Narrative Information Management

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A B S T R A C T

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.

Contents

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].

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 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 [244]

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 offer the following recommendations for continuing work on NIM:

- 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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