More Than Data Stories: Broadening the Role of Visualization in Contemporary Journalism

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(Survey Paper)

***Abstract*—Data visualization and journalism are deeply connected. From early infographics to recent data-driven storytelling, visualization has become an integrated part of contemporary journalism, primarily as a communication artifact to inform the general public. Data journalism, harnessing the power of data visualization, has emerged as a bridge between the growing volume of data and our society. Visualization research that centers around data storytelling has sought to understand and facilitate such journalistic endeavors. However, a recent metamorphosis in journalism has brought broader challenges and opportunities that extend beyond mere communication of data. We present this article to enhance our understanding of such transformations and thus broaden visualization research's scope and practical contribution to this evolving field. We first survey recent significant shifts, emerging challenges, and computational practices in journalism. We then summarize six roles of computing in journalism and their implications. Based on these implications, we provide propositions for visualization research concerning each role. Ultimately, by mapping the roles and propositions onto a proposed ecological model and contextualizing existing visualization research, we surface seven general topics and a series of research agendas that can guide future visualization research at this intersection.**

***Index Terms*—Journalism, data visualization, computational journalism, data-driven storytelling.**

I. Introduction

DATA interacts with journalism in many ways. One of the most important ways is the communication of data, frequently performed through charts and visualizations. Newspapers were among the first media to bring infographics to the public's attention, with well-known examples like USA Today's Snapshots, which often employed embellished and straightforward graphics [1]. More recently, enhanced web-based interactive visualization technologies, notably D3.js [2], have given rise to new forms to communicate data stories. Mainstream news platforms like The Guardian, The New York Times, and The Washington Post were early adopters and trailblazers of such Web-based interactive and dynamic visual communication. Following them, a new generation of websites, such as FiveThirtyEight and the Pudding, has emerged in the midst of this wave, progressively gaining attention from broader audiences.

While data journalism exhibits promise, conventional journalism has been facing increasing challenges and turbulence [3], [4]. The story depicted in HBO's series *The Newsroom* about how a cable news network fights new business models, arising citizen journalism, and online journalism to preserve their editorial autonomy and journalistic integrity is fictitious — and some see it as an elitist presentation of journalism — but the diverse threats faced by journalism and its sweeping transformation are reflective of reality. Over the past decades, journalism has undergone various changes driven by multiple social and technological forces, particularly the digitalization of the media environment.

Journalism has long been our primary source of information, a channel that connects us to the world outside our tangible surroundings, a social glue that binds people together in our "imagined community" [5], [6]. In many countries, it is closely tied to democracy and a "watchdog" role — to scrutinize powerful institutions, be they governments or companies [7]. Journalism's historical importance is undeniable, as illustrated by Pulitzer's famous remark — *"Our Republic and its press will rise or fall together"* and Burke's reference to it as *"Fourth Estate"*.

However, contemporary journalism has experienced a crisis in perceived importance and credibility, as manifested by the decline in its overall financial health and audience trust [8], [9], [10], [11]. Online journalism and citizen journalism, both spawned by digital technologies, have been assigned blame due to emphasizing speed and undermining journalism's professional boundaries and its conventional pursuit of objectivity. These are not the lone challenges — our increasingly complicated world and the explosive growth of information transform journalists' role into a more challenging one — a filter, a transmitter, an organizer, an interpreter, and a fact-deliverer [12]. Technology has also brought opportunities — hypermedia/multimedia content that provides better context, interactivity that allows more agency of audiences and potentially sparks engagement, and platforms that enable ordinary people to participate in civic dialogues. Journalists have turned to computational technologies to counter their role transformation. The early adoption of computer-assisted reporting leveraging social

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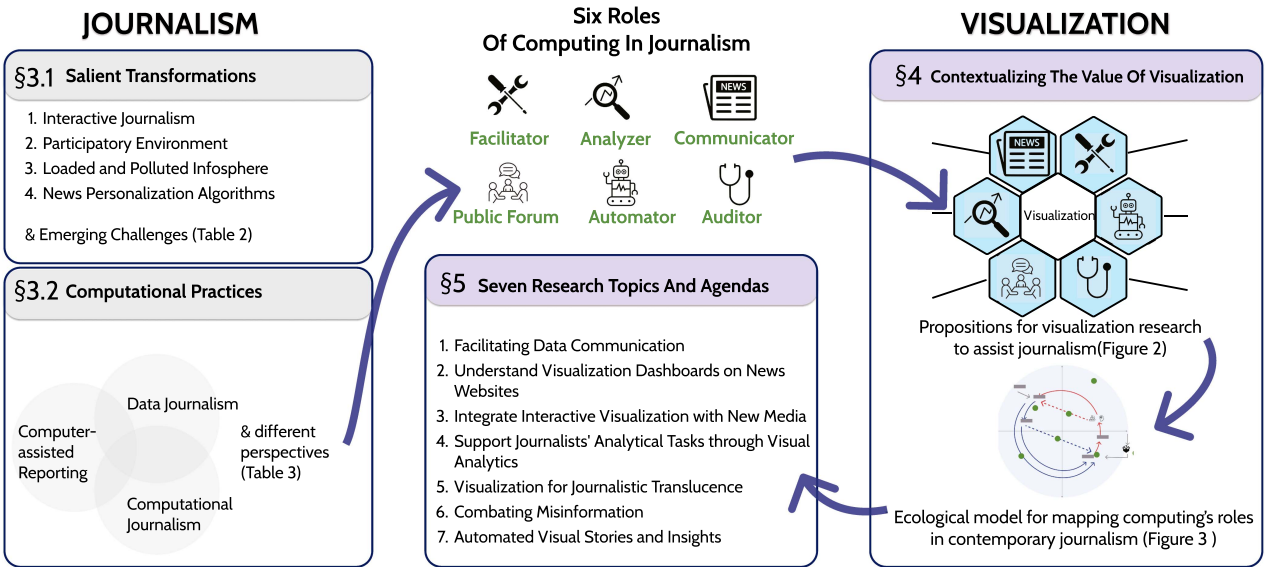

Fig. 1. An overview of the paper structure and contributions.

science statistics won investigative journalists multiple Pulitzer prizes. Data journalism featuring data-driven storytelling and interactive visualization dashboards has recently garnered mainstream attention and played a vital role in combating the pandemic and informing the public [13].

Using data to tell stories has drawn significant attention from the visualization research community [14], [15], [16], with influential researchers advocating for its importance [17], [18]. Data storytelling has likely become the most prominent topic at the Journalism-Visualization intersection, and rightfully so. However, existing visualization research centering around data storytelling (e.g., [16]) tends to focus on data journalists/platforms and their audiences, i.e., those who are already comfortable with data communication. We consequently lack a comprehensive understanding of other journalists and audiences with limited data infrastructure, skills, experience or literacy. Furthermore, data-driven storytelling emphasizes the communicative role of visualization, whereas journalists' tasks extend beyond mere communication. In addition, the traditional perspective regarding news organizations as fixed institutions does not adequately consider today's increasingly dynamic and participatory information environment.

We believe it is an appropriate time to review the state of contemporary journalism and explore how data visualization research can contribute to the discipline's growth and evolution. In particular, we ask:

- In light of the recent shifts in the information landscape and journalistic metamorphosis, what new visualization research opportunities could emerge at this intersection?
- How could visualization research contextualize its work to address broader challenges in journalism?

To answer these questions, we conducted an exploratory scoping review [19], [20] of literature from both journalism study and visualization research. In doing so, we aim to shed light upon contemporary journalistic contexts and challenges faced by broader journalists (e.g., public/independent journalists) and their audiences, the roles played by computational technologies in addressing such challenges, and the unique value that data visualization can contribute to these roles. Our goal is to provide an updated and holistic perspective on how visualization research could aid journalism. This review consists of three major parts, with each denoting a facet of our contribution, as shown in Fig. 1:

C1: In Section III, we distill a set of important changes in journalism driven by digital technologies, along with journalism's computational turn in response to emerging challenges. We summarize six roles of computational technology in contemporary journalism and explain the rationale behind and implications for computing intervention.

C2: In Section IV, we review discourse on the value of visualization and contextualize these values in journalism. Building off these discussions on visualization values, we offer propositions (Fig. 2) concerning each of the six roles and map them onto an ecological model (Fig. 3) to further contextualize them.

C3: In Section V, based on our propositions, we surface seven general topics and multiple subtopics to encompass future Journalism-Visualization interdisciplinary research. For each subtopic, we synthesize existing visualization research, contextualize the work in journalism, and identify future research agendas.

II. Methodology

A. Review Methodology

Due to the complex and heterogeneous nature of the two fields and the variety of topics to be covered, we did not choose a systematic review or a traditional survey. Instead, our method resembles a scoping review, a relatively new, but increasingly popular approach for synthesizing research evidence [19]. HCI researchers have recently adopted scoping reviews on different occasions [21], [22]. Such a review aims to *"map rapidly the key concepts underpinning a research*

area and the main sources and types of evidence available" and is commonly used to understand the range and nature of research activity, determine the value of a full systematic review study, summarize and disseminate research findings, and identify research gaps in the existing literature and aid formulating future research agendas [23]. Compared to a traditional systematic review, a scoping review tends to address broader topics instead of seeking answers to specific research questions. According to CIHR's *Guide to Knowledge Synthesis*, scoping reviews *"often do not undertake a detailed appraisal of identified evidence sources and detailed synthesis of the results of the studies"* [20].

We used Google Scholar as our primary search platform since the literature we need to review spreads across two fields and their sub-domains. Our review was an iterative process, and we progressively expanded and revised our search term pool during the process. We began by searching for literature that discusses journalism more comprehensively, focusing on the changes and challenges brought about by technological developments. Therefore, we started with broader terms such as "journalism studies", "journalism + new media". Since these terms often led to vast and homogeneous literature, we tended to follow highly cited work. In journalism, these are often books that cover various topics. We skimmed through the books and reviewed the chapters and content that we deemed relevant – for example, we included *Journalism, Trust, and Credibility* and excluded *Journalism Education* from *The Handbook of Journalism Studies* [24]. We distilled themes (e.g., participatory journalism, interactive journalism, news personalization, journalistic routine, journalism and trust, etc.) from our initial review phase, and used these themes for our second-round search. Our third round search focused on the computational exploration in journalism; our search terms include area-based ones like "computer-assisted reporting", "precision journalism", "data (-driven) journalism", "computational journalism", and topic-based ones, like "automated journalism", "algorithmic accountability + journalism", "misinformation", "fact-checking in journalism", and so on. We also expanded our pool by following leading researchers in the respective areas (e.g., Meyer, Diakopoulos, Lewis) and using snowballing procedures [25]. This literature is mostly peer-reviewed articles. As for the InfoVis literature, we expanded our literature pool by searching matching visualization keywords (e.g., "augmenting video + visualization") and from our personal collections. We also searched the ACM digital library and the IEEE Xplore library. The literature we reviewed across these two fields and multiple topics included 187 documents. Table I shows the distributions of publication venues of literature from both fields. We submit the list as supplementary materials, available online.

TABLE I
LITERATURE VENUES

Publication Venue	Count	Publication Venue	Count
IEEE TVCG	37	Digital Journalism	11
ACM CHI	16	Journalism Practice	4
ACM UIST	4	New Media & Society	3
IEEE CGA	4	Journalism	2
ACM BELIV	4	Journalism Studies	2
Others	28	Others	72
Total	**93**	**Total**	**94**
(a) Visualization Literature		(b) Journalism Literature	

B. Reflexivity

This study is based on existing work that spreads across different topics in these two large fields. While we strove to be unbiased during the process, our experiences unavoidably affected how we screened, organized, and presented the work we reviewed. The first author has multiple years of experience as a professional/independent journalist and is now a visualization researcher. The second author is a seasoned visualization researcher. Our experiences in these two fields lend us a unique yet balanced perspective on the challenges and opportunities faced by broader journalists and audiences, as well as the value visualization can provide. While we present a series of potential technological solutions, we do not endorse a technological determinism/solutionism perspective. Rather, we believe visualization technology simply offers another option that has its unique merits and shortcomings — their impact on public communication awaits further investigation. We would also point out a limitation of our study — the journalism literature we reviewed is primarily about journalism in the Western world, but journalism in other countries may have distinctly different roles and characteristics.

III. Journalism's Digital Metamorphosis and Computational Turn

Since entering the digital age, journalism has undergone a continuous metamorphosis. A new form of journalism featuring ubiquitous news, global information access, instantaneous reporting, interactivity, multimedia content, and customized content has arisen [9], [26], followed by social media, offering the promise of the *"biggest audience reach"* and a *"perfect public sphere where everyone can have a voice"* [27]. Such a metamorphosis pervades and affects many aspects associated with journalism.

