravating effects of the veil of opacity resulting from collective inability to discern reliably and predictably encoded signals from complex interactions. Among the potential approaches is the potential for a syntheses of intelligences (SI) among the components of the system in a manner that avoids avoidable harms. In those contexts, risks can potentially be mitigated in ways that no one party can achieve unilaterally, which helps to recruit participation without resort to beneficence. THis is helpful in the context of mitigating information harms in conflict settings, where the parties are not predisposed to cooperate, but will seek to enhance their own risk mitigation. Non-zero sum settings arise when a single structure can simultaneously de-risk a set of interactions for a set of parties with adverse interests and in conflict.

While many conflicts reflect existential differences among actors, a significant portion can be attributed to lack of shared information which itself is the result of a lack of shared meaning. One party might simply not know some important things that are known to another party – things that might dissipate differences if they were known to both parties. Consider, for example, how the prisoners in the classic "prisoner's dilemma" setting would act if they had the same information as the guards.

How can a party know that they are in possession of all relevant information and meaning known to others? It's possible that the creation of a newer model encompassing conflict may reveal and communicate the need for a new prioritization on "unknown knowns", the need to strengthen Cognitive Security, and to improve the resilience of complex multiscale systems (e.g. teams of teams involved in cyber physical operations).

Mission

Given the situation, what are the team's explicit objectives?

To produce a new, easily communicated, and easily adoptable model of conflict that describes and encompasses both abstract and kinetic conflicts.

Potential Avenues of Approach

Given the situation and mission, what are the potential or current avenues of approach? For each potential or for the current approach: What tools, techniques, or expertise, alone or in combination, would be required or provide opportunities? What are the risks? What are the potential limitations?

We will produce a new model drawing on active inference and "defensive curiosity".

In the interest of facilitating understanding and adoption, this model should be able to incorporate aspects of the generations of warfare model as well as the often repeated "Rumsfeld quadrants."

We will write a paper which will:

- Show & Describe why there is a need for a new model of conflict.
    - We will open this paper with a story about the differences between behavioral research in the US and USSR (indicating that conflict is the default).
- Communicate and define a new Active Inference-driven model of conflict
- Show examples of its successful application to situations other models were used for (1st/2nd generation warfare),
- Show examples of its successful application to situations where other models have failed (conflict over law, trade, cyber, etc.)
    - Success in applications of the AIC model would be defined as leading to demonstrated increased explanatory, descriptive, predictive, power of models and/or increased clarity/ efficacy/ scope/parsimony/generalizability.

- Discuss the first valuable outputs of the use of this particular model;
    - how it communicates the need to focus our prioritization on the unstated quadrant of a 4 square based on charting Donald Rumsfeld's characterization of knowns and unknowns, namely the unstated unknown knowns quadrant
    - how it communicates de-risking as a process, not a state to achieve
    - Exploring how addressing the Unknown-Known quadrant offers pathways to "Trust" and reduced conflict by expanding mutual situational awareness.

Implications of Outcome

If all or some milestones were achieved what does the success mean to stakeholders, the situation, and to team members? What else might be affected? What work will come next?

A model and a preprint document could be utilized as an opening statement when reaching out to potential funders and collaborators. It could function similarly to a policy paper, as a document which can help stakeholders in the military-academic and military-research spaces understand our interests and work through a lens they're familiar with.