In this section, we first highlight four salient transformations driven by more general developments in technology and discuss the challenges accompanying them. Next, drawing from digital journalism and computational journalism literature, we introduce how journalism practitioners and scholars have proactively pursued computing technologies to aid journalism and their different perspectives. Ultimately, by synthesizing such shifts, we summarize six roles that computational technologies play in contemporary journalism, along with the rationales and implications.

A. Salient Transformations in Digital Era

Recent shifts in journalism span multiple dimensions, ranging from the nature of news content to news dissemination, from internal organizational structures to external information environments. Specifically, we highlight these four salient transformations:

TABLE II
RELEVANT JOURNALISTIC TRANSFORMATIONS AND THE EMERGING CHALLENGES

Transformations	Challenges
(T1) Interactive Journalism	**C1.1**: creating interactive content requires different skills than those typically acquired by traditional journalists, notably programming skills [30] **C1.2**: audiences may be unaware of or less motivated to exploit rich interactivity [29]
(T2) Participatory Journalism and Communication Environment	**C2.1**: it weakens journalism's occupation boundary and roles [31], upsets its previous institutional power on gatekeeping [4], [32], [33], and diminishes its traditional authoritative voice [30] **C2.2**: it lowers the threshold for producing and distributing news and potentially enables an influx of misinformation or even hate speech[34] **C2.3**: it is challenging to enable more coherent, elevated online discussion [35]
(T3) A Loaded and Polluted Infosphere	**C3.1**: it creates a polluted public sphere where information is often met with skepticism [10] **C3.2**: it places a *"heavy mental burden"* on the audience to distinguish trustworthy information from a sea of misinformation [10]
(T4) News Personalization	**C4**: inadequate awareness of such filtering and prioritization could exacerbate the "filter bubble" phenomenon or algorithmic biases [36], [37], [38]

Enriched Media Content: The transformation in news content should not be alien to most audiences. New capabilities such as interactivity, on-demand access, user control, and personalization coupled with enriched and hyperlinked multimedia have driven digital journalistic content to be more contextualized, navigatable, and interactive [9], [28], [29]. Amidst such changes, one relevant instance we highlight is *interactive journalism* — multilayered visual storytelling that engages users in interaction to unfold the narratives [30]. Such interactive features not only have the potential to help journalists establish authority through enhanced visuals and sophisticated data [30], but also provide enjoyment that can re-engage audiences [29], [30] and expand ways of thinking about journalism [30].

Participatory Environment: The Internet, digital media technologies, and social media create the conditions for people formerly known as "the audience" to enter journalism by enabling them to gather, create, and distribute information in a much easier and more effective manner [6], [27], giving birth to *participatory journalism*, or citizen journalism. While participatory journalism promises to engage and connect people [39] and provides a more inclusive public communication environment that encourages citizens to play an active role [40], [41], it nevertheless weakens the occupation boundary and roles [31], upsets journalism's previous institutional power on gatekeeping [4], [32], [33], and diminishes traditional journalism's authoritative voice [30]. The public's competence to participate in journalistic production and civic affairs, however, varies widely [42], as do their interests in doing so. Technological advances have also facilitated other participatory activities, such as quizzing (e.g., polls, questionnaires), voicing one's own opinion, and commenting [42]. News consumers have welcomed and grown accustomed to a *more symmetrical communication mode* [42], [43], changing the traditional journalist-audience relationship from a one-way, asymmetrical communication model to a two-way dialogue [42], [44].

A Loaded and Polluted Infosphere: A more complex world and an explosive growth of data have significantly complicated journalists' roles [45]. Further, the lowered threshold has let in a flood of information, laced with a plethora of misinformation, conspiracy theories, and fake news — people constantly need to distinguish trustworthy information from them [45]. In addition, a more sensationalistic and politically biased coverage led by competitive business and a polarized political environment has further eroded audiences' trust in media [9], [10]. Collectively, these factors have molded *a loaded and polluted infosphere* where information is often met with skepticism [10], making journalism's role as information gatekeeper more important, yet increasingly challenging.

News Personalization: To counter the enormous volume and multiplicity of information that overwhelms audiences, tech companies like Google and Meta (Facebook) are spearheading efforts to deliver tailored news content using personalization algorithms fed by user data [37], [46], [47]. Personalization has grown popular among news publishers as well [48], worrying scholars as it could largely reduce serendipitous news discovery and exposure to alternative viewpoints [37], thus exacerbating the "echo chamber" phenomenon [36], [37], [38]. While other researchers have presented counter-evidence [49], [50] or advocated the positive impact of news personalization [48], its potential to regulate people's belief systems and social influence has attracted wide attention from researchers in different fields.

Apart from the aforementioned changes, generative AI systems (e.g., large language models) and their applications, with their rapidly evolving ability to perform tasks once within the purview of journalists, have started to exert a pervasive influence on journalism and our society as a whole. The ensuing transformation is unfolding before our eyes and carries great potential to revolutionize journalism anew. On the one hand, it is foreseeable that such AI applications (e.g., ChatGPT) will be capable of assisting journalists with many tasks, particularly text content generation. On the other hand, this generative AI could exacerbate information pollution by reducing the cost and time to produce misinformation/disinformation.

Regardless, further systematic investigation is needed to identify the emerging challenges and opportunities as well as the long-term effect generative AI technologies pose to journalism and the journalistic environment.

TABLE III
JOURNALISM'S COMPUTATIONAL PRACTICES AND THEIR PERSPECTIVES

Forms	Perspectives
Computer-assisted Reporting (CAR)	- associated closely with professional investigative reporting [51], [52], [53] - leverages scientific methods and statistics to enhance journalism's credibility [12], [51], [54] - harnesses the computer's power to manage data, conduct statistical analysis [12], [51]
Data Journalism	- places data as an information source [55] and a core in the journalistic workflow (curation, analysis, communication, etc.) [51], [52] - develops news applications that allow readers to access and explore data [55], [56], [57] - democratizes journalistic resources, tools, and methodologies [58] and invites non-journalists to participate in public data-driven analysis and communication [51], [58]
Computational Journalism	- leverages computer's processing capabilities to aggregate, automate, and abstract information [59], make sense of information, and free journalists from low-level work [60] - critically examines computation's influence on journalism practice, content, and reception [53], [61], with a focus on transparency and accountability of journalism's algorithms [62], [63]

B. Understanding Journalism's Computational Turn

Like many other fields, journalism has embarked on its own journey of computing innovations to accommodate its multifaceted shifts. According to Coddington's typology [51], its computational practices have occurred in different forms: computer-assisted reporting, data journalism, and computational journalism.

Computer-Assisted Reporting (CAR): With pioneers like Philip Meyer [12], [54], CAR marks the entry of computing into journalism. CAR journalists transitioned from mainframe machines to personal computers, from simply sorting numbers or searching for information to more sophisticated database management and statistical analysis. Particularly, CAR enriched the content and boosted the credibility of investigative journalism [51]. Combined with the emergence of the Web, CAR evolved into its second generation. On the one hand, more general journalists began to acquire basic computer-based skills and technologies for information gathering; on the other hand, those CAR pioneers embarked on more sophisticated tools for data gathering and statistical analysis. The latter form arguably evolves into the contemporary approaches: data journalism and computational journalism [51], [52].

Data Journalism: The relationship between data journalism and CAR also remains debated [64]. Bounegru [58] suggests two main differences between them. One lies in the role of data in news production — CAR stresses using data as a means to enhance reporting with a focus on journalistic tasks, while data journalism emphasizes data itself and its function within the whole journalistic workflow. Another difference lies more in the overall data environment — CAR took place when digital data was scarce, and journalists needed to actively seek information to answer their questions, whereas now, a vast amount of data has overwhelmed us, and making sense of it comes as a priority [58]. Data journalism has also delved into broader journalistic practices, while CAR is more rooted in investigative journalism [51]. Parasie and Dagiral suggest that data journalism challenges traditional CAR's epistemological model as it attempts to decentralize the construction of moral claims using data analysis and consider readers as *"legitimate and active contributors"* [65]. It echoes Holovaty's early calling for journalism to abandon "*the story-centric worldview*" and accept computer programming as a form of journalism [57].

Despite that scholars and practitioners championing its importance in today's society due to an array of benefits, including its capability to shift journalistic context, foster the development and application of news apps, and facilitate trustworthy journalism [55], [56], data journalism encountered its obstacles, evidenced by the shutdown of the *EveryBlock* due to its inability to engage audiences — *"pages of data weren't enough to engage the public on their own"* [55]. As Kovach and Rosenstiel [38] remark, *"Journalism must make the significant interesting and relevant"* and *"Engagement should be seen as being part of journalism's commitment to the citizenry"*, while traditional journalists rely on instinctive judgments and superior writing, data journalism starts to seek for solutions from information and HCI studies [66].

Computational Journalism: Computational journalism has emerged as an academic field to investigate how to advance news gathering and improve journalism workflow via computational technologies [67]. Hamilton and Turner define computational journalism as *"the combination of algorithms, data, and knowledge from the social sciences to supplement the accountability function of journalism"* [68]. Cohen et al. [69] prioritize computational tools that can boost journalistic accountability and bring positive social impact. Researchers in this field have proposed refined conceptions and focus: Diakopoulos suggests that computational journalism focus on the processing capabilities of computing, notably, the capabilities to aggregate, automate, and abstract information [59]; Flew et al. [60] underscore computational journalism's aim to facilitate sensemaking in journalism and its capability to free journalists from the low-level work (i.e., discovering/obtaining facts) as well as enhance user engagement and enable richer user interaction with news media. Thurman [53] notes that the scope of computational journalism has expanded over the years, with an emphasis on human-centric considerations and examining the use of technological artifacts and influence in journalism [70].

C. Roles for Computing in Journalism

Schudson lists six functions journalism has served, particularly in a democratic society: *informing* the public, *investigating* to keep power accountable, *analyzing* to help citizens comprehend a complicated world, *promoting social empathy* to allow other viewpoints to be appreciated, providing a *public forum* for dialogue among citizens, and *mobilizing* people to support certain programs [71], [72], [73]. Our previous discussions suggest that there are various angles for computing to support such functionalities and respond to the challenges we identified in Table II: technological advances to make certain tasks possible, HCI perspectives to accommodate the specific needs of journalists, information and communication perspectives to understand news/information experience and how information disseminates, and critical lens to examine technology's social impacts. Drawing on Abebe et al.'s discourse on roles for computing in social change [74], we summarize six roles that computing plays in journalism that go beyond the general use of technology (e.g., smartphones, search engines) and explain their respective emphases:

Communicator — Computer-enabled artifacts that communicate (i.e., engage/inform/affect) insights or narratives to audiences: Such artifacts underscore computing's contribution to enriching news content. They range from simpler multimedia news [44] to more sophisticated interactive content (e.g., data-driven stories) [30]. The latter are mostly products of interactive journalism or data journalism and inherit their characteristics and ethos. *Computing as Communicator* concerns the design of information products for the public that can better inform and engage them.

Facilitator — Tools that facilitate news production, including news gathering, filtering, fact-checking, and particularly, content authoring: In its broader sense, Facilitator could encompass computational applications that facilitate various responsibilities throughout the news production pipeline, from handwriting transcription [9], [68] to data wrangling (e.g., Google Refine) [69]. The rise of interactive content and enriched media types is challenging the longstanding supremacy of written text, compelling journalists to rely more heavily on technology to create computer-enabled content. Hence, we focus on a more specific interpretation of *Computing as Facilitator*, which attends to journalists' growing demands to create enriched journalistic products (e.g., narrative visualization) by facilitating the authoring process. Moreover, it is important not to disregard independent/citizen journalists, who are increasingly assuming an important authoring role.

Analyzer — Tools that assist in exploring and making sense of information, such as extracting salient information, deriving statistical characteristics, inferring trends, and constructing insights/narratives: While Analyzer can be considered a specialized type of Facilitator that assists in data analysis, we classify it as a separate category. Such tools have existed since the early days of CAR and have been adopted by data journalism and computational journalism in their respective ways. Computational journalism's perspective focuses on aiding journalists with analytical activities, such as combining information from various sources, extracting information, and exploring and mining documents [68], [69]. One specific example that Cohen et al. mentioned is to analyze and visualize the relationships among entities across a document collection [69]. Data journalism's perspective seeks to provide the public with analytical tools to interrogate data and develop their own interpretations. Well-known examples include data dashboards appearing on news websites. In this context, computing's role as *analyzer* can overlap and be blended with its role as *communicator*. *Computing as Analyzer* cares about helping both journalists and their audiences better analyze information and obtain insights and how to make analytical activities more engaging when facing the public.

Public Forum — Digital platforms and mechanisms for dialogue among the public and serving as a common vehicle for perspectives of different social groups: Kovach and Rosenstiel state that "*journalism has always been a forum for public discourse*" since its origin in the Greek marketplace, but today, this role is largely filled and failed by social media as they enable bad actors to "*distort, mislead, and overwhelm*" [38]. Allowing audiences to comment has been the primary practice for news organizations to fulfill this functionality in the digital era [35], [75]. But the emergence of participatory journalism and enriched content further complicates this functionality. For example, how could computing facilitate and elevate public discourse around a COVID data dashboard and drive data-driven conversations? Such emerging topics continue to await investigation. *Computing as Public Forum* focuses on news platform designs that adapt well to new media forms and enable more coherent and elevated public discussions.

Automator — Computational technology (e.g., algorithms) that automates journalistic tasks (e.g., news delivery, content creation): Automator includes personalization algorithms [37], [62], algorithms that auto-generate content/insights [76], [77], and algorithms that alert journalists/audiences about emerging events/news, etc. In particular, automated journalism that transforms structured data to publishable news stories using programs/algorithms has gained momentum recently, due to its potential to generate news content in scale and in a faster, less-biased, less error-prone manner [77]. News magnates such as the Associated Press have already been publishing automated news content [77], [78]. Furthermore, generative AI systems have certainly fueled the development of Automator applications. *Computing as Automator* offers an alternative news production paradigm by freeing journalists from tedious, often low-level tasks. Although it simultaneously brings complicated social and economic considerations.

Auditor — Technology that uncovers the effect of algorithms and audits news credibility and biases: As algorithms have infiltrated more facets of journalism, researchers in computational journalism started to advocate investigations of algorithmic accountability and transparency [62], [63], [79] and using computing as diagnostic device [61]. Another approach is to employ computing technology as a safeguard against misinformation. Lazer et al.'s Science article identifies two categories of intervention — individual empowerment and platform-based detection and intervention [80]. *Computing as Auditor* offers the

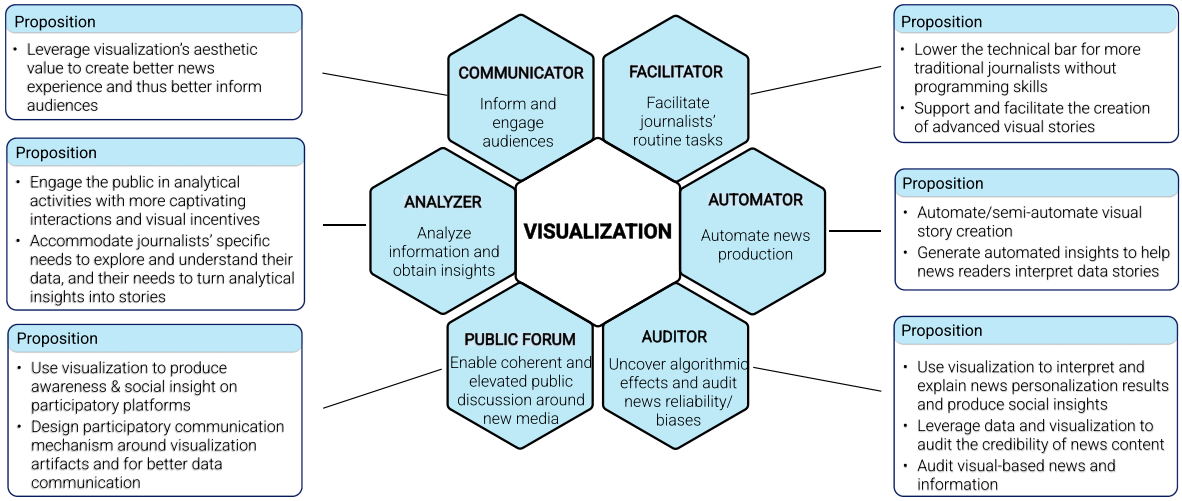

Fig. 2. Propositions for visualization with respect to computing's roles in journalism.

potential to detect algorithmic biases and audit single/collective news content for credibility in a more ubiquitous manner, thus empowering individual readers in today's overloaded and polluted infosphere.

IV. Contextualizing the Value of Visualization in Journalism

The previous section builds up to computing technology's six roles in journalism and their emphases. In this section, we explore how data visualization can serve these roles and provide its unique set of values to journalists and audiences from the perspectives listed in Table III. To achieve that, we first explore the fundamental values ascribed to visualization by researchers/practitioners as a starting point.

A. Discourse on the Value of Visualization

Data visualization is often touted for its value in amplifying human cognition, such as expanding working memory, enhancing pattern recognition, and making information manipulable [81]. Norman suggests that visual representations can largely impact how efficiently we perform tasks [82]. Fekete et al. focus on knowledge generation and propose an economic model that defines the total cognitive benefits [83]. Stasko remarks that the merit of visualization lies in its capabilities to minimize the time people need to understand the overall essence of data or discover insights about the data, and with greater confidence [84]. He also emphasizes the importance of interaction to these values, concurring with Elmqvist et al.'s referring to interaction as *"the catalyst for user's dialogue with data"* [85].

The visualization community has reflected on its roots in computer science and its tradition of supporting information workers with well-defined analytical tasks. Traditional visualization research often adopts a utilitarian view that focuses on efficiency, insights, and comprehension [86]. The utilitarian view sees the functional side of visualization and worries about aesthetics undermining this functional value, while the aesthetic view sees its artistic side and fears that functional foci could bore or even intimidate an audience.

Over the years, visualization researchers have explored the values of visualization using alternative lenses. For example, Pousman et al. proposed a new subdomain termed "*Casual InfoVis*", differentiating it from the traditional view of visualization interfaces in four aspects: user population, usage pattern, data type, and insights [87]. They expanded the traditional view of visualization for analytic insight, stating that casual visualizations add awareness insight, social insight, and reflective insight. In other words, casual visualizations can provide information that is less crystalized but *"subtly useful"*, information that improves understanding of a *"social group and one's place in it"*, and information that support *"self-contemplating one's personal and idiosyncratic thoughts"* [87]. Building off Casual InfoVis, researchers have sought to understand the broader value of visualization in a leisure context. Danziger [88] advocated *"Information Visualization for the People"*, emphasizing regular people's growing needs to make sense of information in everyday life. Sprague and Tory [89] explored people's casual encounters with visualizations and uncovered their motivations for using visualization beyond the utilitarian view, including entertainment, curiosity, and social activities. More recently, researchers started focusing on emotional responses or affective effects of visualizations, particularly those for communicative purposes [86], [90], [91], [92]. Such affective influences are tied to the aesthetic value of visualization.

In journalism, visualization is beautifully referred to as *"the functional art"* by Cairo [93] as it often embodies both functional and artistic values. Though Cairo acknowledges that journalism has a long history of treating infographics as *"mere ornaments"* that attracts audiences and underestimates their functional value. Cohen concurs by stating that the core value of journalistic visualization is *"deeply rooted in measurable facts"* and provides that it *"offers a tantalizing opportunity for storytelling that is above all driven by facts, not fanaticism"* [94]. Data visualization has evolved well beyond static infographics — its

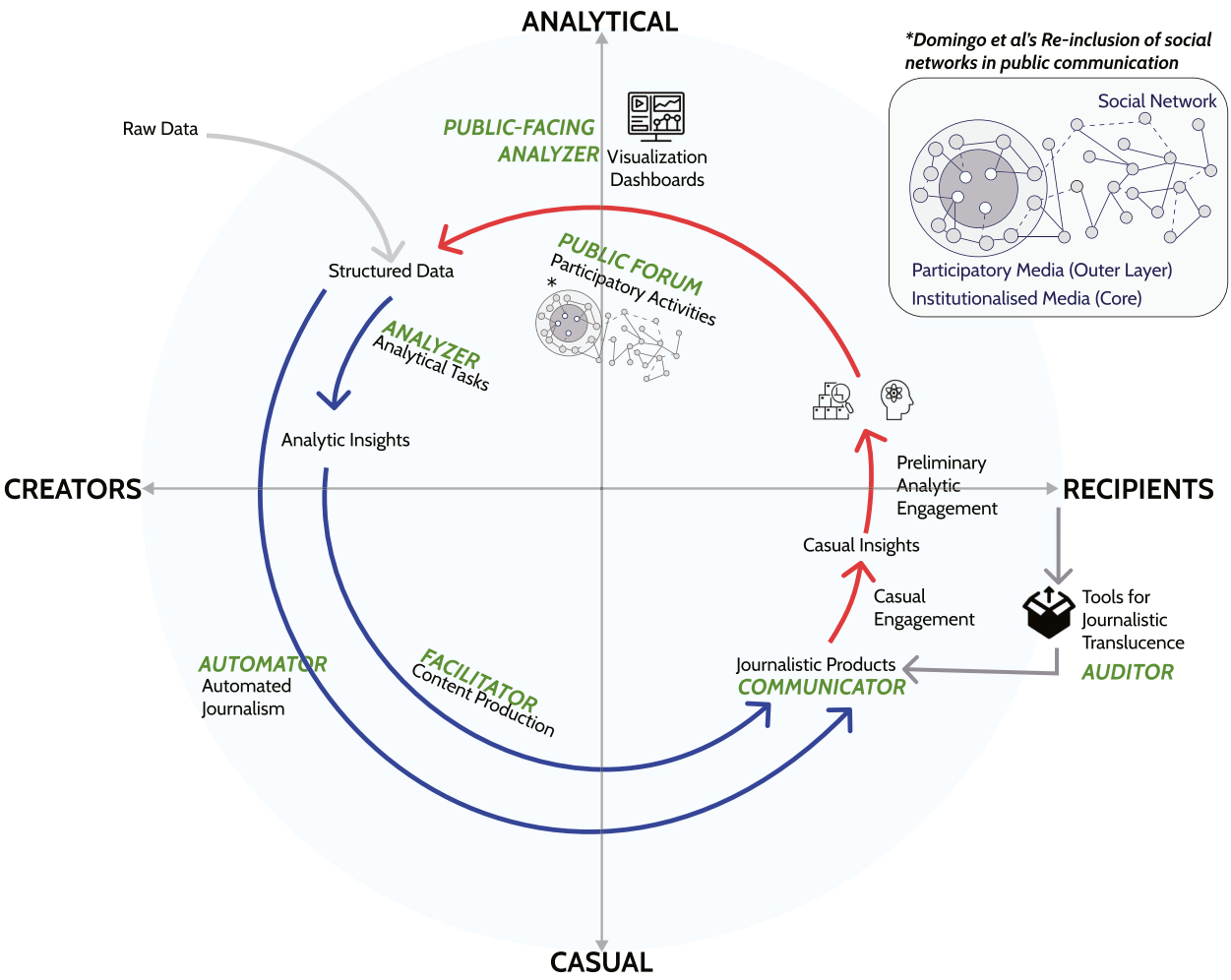

Fig. 3. An ecological model for mapping computing in contemporary journalism. This model consists of two primary processes: *the news production process* that roughly equates to Lee et al.'s storytelling process [18] and *the news consumption process*. During the production process, creators explore and analyze data using *Analyzers* (e.g., visual analytic systems), organize story pieces, then produce journalistic products using *Facilitators* (e.g., visualization authoring tools). The resulting products are *Communicators*, including infographics, narrative visualizations, or even data videos. *Automators* also have the potential to complete this process by generating journalistic content directly from structured data. The news consumption process starts when audiences encounter these products and decide to engage. Such engagement with visualization can provide casual (i.e., awareness, social, reflective) insights, curiosity, or simple entertainment. Recent data-driven storytelling that employs interactivity enables audiences to dive further and engage in preliminary exploration, invoking visualizations' value as *Analyzers*. In today's participatory environment, if a *Public Forum* (participatory opportunity) is provided, interested audiences can easily transition into the creators' role, triggering further analytical engagement and completing the circle.

aesthetic values and functional values do not have to be encapsulated within static views simultaneously. A comprehensive understanding of how to leverage its aesthetic value to enhance its functional value is a key for visualization to better support journalism — the exquisiteness of well-made visualizations can enthrall audiences, and that is *"a valuable social currency for sharing and attracting readers"* [94].

B. Implications of the Six Roles for Visualization

One seemingly cogent question is how do these values of visualization relate to computing's six roles in journalism? And how can visualization better support or be supported by these six roles?

First, it is helpful to distinguish journalistic content creators from recipients (we choose it over journalist/audience classification since journalists can be information recipients and 'audiences' are able to create content in today's participatory environment). Journalistic content creators are information workers and need to accomplish comparably crisp tasks such as gathering, filtering, and analyzing raw information and then weaving insights and narratives into a journalistic product. These tasks align better with the functional value of visualization. Recipients, contrastingly, do not necessarily need to engage in these tasks — their encounters with visualization are leisure and loosely bounded, thus fitting better with the Casual visualization notion.

Second, journalism is a type of public communication — the social influence should not be overlooked, especially in the increasingly participatory journalism environment. Therefore, we propose to borrow Domingo et al.'s theoretical model on inclusive public communication and derived analytical grid (access/observation, selection/filtering, processing/editing, distribution, interpretation) [27] as a lens.

Conventionally, visualizations are often employed in journalism as *Communicator* — journalists use visualizations, often static infographics, to aid their traditional storytelling that *"seldom lets audience explore, but explains and conveys ideas already thought out"* [95]. But the emerging data journalism has shifted such ethos by unleashing a certain level of exploratory freedom to audiences. Resulting visualization products include data dashboards, which allow the public to explore and analyze data independently, and data-driven stories, which integrate visualization's exploratory and explanatory power [96] to "*lead readers towards a valid interpretation of underlying data*" [16]. The former is a public-facing *Analyzer*, and the latter is a hybrid of *Analyzer* and *Communicator*. Journalist-facing visualization *Analyzer* also deals with unstructured and textual data. For example, scholars and practitioners [53], [69] have highlighted visual analytic tools like Jigsaw [97] and Overview [98] that can mine insights from documents. *Facilitator* in this context aims to facilitate the creation of visualization artifacts. Mainstream generic tools like ManyEyes [99], Tableau [100], and Datawrapper have been underlined by scholars from both fields [68], [69], [101], [102]. However, both parties acknowledge the demands for more appropriate tools that support and accommodate journalism's workflow [69], [102].

The linkages between the other three roles (i.e., *Public Forum*, *Automator*, *Auditor*) and visualization have mostly remained modest in practice and experimental in research. While these three roles are not traditionally associated with data visualization, their growing importance drives us to explore and investigate their potential marriage, benefits, and consequences. To strengthen the existing roles (i.e., Communicator, Analyzer, Facilitator) and explore new roles (i.e., Public Forum, Automator, Auditor), we offer our propositions with respect to each role (Fig. 2) and map them onto an ecological model (Fig. 3) that takes into account the distinction of news creators and recipients, visualization's analytical and casual values, and Domingo et al.'s public communication model [27].

V. Research Topics and Agendas

In this section, we present and discuss seven research topics and their subtopics at the Journalism-Visualization intersection. These topics are distilled from the propositions and the ecological model we proposed. For existing roles, we contextualize recent visualization research and explain how it can contribute. For unexplored roles, we point out the research gaps and speculate on potential research directions. By doing so, we intend to provide a map for future visualization research to position itself and inspire investigations beyond current mainstream practices.

A. Facilitating Data Communication

Subtopic 1.1: Facilitate Narrative Visualization Authoring (Facilitator)
Agenda: Support sophisticated and expressive narrative visualization creation while lowering the barrier.
Literature: [103], [104], [105], [106], [107], [108], [109], [110], [111], [112]

Supporting more sophisticated and expressive interactive visualization creation while lowering the barrier for data visualization authoring has always been a central focus for visualization researchers. Visualization researchers have explored different forms of tools to author engaging narrative visualizations. For example, SketchStory [104] allows users to sketch narrative visualization in a freeform way with pen and touch interactions. Ellipsis [113] decouples narrative structure from visualization creation and allows users to create visualization scenes, add annotations and organize storylines. Recent tools like Lyra [105], Data Illustrator [106], and Charticulator [107], focus on expressive authoring and distinguish themselves from prior template editors and shelf constructions (e.g., Tableau). According to Satyanarayan et al. [114], such authoring tools, including subsequent Lyra 2 [108] and Data Animator [109], often assume authors' familiarity with computational thinking and are already acquainted with datasets [114]. Journalists' interests tend to align with the general direction of research on visualization authoring tools — to lower the threshold (e.g., reducing programming, data wrangling) and raise the ceiling (e.g., improving expressiveness) [114]. Idyll Studio [110], based on the Idyll markup language [115], exhibits great potential by lending authors the freedom to write texts and binding texts with data and variables. Its WYSIWYG-style interface resembles journalists' writing environment. It also supports Vega-Lite [116] charts and dynamic layouts and reactive triggers that can support techniques like scrollytelling. Furthermore, CrossData [111] automates the establishment of connections between textual content and underlying data, streamlining the process of authoring data articles. DataParticles [112] also leverages such latent connections to facilitate authors to create animated unit visualization, further extending the expressive capabilities of such visualization authoring tools.

Subtopic 1.2: Bridge the gap between exploration and presentation (Facilitator)
Agenda: Allow journalists to visually explore data, obtain insights, then organize the insights into engaging visual presentations (e.g., narrative visualization) in a more efficient and seamless way
Literature: [117], [118], [119]

A salient feature of journalists' information intermediary role is that they need to perform both analytical and communicative tasks. Journalists are usually knowledgeable of their domains but less data-savvy. Therefore, data acquisition and wrangling can prevent them from adopting information tools — traditional journalists are more likely to interact with information tools through direct manipulation [120] to find insights and construct narratives [117]. Narrative visualization authoring tools like Ellipsis [113] and Idyll Studio [110] do not take data analysis into consideration. Recently, visualization researchers have advocated a more seamless and integrated authoring pipeline [18], [117], [118], [119] where users can perform exploratory data analysis to discover insights and narratives, then organize them into narrative visualizations by manipulating layouts, annotating, highlighting, or even re-configuring visual elements.

Such integration presents new challenges and opportunities. Gratzl et al. propose the CLUE model, aiming to integrate data exploration and presentation by capturing provenance data during exploration and then apply such provenance data to presentation [118]. However, visual encodings optimized for exploratory purposes are not necessarily optimal for communication. Chen et al. propose a different approach by inserting a story synthesis phase between analytics and storytelling. It enables users to arrange and aggregate story slices and add annotations and visual linkings [119]. In journalism, the data exploration and insights finding can be messy — narratives may come from different views and datasets across different visual analytic systems, and their story authoring often demands originality and creativity. It is worth exploring how to support such demands while respecting the underlying data and relationship.

Subtopic 1.3: Enable, facilitate, and understand data-driven commenting (Public Forum)
Agenda: Enable audiences of data story/dashboard to comment with data-driven insights (i.e., their findings/interpretations from interacting with dashboards), design interactive mechanisms to facilitate such data-driven dialogues among commenters, and study its influence on data-driven public communication
Literature: [14], [99], [117], [121], [122], [123]

While data-driven storytelling combines data exploration with data communication through interactivity and is equipped with novel techniques to keep audiences engaged, we have yet to see platforms that facilitate audiences participating in data-driven dialogues. By data-driven dialogues, we mean activities in which audiences comment and interact with others using their own analytic insights. Commenting is among the most used feature to foster user input in online journalism, especially when it comes to controversial topics such as politics [123]. Surveys [122] show people comment on the news to express emotion or opinions, add information or correct misinformation, participate in debates, etc. In a traditional textual environment, it is a relatively balanced communication for audiences to respond with texts. When arguments are accompanied by visual support, researchers have observed that comments tend to be more analogous and supportive [117]. Although it could be a sign of improved credibility, it can also be interpreted as suppression of counterarguments. Data visualization's effect on audiences' commenting behavior remains understudied. How can we facilitate better data-driven conversational experiences for audiences? The Martini Glass structure suggested by Segel and Heer [14] can potentially prompt readers to explore, but readers still lack an interactive mechanism to facilitate effective exchanges of the analytic insights they discover. Viegas et al. [99] discusses *ManyEyes*' social features — it not only allowed users to comment underneath visualizations and datasets but also enabled them to "snapshot" a visualization's state or include graphical annotations into their comments. Hullman et al.'s study on visualization blog comments discusses the possibility of more sophisticated commenting interfaces that support functionalities such as comment-presentation linking [121]. We envision further research in this direction, including exploring the design space for data commenting, developing prototypes to enable data commenting activities (e.g., linking "states" of a COVID dashboard to readers' comments and allowing others to access quickly), and field deployment to investigate their impact on public data discussions using such prototypes.

B. Understand Visualization Dashboards on News Websites

While the previous subsection primarily focuses on the technical perspective, this subsection places emphasis on empirical knowledge concerning current practices and design knowledge aimed at improving existing technology, specifically regarding visualization dashboards.

Despite the widespread presence of visualization dashboards across different industries, it is only recently that they have begun to enter our daily lives. An unprecedented amount of visualization dashboards have been produced to combat the COVID-19 pandemic [124]. They have played a vital role in assisting both top-down policymakers' decision-making and informing the public about the situation from local to global levels, thus altering our awareness and behaviors [13]. The importance of well-designed data dashboards cannot be understated in this misinformation-flooded era. News organizations, represented by the New York Times, have contributed a significant portion of these dashboards. Such visualization dashboards as news applications have become a predominant form of data journalism [30], [55], [56].

Subtopic 2.1: Investigate how visualization dashboards are created and used as a form of journalism (Analyzer, Communicator)
Agenda: Empirically investigate how visualization dashboards are designed and implemented by news organizations and used by news readers and other stakeholders (e.g., participatory journalists)
Literature: [13], [125], [126], [127]

Visualization researchers have recently studied how dashboards are designed and used in the wild. Through their case survey and literature review, Sarikaya et al. [125] characterize and organize 15 factors into categories, including purpose, audience, visual & interactive features, and data semantics. They also advocate for visualization researchers to engage with users in the wild and systematically study dashboard design and implementation. Zhang et al. answer their calling by interviewing people involved in the COVID-19 dashboard design & creation process [13], including those from news organizations. Their study highlights the entangled relationships among actors and suggests a sociotechnical perspective for future investigation. Bach et al.'s recent design workshop offers insights on dashboard design patterns and tradeoffs [127]. Such empirical studies can deepen our understanding of design knowledge, stakeholders'

practical pain points, the relationships among actors and technologies, and the role that visualization dashboards play in a larger social context.

An operationalizable contribution is design guidelines for public-facing visualization dashboards. Design guidelines for other users (e.g., analysts, domain experts) are often crisp and tailored for a set of design requirements. Design practices often require designers to *"know your audiences"*. When it comes to the public, audiences are so diverse that designs are often geared toward the majority, marginalizing other groups. How could interactive visualization dashboards benefit more groups? We envision more flexible, customizable, and adaptable design guidelines as Sarikaya et al. advocate [125]. Also, evaluating visualization artifacts has already been a big challenge in the visualization community [128], let alone evaluating tools that are public-facing. In-the-wild, long-term evaluation methods like the *multi-dimensional in-depth, long-term case studies* (MILC) method [129] proposed by Shneiderman and Plaisant could offer inspiration for future research to develop public-facing evaluation methods.

Subtopic 2.2: Explore the design space of engaging casual audiences into analytical tasks (Analyzer)
Agenda: Use design studies as knowledge production devices to understand how different visual/interaction designs impact different audiences' transition from casual engagements into more analytical ones
Literature: [130], [131], [132], [133]

Visualization dashboards are at their best when the power of interactivity can be fully wielded by their users. But as noted by multiple studies [126], [134], the usage of interactivity in online news is an *"uncomfortable myth"* [134]. Then how can visualization and interaction design better engage and encourage audiences to interact and conduct analysis? A suitable approach to investigate such topics is through *design study*. In visualization research, a design study investigates a real-world problem and its context, design and develops a visualization system solution, validates design choices, and reflect on lessons learned [130], [131]. The resulting artifacts are usually visualization prototypes and design guidelines, which can be valuable for data journalists to borrow and follow. There is a disparity, however — data journalists desire to inform the public who have greater variance in data literacy, prior knowledge, and intention, while visualization design researchers have specific domain experts in mind and would prefer crisp domain tasks [135]. Meyer and Dykes's renewed discussion on design study draws on Research through Design (RtD) [132], [133] and emphasizes reflectively generating knowledge about "*the complex, messy, nuanced, and evolving relationships of people with data and technology*" through visualization design [131]. For design studies to benefit public-facing data journalism, visualization design researchers can explore visual/interaction design space with our ecological model (Fig. 3) in mind, which means considering recipient's' encounters with dashboards casual and incentivize their analytical engagement and possible transition into creators' role. Such design studies should shy away from a full "utilitarian perspective" that aims at "the most effective" solutions and "in-lab" user studies that often omit the connections among different stakeholders. Instead, design researchers can intentionally produce insights through different visual/interaction designs and gather long-term user feedback from different social groups.

C. Integrate Interactive Visualization With New Media

Subtopic 3.1: Facilitate data video authoring and augmenting (Facilitator)
Agenda: Facilitate data video authoring and presentation and augment video with visualization and novel interactions
Literature: [14], [136], [137], [138], [139], [140]

The importance of video content in journalism cannot be overstated. The emergence of short-form video platforms (e.g., TikTok) has taken its importance to an unprecedented level [140]. Segel and Heer [14] include Film/Video/Animation as a basic narrative visualization genre. Nevertheless, integrating data visualization into videos requires tremendous effort and skills, along with a plethora of tools [136]. Visualization researchers have made attempts to address these challenges. One route is to develop tools that directly facilitate data video authoring. For example, Amini et al. developed *DataClips* [136] to consolidate these creation tasks into one tool, significantly reducing the production efforts and time while maintaining similar quality similar to professional editing tools. Recently, Shin et al. developed *Roslingifier* [138] to semi-automate the data presentation. Another route is to augment existing video footage with visualization. It is commonly seen in content-focused journalism domains, such as sports. Sports journalists and analysts frequently need to employ analytics to tell a narrative [117]. Besides the efforts from commercial companies, Chen et al. have done extensive work on this front. They developed VisCommentator [137] and Sporthesia [139]. The former takes raw video footage and extracts data via an ML model, allowing users to interact with objects in the video and select the data to visualize. The latter further eases the creation process by supporting natural language control by leveraging NLP techniques. Furthermore, Lin et al. recently developed Omnioculars [141], which embedded interactive visualizations into in-game video, extending visualization's potential to augment broadcasting and situated in-game journalistic analysis.

Subtopic 3.2: Visualization for live streaming (Facilitator, Communicator)
Agenda: Design *expressive spectator interfaces* for mobile device interaction and study their adoption and effects
Literature: [142], [143], [144], [145]

Live streaming has recently emerged as a popular form of social interaction, and many journalists have adopted it as a way to do journalism. Visualization in a broadcasting setting is not a new thing — news TV channels have been using interactive

dashboards on multiple occasions (e.g., CNN's Magical Wall, ESPN). Online streaming allows more journalists to participate in this type of communication, which Wattenberg describes as "*one person will be active, controlling the input, while others in the group will act as spectators*" [142]. He calls such interactive visualizations the "Expressive Spectator Interface." Online streaming revitalizes an old design challenge for HCI — "designing the spectator experience" [146]. From a sole interface design perspective, as online streaming tends to happen on the mobile end, we speculate that it poses new research questions that align well with recent visualization research concerning visualization on mobile devices and multi-modal interactions for data visualization [143], [144], [145], though audiences' willingness to spectate and journalists' needs for such interfaces are subject to future investigation.

D. Support Journalists' Analytical Tasks Through Visual Analytics

Subtopic 4.1: Support data-driven narrative construction (Analyzer)
Agenda: Design and develop domain-driven visual analytic systems that help journalists uncover novel data-driven storylines from a growing amount of domain data and analytics
Supporting Literature: [117], [147]

As more domains are becoming data-driven, journalists' demand for analytics and visualization tools to uncover novel narratives has grown in parallel, particularly within areas that have an abundance of data and analytics, such as finance and sports. For example, sports journalists increasingly rely on analytics to construct novel and credible narratives, and interactive visualization offers a way to rapidly obtain analytical insights and engaging visuals for their storytelling [117]. Zhi et al. [147] investigated how sports writers and fans can both benefit from interactive visualization to access statistics. Fu and Stasko [117] took consideration of the shifts triggered by sports analytics and developed two visualization systems tailored for basketball journalists/analysts to explore data and obtain insights [117]. Assisting them in such endeavors would require a deeper understanding of both journalists' narrative construction, workflow, and the characteristics of domain data/analytics. As such, contributions of such design study include formative investigation to identify domain journalists' analytical tasks, visualization prototypes that lead to rapid analysis, novel/interesting storylines, and visual representations that can be incorporated into stories and insights about how such interventions impact journalists' and their audiences.

Subtopic 4.2: Support document investigation through visual analytics (Analyzer)
Agenda: Simplify the use of such systems; reduce data wrangling; support flexible data import, integrate new text mining techniques; support evidence marshaling
Literature: [97], [98], [148], [149], [150]

From early CAR to recent computational journalism, investigative journalists employ various computational approaches to perform their watchdog duties. Assisting them in making sense of quantitative data can certainly lead to valuable storylines, as we discussed, but here we intend to highlight another approach that is in line with traditional investigative tasks — finding leads for stories from large numbers of textual documents. Modern-day text mining/analytics technologies, notably natural language processing (NLP), have allowed the transformation of unstructured textual data into more structured, analyzable data, extending visualization's capability to represent qualitative information and help make sense of it. A cluster of visualization research has been dedicated to mining insights from a large corpus. Jigsaw [97], [148], for example, leverages visual analytics to aid investigative analysis. Jigsaw features flexible data imports, entity identification, and a set of interconnected views to help analysts identify the connections between entities in documents in order to glean a comprehensive understanding of the themes and patterns across textual documents. Brehmer et al. specifically targeted investigative journalists and closely collaborated with them. They developed multiple versions of Overview [98], which led to nine published investigative stories. They studied how journalists adopt Overview and suggested simplifying the use and reducing data wrangling. For future research, Görg et al. [149] reflect that data ingestion that supports *"flexible data import is challenging but vital"* as documents to investigate are in a great variety of sources, forms, and formats. Another key is to integrate more advanced text mining techniques that can improve entity identification [149]. Evidence marshaling, a capability to support analysts in drawing connections and adding annotations, was also proposed to be included as an important feature [149], [150].

E. Visualization for Journalistic Translucence

In their prescient paper on designing digital systems that support social processes, Erickson and Kellogg propose three building blocks of social interaction: *visibility, awareness, and accountability* [151]. They employ visualization to address "blindness" in their demonstration application "*Babble*". Many online communities or conversations now have built-in socially translucent structures or functionalities. Our digital blindness has been reduced to a certain degree when it comes to awareness of other people's presence and status. When it comes to our information ingestion, however, our vision has seemingly become narrowed — in today's algorithm-pervasive information spaces, our vision often zooms in on what is on our screens and tends to lose track of information beyond that, which can impose walls between algorithmically classified groups and lead to further social fragmentation. As demonstrated by "*Babble*", visualization representations have great value in reification. In other words, they make abstract information perceivable, interpretable, and even actionable. Inspired by their work, we propose to appropriate the concept of social translucence in journalistic contexts — *journalistic translucence* that consists of three aspects: *making news personalization "visible"*, *raising*

awareness of journalistic content consumption, and *holding media content production accountable*. Achieving these goals, however, requires more sophisticated computational support. Fortunately, the abundant data and information extraction technologies (e.g., NLP, ML), along with advances in information visualization, particularly interactivity, provide the repertoire to make it possible.

Subtopic 5.1: Make news personalization "visible" (Auditor)
Agenda: Leverage interactive visualization/visual analytics to interpret news personalization algorithms and reverse engineer them to inform the public
Literature: [62], [152], [153], [154], [155], [156], [157], [158]

HCI researchers have explored the use of visualization to raise news personalization awareness. For example, Eslami et al. developed FeedVis [152], which employs straightforward views to demonstrate the proportion of news that is shown or hidden by the algorithm and allows users to adjust the algorithms based on authorship and story content. Their study also points out four paths to news awareness. Additionally, leveraging visualization to enhance the interpretability of AI and machine learning models has been a recent trend and promising research area [153], [154], [155], [156]. Inspired by this cluster of research, we envision that visualization research can contribute in two ways: within news organizations, where news personalization algorithms are available to be directly audited, visualization can be applied to interpret and explain such algorithms to decision-makers; for news audiences who do not have access to such algorithms, visualization can help with "reverse-engineering" algorithms and informing the public [62], [157].

Subtopic 5.2: Raise news consumption awareness (Auditor)
Agenda: Combine personal data tracking, text analytics, and visualization to raise individual readers' awareness of news consumption; potentially employ personal data art to motivate them to explore and share with others
Literature: [159], [160]

People's personal data has been used by media platforms for personalization, but users themselves have very limited access to their own data, let alone the tools to support them in making sense of it. Recent trends, nevertheless, are revealing people's desire to better understand themselves using the collection of personal data. Tech companies have attempted to visualize users' personal data for marketing purposes. For instance, Wrapped, Spotify's year-end visual review of users' music tastes, went viral and won Webby People's Voice Award for Best Data Visualization [161]. The New York Times recently launched a similar endeavor — Story Portrait, which generates a personalized and shareable visual portrait of the headlines of the stories from the past two years, with colors representing different sections [162]. The capabilities to track and collect personal news intake can provide opportunities for readers to be aware of the news they consume. Researchers in other areas have explored providing feedback to news readers about their news consumption. For example, Munson et al. recently developed Balancer [163], a Chrome Extension featuring icons with minimum visualization. Their deployment study suggests that showing aggregated feedback can nudge some readers toward more balanced news consumption. As we discussed, visualization researchers have created tools to assist corpora analysis that could provide news readers with more sophisticated insights beyond mere political stances. We envision that to graft these techniques and tools onto a journalistic setting requires further examination of how to incite audiences' curiosity and prompt them to explore, as audiences do not have the motivation to expose themselves to information outside their ideological niche. Considering people's favor for the aestheticization of personal data [159], [160], data art could potentially engage audiences and provide motivations for them to explore and share.

Subtopic 5.3: Hold news production accountable (Auditor)
Agenda: Leverage text analytics and interactive visualization and adopt action research methodology to help activists/advocacy hold news organization accountable
Literature: [164], [165], [166], [167], [168], [169]

Similar visual text analytics tools/techniques can be used to examine individual/institutional news production, potentially by social activists. News practitioners and activists have made efforts and provided inspiration. For instance, the Pudding recently published a visual essay titled *When Women Make Headlines* [168]. They used data scraped from Google News and leveraged gendered language, bias calculation, theme dictionaries, and polarity analysis to foreground the misrepresentation of women in the news. Similarly, VisualizeNews combined NLP and intriguing narrative visualizations to examine the press coverage of the 2019 Indian general election [166]. More serious democracy activist efforts like Hamilton 2.0 Dashboard [167] have employed interactive visualization dashboards to demonstrate analysis of narratives and topics promoted by state-funded media. Research in this direction can potentially adopt action research [164], [165], [169] as a methodology.

F. Combat Misinformation

"Fake news" is accelerating and impairing people's judgment of information, worsening the information environment for journalism, which is already suffering from trust crises. Combating the scourge of misinformation is essential to our society and has attracted serious attention from various disciplines. Additionally, large language models have the capacity to generate more persuasive misinformation on a massive scale [170], highlighting the urgent need for counteracting technologies.

Visualizations have been used to present the characteristics of misinformation. For example, FakeNewsTracker [171] employs visualization interfaces to demonstrate the fake news they detect using machine learning models. Instead of adding to this thread, here we identify three other directions where

visualization research can perform a larger role in combating misinformation.

Subtopic 6.1: Visualization for investigating and communicating misinformation (Analyzer, Communicator)
Agenda: Leverage visual analytics to surface the trustworthiness and biases of news sources/content in order to facilitate decision-making and fact-checking endeavors and mitigate confirmation biases; employ narrative visualization to communicate fact-checking results in a more convincing and digestible way
Literature: [45], [80], [172], [173], [174], [175], [176], [177], [178]

Fact-checking has a long history as a standard and essential routine in the newsroom [45]. With the explosion of misinformation, fact-checking has become increasingly challenging, yet critically important [80]. We identify two angles to approach this matter with the assistance of visualization. The first angle concerns the analysis of fact-checking. Fact-checkers often need to examine different attributes of the information [45], including entities, linguistic features (e.g., sentiment), and metadata (e.g., sources, timestamps). Visualization possesses the capability to represent such high-dimensional information and relationships among various entities. Coupled with interactivity and analytics, it could enable fact-checkers to label sources, claims, and relationships more efficiently and with fewer biases. Visualization researchers [172], [173], [174] have contributed tools and designs to help investigate misinformation. Future research can investigate fact-checking workflow and develop analytic tools that empower them to rapidly check claims against other statements/facts or quantitative data and assess their credibility. In addition, techniques [177], [178] used to surface analysts' biases and promote self-awareness can also be integrated into such fact-checking tools.

The second angle attends to the challenge of communicating results. Fact-checking websites adopt various ways to present their verdict and analysis on claims/rumors, including visual representations (e.g., PolitiFact's *Truth-O-Meter* [179]). Despite their efforts, delivering such verdicts can be laborious and sometimes counterproductive if done in a threatening manner [175], [180]. There are also initiatives aiming to make fact-checking more visible [45]. We speculate narrative visualizations, with their capabilities to deliver sophisticated information in an engaging manner, could support communicating fact-checking verdict/analysis in a more digestible and transparent way (e.g., demonstrating a verdict's relationships with multiple sources supporting/refuting it). Another promising approach is to employ visualizations to effectively communicate the verdicts on data-driven/statistical claims, as visualization can potentially provide context for the data claims and help audiences to comprehend the verdicts. Future research can explore the design space and evaluate its influence on audiences' reception of fact-checking verdicts, regarding aspects such as engagement and persuasiveness.

Subtopic 6.2: Detect visual deception (Auditor)
Agenda: Develop end-user tools (e.g., browser extensions) that can detect visual deception/distortion and alert news readers with annotations and visual augmentations
Literature: [181], [182], [183], [184]

While visualizations possess communicative and even persuasive power, they can also be used for deception [181]. There are countless notorious cases from marketing companies, news organizations, and government institutions — even the White House posted a problematic chart on Twitter recently [185]. Regardless of their intentions, it becomes increasingly important to alert and inform the public about potential visual deception. Visualization design guidelines are often about "how *NOT* to lie with charts" [186], [187] but in reality, people have so many incentives not to follow them. More researchers have begun to focus on detecting these "graphical lies." Pandey et al. summarize popular distortion techniques and their effect. They classify deceptive visualizations into two groups: message exaggeration/understatement and message reversal [181]. Hopkins et al. create VisualLint to alert visualization designers about such errors. McNutt et al. introduces a concept of "visualization mirages" and suggests alerting readers to potential issues [183]. Fan et al. developed a Chrome Extension that automatically reads and annotates potential deceptions in line charts, making such techniques more easily accessible for readers [182]. This opens up future research possibilities to broaden the chart types and increase accessibility.

Subtopic 6.3: Detect text-visualization misalignment (Auditor)
Agenda: Develop end-user tools (e.g., browser extensions) that can point out the misalignment between visualization and text (e.g., titles, annotations)
Literature: [188], [189], [190]

Deception can also occur when visualizations do not match the textual descriptions or claims in titles or annotations. Borkin et al.'s experiment based on eye-tracking suggests that titles and text can greatly impact how people recall the gist of visualization [188]. Kong et al.'s studies demonstrate that slanted titles and misaligned annotations can mislead audiences' interpretation of visualizations and have more persistent impacts on recalling than visualizations do [189], [190]. They also suggest using algorithms and NLP methods to combat text-visualization misalignment and tools to foreground such misalignment and raise readers' awareness [190]. We anticipate that web browser plugins capable of detecting and notifying readers of such misalignment would come in handy, although it presents technical challenges to improving the accuracy, and its impact on reader experience needs further examination.

G. Automated Visual Stories and Insights (Automator, Communicator)

Subtopic 7.1: Automate visual data story creation (Automator)
Agenda: Enable (semi-)automated generation of more sophisticated and engaging data-driven storytelling and understand readers' perception of such automated content
Literature: [76], [77], [191], [192], [193], [194], [195]

Robot-generated news has its advantages when it comes to speed, scalability, and even objectivity, but it often lacks sophisticated narratives and has been deemed boring and technical [77]. HCI researchers have explored automated news content beyond just text. Oh et al. developed a system NewsRobot [192] that automatically generates different types (general/personalized) and styles (text/image/sound) of news content using sports data, and they used generated news as a probe to understand audiences' perception of different combinations of automated news. Visualization researchers have studied it from a broader perspective — auto-insights, defined as *"data observations revealed by automation"* by Law et al. [191]. Their review [191] found that only a few studies were dedicated to automated data-driven storytelling. Systems like DataShot [193], Temporal [194], and Calliope [195] are pushing towards more sophisticated and engaging automated visual data stories while supporting human editorial intervention. This direction still imposes great technical challenges (e.g., extracting data insights, generating proper visualization, linking texts to charts, supporting sophisticated techniques like scrollytelling) and lacks design implications and understanding of audience perceptions.

Subtopic 7.2: Augment interactive visualization with automated insights and guidance (Automator)
Agenda: Provide auto-generated insights and guidance based on users' interactions to help ordinary audiences interpret data and visualization
Literature: [196]

With visualization dashboards permeating various areas in journalism and reaching broader audiences, the public's need for assistance in interpreting these visualizations and extracting insights also grows. Driven by commercial companies like Automated Insights, multiple auto-insight systems have emerged. Such systems use statistical models to infer potentially interesting/relevant facts in the data and generate natural language to communicate them [196]. Srinivasan et al. discuss such template-based natural language generation systems that assist users in visualization interpretation. They introduce Voder, a system that automatically generates data facts according to visualization and links data facts to the visualization through visual embellishments (i.e., opacity, regression lines) [196]. As they note, such tools are still in their infancy and how to contextualize them in journalism to benefit the audiences is still a target for future investigation. Nevertheless, such systems offer the potential to guide ordinary people in data exploration and interpretation and ultimately increase their data literacy.

H. Topic Connections and Other Topics

It is worth noting that not all of the topics we list are independent. The ecological model (Fig. 3) we propose could help demonstrate their intricate relationships. Such relationships can be synergistic — e.g., the relationship between investigating misinformation and communicating verdicts, two directions mentioned in *Subtopic 6.1*, can be strengthened by a facilitating tool advocated in *Subtopic 1.2*. The relationships can also be antagonistic — e.g., automated visual storytelling technology discussed in *Subtopic 7.1* could potentially weaken human-centric approaches as it bypasses the topics associated with *Analyzer* (*e.g., Subtopic 4.1 & 4.2*) and *Facilitator* (*e.g., Subtopic 1.1*) and generates *Communicator* with minimum human intervention.

In addition, our proposed set of topics is not intended to be exhaustive. Our goal is to open up the possibilities for this cluster of research. Other topics, such as *playable visualization* [197], [198], *immersive data-driven stories* [199], and *archiving data-driven stories and apps* [200], [201], [202], [203], [204] are worthy topics that have been studied by researchers and likely have applications in journalism.

VI. Reflection

Although the main thrust of this paper is to explore the broader role of visualization in journalism and thus provide future agendas for visualization research to better assist contemporary journalism, our review of the literature on both fronts indicates shared interests between the two research areas and potential benefits for visualization research.

As Meijer [66] notes, journalism researchers have turned to "news experience" and considered an "expressive" angle to study journalism. Scholars have employed new concepts and explanatory frames, including HCI studies and information studies, to analyze topics like people's experience of information and how computing-mediated interactive experience can alter audiences' preferences, perceptions, and experiences of news [66]. Such goals align well with the visualization/HCI research, though they are likely to have different foci. We advocate closer collaborations between these fields. It can lead to a more balanced and heterogeneous perspective — visualization/HCI researchers tend to lean towards a technological or cognitive science one while traditional journalism study is dominated by a sociological perspective [205]. For example, both sides have shown interest in *data literacy* of the public — visualization researchers may have a stronger interest in how it affects people's interpretation of different visual representations [206], how to better design visuals and interactions for the public with varying levels of data literacy, and how to improve people's data/visualization literacy [207], while journalism scholars may focus on how data/visualization literacy impacts public discourse and its implications for journalistic products. Visualization research can provide devices for data gathering and cognitive bases to explain high-level social phenomena, while journalism study offers a holistic social context to situate the generated knowledge and make such knowledge more useful and actionable.

In addition to collaborating with journalism scholars, visualization research can also benefit from working with journalism

practitioners. Apart from the fact that they are top-tier stakeholders and hence the necessity to understand their workflow and needs, another practical benefit is that journalists can potentially increase the visibility and appreciation of visualization outside the core visualization community, which has been advocated by some visualization researchers [208]. The value of visualization is challenging to perceive without "seeing it" or "interacting with it", especially for audiences less familiar with the affordance of interactive visualizations and/or with limited data/visual literacy. Journalists' platforms, whether institutional or individual, can provide vehicles for visualizations to reach broader audiences, increase the visibility of visualization, and potentially improve the data and visual literacy of the masses. Journalists are natural information transmitters — assisting journalism in a broader way offers visualization research a chance to increase its real-world visibility — not only putting enthralling graphics in front of people but also demonstrating to them how they can converse with their surrounding information in an effective yet joyful way.

VII. Conclusion

Journalism and visualization have an intertwined relationship, one that is often overshadowed by visualization's capability in communication. Indeed, visualization excels at aiding data-driven storytelling, but it can also be instrumental to journalists and news audiences in many other ways, with its own set of aesthetic and functional values. In this study, we took a step back and examined journalism's digital metamorphosis to identify the emerging challenges and their implications, as well as journalism's computational exploration to address such challenges and shifts. Based on our findings, we identified computing's six roles in contemporary journalism, and their corresponding focuses. Next, we revisited discourse on the fundamental values of visualization and proposed a set of propositions about how visualization can support or be supported by computing's six roles. By situating these roles and propositions in an ecological model, we ultimately surfaced a range of research topics and respective agendas. Through this paper, we hope to shed light upon the shifts in contemporary journalism and their implications for visualization research and inspire broader research exploration at the intersection of these two dynamic fields.

References

[1] J. J. Otten, K. Cheng, and A. Drewnowski, "Infographics and public policy: Using data visualization to convey complex information," *Health Affairs*, vol. 34, no. 11, pp. 1901–1907, 2015. [Online]. Available: https://doi.org/10.1377/hlthaff.2015.0642

[2] M. Bostock, V. Ogievetsky, and J. Heer, "D^3 data-driven documents," *IEEE Trans. Vis. Comput. Graph.*, vol. 17, no. 12, pp. 2301–2309, Dec. 2011.

[3] A. Bruns, "Gatekeeping, gatewatching, real-time feedback: New challenges for journalism," *Braz. Journalism Res.*, vol. 7, no. 2, pp. 117–136, 2011.

[4] S. C. Lewis, K. Kaufhold, and D. L. Lasorsa, "Thinking about citizen journalism," *Journalism Pract.*, vol. 4, no. 2, pp. 163–179, 2010. [Online]. Available: https://dx.doi.org/10.1080/14616700903156919

[5] B. Anderson, *Imagined Communities: Reflections on the Origin and Spread of Nationalism*. London, U.K.: Verso Books, 2006.

[6] K. Wahl-Jorgensen and T. Hanitzsch, "Journalism studies: Developments, challenges, and future directions," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 3–20.

[7] B. McNair, "Journalism and democracy," in *The Handbook of Journalism Studies*, 1st ed. Evanston, IL, USA: Routledge, Jan. 2009, pp. 257–269.

[8] C. Peters and M. Broersma, *Rethinking Journalism: Trust and Participation in a Transformed News Landscape*. Evanston, IL, USA: Routledge, 2013. [Online]. Available: https://books.google.com/books?id=Z87HrlkBZiEC

[9] J. Pavlik, *Journalism and New Media*. New York, NY, USA: Columbia Univ. Press, 2001. [Online]. Available: https://doi.org/10.7312/pavl11482

[10] A. V. Dalen, "Journalism, trust, and credibility," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 356–371.

[11] J. M. Ladd, *Why Americans Hate the Media and how it Matters*. Princeton, NJ, USA: Princeton Univ. Press, 2012. [Online]. Available: http://www.jstor.org/stable/j.ctt7spr6

[12] P. Meyer, *Precision Journalism: A Reporter's Introduction to Social Science Methods*. Lanham, MD, USA: Rowman & Littlefield Publishers, 2002. [Online]. Available: https://books.google.com/books?id=1YB4AAAAQBAJ

[13] Y. Zhang, Y. Sun, J. D. Gaggiano, N. Kumar, C. Andris, and A. G. Parker, "Visualization design practices in a crisis: Behind the scenes with COVID-19 dashboard creators," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 1, pp. 1037–1047, Jan. 2023.

[14] E. Segel and J. Heer, "Narrative visualization: Telling stories with data," *IEEE Trans. Vis. Comput. Graph.*, vol. 16, no. 6, pp. 1139–1148, Nov./Dec. 2010.

[15] J. Hullman and N. Diakopoulos, "Visualization rhetoric: Framing effects in narrative visualization," *IEEE Trans. Vis. Comput. Graph.*, vol. 17, no. 12, pp. 2231–2240, Dec. 2011.

[16] N. Riche, C. Hurter, N. Diakopoulos, and S. Carpendale, *Data-Driven Storytelling*. Boca Raton, FL, USA: CRC Press, 2018. [Online]. Available: https://books.google.com/books?id=bnxTDwAAQBAJ

[17] R. Kosara and J. Mackinlay, "Storytelling: The next step for visualization," *Computer*, vol. 46, no. 5, pp. 44–50, May 2013.

[18] B. Lee, N. H. Riche, P. Isenberg, and S. Carpendale, "More than telling a story: Transforming data into visually shared stories," *IEEE Comput. Graph. Appl.*, vol. 35, no. 5, pp. 84–90, Sep./Oct. 2015.

[19] M. T. Pham, A. Rajić, J. D. Greig, J. M. Sargeant, A. Papadopoulos, and S. A. Mcewen, "A scoping review of scoping reviews: Advancing the approach and enhancing the consistency," *Res. Synth. Methods*, vol. 5, no. 4, pp. 371–385, 2014. [Online]. Available: https://dx.doi.org/10.1002/jrsm.1123

[20] C. I. of Health Research, "A guide to knowledge synthesis - CIHR," 2010. [Online]. Available: https://cihr-irsc.gc.ca/e/41382.html

[21] D. Long and B. Magerko, "What is AI literacy? Competencies and design considerations," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2020, pp. 1–16. [Online]. Available: https://doi.org/10.1145/3313831.3376727

[22] V. Herdel, L. J. Yamin, and J. R. Cauchard, "Above and beyond: A scoping review of domains and applications for human-drone interaction," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2022, Art. no. 463. [Online]. Available: https://doi.org/10.1145/3491102.3501881

[23] H. Arksey and L. O'Malley, "Scoping studies: Towards a methodological framework," *Int. J. Social Res. Methodol.*, vol. 8, no. 1, pp. 19–32, 2005. [Online]. Available: https://dx.doi.org/10.1080/1364557032000119616

[24] K. Wahl-Jorgensen and T. Hanitzsch, *The Handbook of Journalism Studies*, 1st ed. Evanston, IL, USA: Routledge, 2009.

[25] C. Wohlin, "Guidelines for snowballing in systematic literature studies and a replication in software engineering," in *Proc. 18th Int. Conf. Eval. Assessment Softw. Eng.*, 2014, Art. no. 38. [Online]. Available: https://doi.org/10.1145/2601248.2601268

[26] B. Scott, "A contemporary history of digital journalism," *Telev. New Media*, vol. 6, no. 1, pp. 89–126, 2005.

[27] D. Domingo, T. Quandt, A. Heinonen, S. Paulussen, J. B. Singer, and M. Vujnovic, "Participatory journalism practices in the media and beyond," *Journalism Pract.*, vol. 2, no. 3, pp. 326–342, 2008. [Online]. Available: https://dx.doi.org/10.1080/17512780802281065

[28] J. Vázquez-Herrero, X. López-García, and F. Irigaray, "The technology-led narrative turn," in *Journalistic Metamorphosis*. Berlin, Germany: Springer, 2020, pp. 29–40. [Online]. Available: https://doi.org/10.1007/978--3-030-36315-4_3

[29] D. S. Chung and C. Y. Yoo, "Audience motivations for using interactive features: Distinguishing use of different types of interactivity on an online newspaper," *Mass Commun. Soc.*, vol. 11, no. 4, pp. 375–397, 2008.

[30] N. Usher, *Interactive Journalism: Hackers, Data, and Code*. Urbana, IL, USA: Univ. Illinois Press, 2016. [Online]. Available: http://www.jstor.org/stable/10.5406/j.ctt1hfr048

[31] S. Jones and A. Bruns, *Gatewatching: Collaborative Online News Production*. Bern, Switzerland: P. Lang, 2005. [Online]. Available: https://books.google.com/books?id=ybSFU9aDzsoC

[32] M. Carlson and S. C. Lewis, "Boundary work," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 123–135. [Online]. Available: https://www.taylorfrancis.com/chapters/edit/10.4324/9781315167497--8/boundary-work-matt-carlson-seth-lewis

[33] P. J. Shoemaker, T. P. Vos, and S. D. Reese, "Journalists as gatekeepers," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019.

[34] J. Singer et al., *Participatory Journalism: Guarding Open Gates at Online Newspapers*. Hoboken, NJ, USA: Wiley, 2011. [Online]. Available: https://books.google.com/books?id=AbJLEAAAQBAJ

[35] R. Zamith and S. C. Lewis, "From public spaces to public sphere," *Digit. Journalism*, vol. 2, no. 4, pp. 558–574, 2014.

[36] E. Powers, "My news feed is filtered?," *Digit. Journalism*, vol. 5, no. 10, pp. 1315–1335, 2017.

[37] E. Pariser, *The Filter Bubble: How the New Personalized Web is Changing What we Read and how we Think*. Baltimore, MD, USA: Penguin, 2011. [Online]. Available: https://books.google.com/books?id=wcalrOI1YbQC

[38] B. Kovach and T. Rosenstiel, *The Elements of Journalism, Revised and Updated: What Newspeople Should Know and the Public Should Expect*, 4th ed. New York, NY, USA: Crown, 2021. [Online]. Available: https://books.google.com/books?id=Kvc3EAAAQBAJ

[39] S. Robinson, "Traditionalists vs. convergers: Textual privilege, boundary work, and the journalist—audience relationship in the commenting policies of online news sites," *Convergence*, vol. 16, no. 1, pp. 125–143, 2010. [Online]. Available: https://doi.org/10.1177/1354856509347719

[40] A. Hermida, *Mechanisms of Participation*. Hoboken, NJ, USA: Wiley, 2011, ch. 2, pp. 11–33. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781444340747.ch2

[41] D. Gillmor, *We the Media: Grassroots Journalism by the People, for the People*. Sebastopol, CA, USA: O'Reilly Media, 2006. [Online]. Available: https://books.google.com/books?id=5DMSVPEv86gC

[42] J. Hujanen and S. Pietikäinen, "Interactive uses of journalism: Crossing between technological potential and young people's news-using practices," *New Media Soc.*, vol. 6, no. 3, pp. 383–401, 2004.

[43] D. S. Chung, "Interactive features of online newspapers: Identifying patterns and predicting use of engaged readers," *J. Comput.-Mediated Commun.*, vol. 13, no. 3, pp. 658–679, Apr. 2008. [Online]. Available: https://doi.org/10.1111/j.1083--6101.2008.00414.x

[44] J. Pavlik, "The impact of technology on journalism," *Journalism Stud.*, vol. 1, no. 2, pp. 229–237, 2000.

[45] L. Graves, *Deciding What's True: The Rise of Political Fact-Checking in American Journalism*. New York, NY, USA: Columbia Univ. Press, 2016. [Online]. Available: https://books.google.com/books?id=VcGlDAAAQBAJ

[46] A. LaFrance, "The power of personalization," Nieman Reports, Feb. 2019. [Online]. Available: https://niemanreports.org/articles/the-power-of-personalization/

[47] M. Powers, "In forms that are familiar and yet-to-be invented," *J. Commun. Inquiry*, vol. 36, no. 1, pp. 24–43, 2012.

[48] N. Thurman and S. Schifferes, "The future of personalization at news websites," *Journalism Stud.*, vol. 13, no. 5/6, pp. 775–790, 2012.

[49] M. Haim, A. Graefe, and H.-B. Brosius, "Burst of the filter bubble?," *Digit. Journalism*, vol. 6, no. 3, pp. 330–343, 2018.

[50] S. Flaxman, S. Goel, and J. M. Rao, "Filter bubbles, echo chambers, and online news consumption," *Public Opin. Quart.*, vol. 80, no. S1, pp. 298–320, Mar. 2016. [Online]. Available: https://doi.org/10.1093/poq/nfw006

[51] M. Coddington, "Clarifying journalism's quantitative turn," *Digit. Journalism*, vol. 3, no. 3, pp. 331–348, 2015. [Online]. Available: https://dx.doi.org/10.1080/21670811.2014.976400

[52] A. Gynnild, "Journalism innovation leads to innovation journalism: The impact of computational exploration on changing mindsets," *Journalism*, vol. 15, no. 6, pp. 713–730, 2014.

[53] N. Thurman, "Computational journalism," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 180–195.

[54] P. Meyer, "Defining and measuring credibility of newspapers: Developing an index," *Journalism Quart.*, vol. 65, no. 3, pp. 567–574, 1988.

[55] A. B. Howard, "The art and science of data-driven journalism," *Academic Commons*, 2014. [Online]. Available: https://academiccommons.columbia.edu/doi/10.7916/D8Q531V1?ref=https://githubhelp.com

[56] J. Gray, L. Bounegru, and L. Chambers, *The Data Journalism Handbook: How Journalists can Use Data to Improve the News*. Sebastopol, CA, USA: O'Reilly Media, 2012.

[57] A. Holovaty, "A fundamental way newspaper sites need to change," 2006. [Online]. Available: http://www.holovaty.com/writing/fundamental-change/

[58] L. Bounegru, "Data journalism in perspective," in *The Data Journalism Handbook*. Sebastopol, CA, USA: O'Reilly Media, 2012.

[59] N. Diakopoulos, *A Functional Roadmap for Innovation in Computational Journalism*, 2011. [Online]. Available: http://www.nickdiakopoulos.com/wp-content/uploads/2007/05/CJ_Whitepaper_Diakopoulos.pdf

[60] T. Flew, C. Spurgeon, A. Daniel, and A. Swift, "The promise of computational journalism," *Journalism Pract.*, vol. 6, no. 2, pp. 157–171, 2012.

[61] L. Leppänen, H. Tuulonen, and S. Sirén-Heikel, "Automated journalism as a source of and a diagnostic device for bias in reporting," *Media Commun.*, vol. 8, no. 3, pp. 39–49, 2020.

[62] N. Diakopoulos, "Algorithmic accountability," *Digit. Journalism*, vol. 3, no. 3, pp. 398–415, 2015. [Online]. Available: https://dx.doi.org/10.1080/21670811.2014.976411

[63] N. Diakopoulos and M. Koliska, "Algorithmic transparency in the news media," *Digit. Journalism*, vol. 5, no. 7, pp. 809–828, 2017.

[64] P. Hammond, "From computer-assisted to data-driven: Journalism and big data," *Journalism*, vol. 18, no. 4, pp. 408–424, 2017. [Online]. Available: https://dx.doi.org/10.1177/1464884915620205

[65] S. Parasie and E. Dagiral, "Data-driven journalism and the public good: "Computer-assisted-reporters" and "programmer-journalists" in Chicago," *New Media Soc.*, vol. 15, no. 6, pp. 853–871, 2013.

[66] I. Meijer, "Journalism, audiences, and news experience," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 389–405.

[67] G. T. G. Center, "Journalism 3G: The future of technology in the field: A symposium on computation + journalism," Feb. 2008. [Online]. Available: https://web.archive.org/web/20100103125218/http://www.computational-journalism.com/symposium/index.php

[68] J. T. Hamilton and F. Turner, "Accountability through algorithm: Developing the field of computational journalism," in *Proc. Rep. Center Adv. Study Behav. Sci. Summer Workshop*, 2009, pp. 27–41.

[69] S. Cohen, J. T. Hamilton, and F. Turner, "Computational journalism," *Commun. ACM*, vol. 54, no. 10, pp. 66–71, 2011. [Online]. Available: https://dx.doi.org/10.1145/2001269.2001288

[70] S. C. Lewis and O. Westlund, "Actors, actants, audiences, and activities in cross-media news work," *Digit. Journalism*, vol. 3, no. 1, pp. 19–37, 2015. [Online]. Available: https://dx.doi.org/10.1080/21670811.2014.927986

[71] M. Schudson, *Why Democracies Need an Unlovable Press*. Hoboken, NJ, USA: Wiley, 2008. [Online]. Available: https://books.google.com/books?id=Q2Dg55cxgfUC

[72] M. Schudson, "News and democratic society: Past, present, and future," *Hedgehog Rev.*, vol. 10, no. 2, pp. 7–21, 2008.

[73] N. Usher, "Michael Schudson: Why democracies need an unlovable press," 2009. [Online]. Available: https://ijoc.org/index.php/ijoc/article/view/582/342.

[74] R. Abebe, S. Barocas, J. Kleinberg, K. Levy, M. Raghavan, and D. G. Robinson, "Roles for computing in social change," in *Proc. Conf. Fairness Accountability Transparency*, 2020, pp. 252–260. [Online]. Available: https://doi.org/10.1145/3351095.3372871

[75] J. D. Wolfgang, "Pursuing the ideal: How news website commenting policies structure public discourse," *Digit. Journalism*, vol. 4, no. 6, pp. 764–783, 2016.

[76] M. Carlson, "The robotic reporter," *Digit. Journalism*, vol. 3, no. 3, pp. 416–431, 2015.

[77] A. Graefe, "Guide to automated journalism," *Columbia Journalism Rev.*, 2016. [Online]. Available: https://www.cjr.org/tow_center_reports/guide_to_automated_journalism.php#executive-summary

[78] L. Leppänen, M. Munezero, M. Granroth-Wilding, and H. Toivonen, "Data-driven news generation for automated journalism," in *Proc. 10th Int. Conf. Natural Lang. Gener.*, 2017, pp. 188–197. [Online]. Available: https://aclanthology.org/W17--3528

[79] B. Mittelstadt, "Automation, algorithms, and politics|auditing for transparency in content personalization systems," *Int. J. Commun.*, vol. 10, 2016, Art. no. 12. [Online]. Available: https://ijoc.org/index.php/ijoc/article/view/6267/1808

[80] D. M. J. Lazer et al., "The science of fake news," *Science*, vol. 359, no. 6380, pp. 1094–1096, 2018. [Online]. Available: https://www.science.org/doi/abs/10.1126/science.aao2998

[81] S. Card, S. Shneiderman, M. Card, J. Mackinlay, and B. Shneiderman, *Readings in Information Visualization: Using Vision to Think*. Amsterdam, The Netherlands: Elsevier, 1999. [Online]. Available: https://books.google.com/books?id=wdh2gqWfQmgC

[82] D. Norman, *Things That Make us Smart: Defending Human Attributes in the Age of the Machine*. New York, NY, USA: Diversion Books, 2014. [Online]. Available: https://books.google.com/books?id=yPKkBQAAQBAJ

[83] J. Fekete, J. J. van Wijk, J. T. Stasko, and C. North, "The value of information visualization," in *Information Visualization - Human-Centered Issues and Perspectives*, A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds., Berlin, Germany: Springer, 2008, pp. 1–18.

[84] J. Stasko, "Value-driven evaluation of visualizations," in *Proc. 5th Workshop Beyond Time Errors: Novel Eval. Methods Visualization*, 2014, pp. 46–53. [Online]. Available: https://doi.org/10.1145/2669557.2669579

[85] N. Elmqvist, A. V. Moere, H.-C. Jetter, D. Cernea, H. Reiterer, and T. Jankun-Kelly, "Fluid interaction for information visualization," *Inf. Visualization*, vol. 10, no. 4, pp. 327–340, 2011. [Online]. Available: https://dx.doi.org/10.1177/1473871611413180

[86] Y. Wang et al., "An emotional response to the value of visualization," *IEEE Comput. Graph. Appl.*, vol. 39, no. 5, pp. 8–17, Sep./Oct. 2019.

[87] Z. Pousman, J. Stasko, and M. Mateas, "Casual information visualization: Depictions of data in everyday life," *IEEE Trans. Vis. Comput. Graph.*, vol. 13, no. 6, pp. 1145–1152, Nov./Dec. 2007.

[88] M. Danziger, "Information visualization for the people," *Mit.edu*, 2008. [Online]. Available: https://dspace.mit.edu/handle/1721.1/43199

[89] D. Sprague and M. Tory, "Exploring how and why people use visualizations in casual contexts: Modeling user goals and regulated motivations," *Inf. Visualization*, vol. 11, no. 2, pp. 106–123, 2012.

[90] X. Lan, Y. Shi, Y. Zhang, and N. Cao, "Smile or scowl? Looking at infographic design through the affective lens," *IEEE Trans. Vis. Comput. Graph.*, vol. 27, no. 6, pp. 2796–2807, Jun. 2021.

[91] E. Lee-Robbins and E. Adar, "Affective learning objectives for communicative visualizations," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 1, pp. 1–11, Jan. 2023.

[92] B. Saket, A. Endert, and J. Stasko, "Beyond usability and performance: A review of user experience-focused evaluations in visualization," in *Proc. 6th Workshop Beyond Time Errors Novel Eval. Methods Visualization*, 2016, pp. 133–142. [Online]. Available: https://doi.org/10.1145/2993901.2993903

[93] A. Cairo, *The Functional Art: An Introduction to Information Graph. and Visualization*. London, U.K.: Pearson Education, 2012. [Online]. Available: https://books.google.com/books?id=xwjhh6Wu-VUC

[94] S. Cohen, "Using visualizations to tell stories," in *The Data Journalism Handbook*. Sebastopol, CA, USA: O'Reilly Media, 2011. [Online]. Available: https://datajournalism.com/read/handbook/one/delivering-data/using-visualizations-to-tell-stories

[95] S. C. Lewis and O. Westlund, "Big data and journalism," *Digit. Journalism*, vol. 3, no. 3, pp. 447–466, 2015.

[96] A. Thudt, J. Walny, T. Gschwandtner, J. Dykes, and J. Stasko, "Exploration and explanation in data-driven storytelling," in *Data-Driven Storytelling*, N. H. Riche, C. Hurter, N. Diakopoulos, and S. Carpendale, Eds., Boca Raton, FL, USA: CRC Press, 2018, pp. 59–83.

[97] J. Stasko, C. Görg, and Z. Liu, "Jigsaw: Supporting investigative analysis through interactive visualization," *Inf. Visualization*, vol. 7, no. 2, pp. 118–132, 2008.

[98] M. Brehmer, S. Ingram, J. Stray, and T. Munzner, "Overview: The design, adoption, and analysis of a visual document mining tool for investigative journalists," *IEEE Trans. Vis. Comput. Graph.*, vol. 20, no. 12, pp. 2271–2280, Dec. 2014.

[99] F. B. Viegas, M. Wattenberg, F. van Ham, J. Kriss, and M. McKeon, "ManyEyes: A site for visualization at internet scale," *IEEE Trans. Vis. Comput. Graph.*, vol. 13, no. 6, pp. 1121–1128, Nov./Dec. 2007.

[100] C. Stolte, D. Tang, and P. Hanrahan, "Polaris: A system for query, analysis, and visualization of multidimensional relational databases," *IEEE Trans. Vis. Comput. Graph.*, vol. 8, no. 1, pp. 52–65, First Quarter 2002.

[101] B. Houston, "The history of data journalism: A historical take on every critical breakthrough from the 1950s until today," 2021. [Online]. Available: https://datajournalism.com/read/longreads/the-history-of-data-journalism

[102] F. Chevalier et al., "From analysis to communication," in *Data-Driven Storytelling*, N. H. Riche, C. Hurter, N. Diakopoulos, and S. Carpendale, Eds., Boca Raton, FL, USA: CRC Press, 2018, pp. 151–183.

[103] A. Satyanarayan, R. Russell, J. Hoffswell, and J. Heer, "Reactive vega: A streaming dataflow architecture for declarative interactive visualization," *IEEE Trans. Vis. Comput. Graph.*, vol. 22, no. 1, pp. 659–668, Jan. 2016.

[104] B. Lee, R. H. Kazi, and G. Smith, "SketchStory: Telling more engaging stories with data through freeform sketching," *IEEE Trans. Vis. Comput. Graph.*, vol. 19, no. 12, pp. 2416–2425, Dec. 2013.

[105] A. Satyanarayan and J. Heer, "Lyra: An interactive visualization design environment," *Comput. Graph. Forum*, vol. 33, no. 3, pp. 351–360, 2014. [Online]. Available: https://dx.doi.org/10.1111/cgf.12391

[106] Z. Liu et al., "Data Illustrator: Augmenting vector design tools with lazy data binding for expressive visualization authoring," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2018, pp. 1–13. [Online]. Available: https://doi.org/10.1145/3173574.3173697

[107] D. Ren, B. Lee, and M. Brehmer, "Charticulator: Interactive construction of bespoke chart layouts," *IEEE Trans. Vis. Comput. Graph.*, vol. 25, no. 1, pp. 789–799, Jan. 2019.

[108] J. Zong, D. Barnwal, R. Neogy, and A. Satyanarayan, "Lyra 2: Designing interactive visualizations by demonstration," *IEEE Trans. Vis. Comput. Graph.*, vol. 27, no. 2, pp. 304–314, Feb. 2021.

[109] J. R. Thompson, Z. Liu, and J. Stasko, "Data animator: Authoring expressive animated data graphics," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2021, Art. no. 15. [Online]. Available: https://doi.org/10.1145/3411764.3445747

[110] M. Conlen, M. Vo, A. Tan, and J. Heer, "Idyll studio: A structured editor for authoring interactive & data-driven articles," in *Proc. 34th Annu. ACM Symp. User Interface Softw. Technol.*, 2021, pp. 1–12. [Online]. Available: https://doi.org/10.1145/3472749.3474731

[111] Z. Chen and H. Xia, "CrossData: Leveraging text-data connections for authoring data documents," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2022, Art. no. 95. [Online]. Available: https://doi.org/10.1145/3491102.3517485

[112] Y. Cao, J. L. E., Z. Chen, and H. Xia, "DataParticles: Block-based and language-oriented authoring of animated unit visualizations," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2023, Art. no. 808. [Online]. Available: https://doi.org/10.1145/3544548.3581472

[113] A. Satyanarayan and J. Heer, "Authoring narrative visualizations with ellipsis," *Comput. Graph. Forum*, vol. 33, no. 3, pp. 361–370, 2014. [Online]. Available: https://dx.doi.org/10.1111/cgf.12392

[114] A. Satyanarayan et al., "Critical reflections on visualization authoring systems," *IEEE Trans. Vis. Comput. Graph.*, vol. 26, no. 1, pp. 461–471, Jan. 2020.

[115] M. Conlen and J. Heer, "Idyll: A markup language for authoring and publishing interactive articles on the web," in *Proc. 31st Annu. ACM Symp. User Interface Softw. Technol.*, 2018, pp. 977–989. [Online]. Available: https://doi.org/10.1145/3242587.3242600

[116] A. Satyanarayan, D. Moritz, K. Wongsuphasawat, and J. Heer, "Vega-Lite: A grammar of interactive graphics," *IEEE Trans. Vis. Comput. Graph.*, vol. 23, no. 1, pp. 341–350, Jan. 2017.

[117] Y. Fu and J. Stasko, "Supporting data-driven basketball journalism through interactive visualization," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2022, Art. no. 598. [Online]. Available: https://doi.org/10.1145/3491102.3502078

[118] S. Gratzl, A. Lex, N. Gehlenborg, N. Cosgrove, and M. Streit, "From visual exploration to storytelling and back again," *Comput. Graph. Forum*, vol. 35, no. 3, pp. 491–500, 2016. [Online]. Available: https://dx.doi.org/10.1111/cgf.12925

[119] S. Chen et al., "Supporting story synthesis: Bridging the gap between visual analytics and storytelling," *IEEE Trans. Vis. Comput. Graph.*, vol. 26, no. 7, pp. 2499–2516, Jul. 2020.

[120] E. L. Hutchins, J. D. Hollan, and D. A. Norman, "Direct manipulation interfaces," *Hum.-Comput. Interact.*, vol. 1, no. 4, pp. 311–338, 1985.

[121] J. Hullman, N. Diakopoulos, E. Momeni, and E. Adar, "Content, context, and critique: Commenting on a data visualization blog," in *Proc. 18th ACM Conf. Comput. Supported Cooperative Work Social Comput.*, 2015, pp. 1170–1175. [Online]. Available: https://doi.org/10.1145/2675133.2675207

[122] N. J. Stroud, E. Van Duyn, and C. Peacock, "News commenters and news comment readers," *Engaging News Project*, pp. 1–21, 2016. [Online]. Available: https://mediaengagement.org/wp-content/uploads/2016/03/ENP-News-Commenters-and-Comment-Readers1.pdf

[123] P. J. Boczkowski and E. Mitchelstein, "How users take advantage of different forms of interactivity on online news sites: Clicking, e-mailing, and commenting," *Hum. Commun. Res.*, vol. 38, no. 1, pp. 1–22, 2012.

[124] E. Dong, H. Du, and L. Gardner, "An interactive web-based dashboard to track COVID-19 in real time," *Lancet Infect. Dis.*, vol. 20, no. 5, pp. 533–534, 2020.

[125] A. Sarikaya, M. Correll, L. Bartram, M. Tory, and D. Fisher, "What do we talk about when we talk about dashboards?," *IEEE Trans. Vis. Comput. Graph.*, vol. 25, no. 1, pp. 682–692, Jan. 2019.

[126] M. L. Young, A. Hermida, and J. Fulda, "What makes for great data journalism?," *Journalism Pract.*, vol. 12, no. 1, pp. 115–135, 2018.

[127] B. Bach et al., "Dashboard design patterns," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 1, pp. 342–352, Jan. 2023.

[128] S. Carpendale, "Evaluating information visualizations," in *Information Visualization - Human-Centered Issues and Perspectives*, A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds., Berlin, Germany: Springer, 2008, pp. 19–45. [Online]. Available: https://doi.org/10.1007/978--3-540-70956-5_2

[129] B. Shneiderman and C. Plaisant, "Strategies for evaluating information visualization tools: Multi-dimensional in-depth long-term case studies," in *Proc. AVI Workshop Beyond Time Errors: Novel Eval. Methods Inf. Visualization*, 2006, pp. 1–7. [Online]. Available: https://doi.org/10.1145/1168149.1168158

[130] M. Sedlmair, M. Meyer, and T. Munzner, "Design study methodology: Reflections from the trenches and the stacks," *IEEE Trans. Vis. Comput. Graph.*, vol. 18, no. 12, pp. 2431–2440, Dec. 2012.

[131] M. Meyer and J. Dykes, "Criteria for rigor in visualization design study," *IEEE Trans. Vis. Comput. Graph.*, vol. 26, no. 1, pp. 87–97, Jan. 2020.

[132] J. Zimmerman and J. Forlizzi, "Research through design in HCI," in *Ways of Knowing in HCI*. Berlin, Germany: Springer, 2014, pp. 167–189.

[133] J. Zimmerman, J. Forlizzi, and S. Evenson, "Research through design as a method for interaction design research in HCI," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2007, pp. 493–502. [Online]. Available: https://doi.org/10.1145/1240624.1240704

[134] D. Domingo, "Interactivity in the daily routines of online newsrooms: Dealing with an uncomfortable myth," *J. Comput.-Mediated Commun.*, vol. 13, no. 3, pp. 680–704, 2008. [Online]. Available: https://dx.doi.org/10.1111/j.1083--6101.2008.00415.x

[135] T. Munzner, "Process and pitfalls in writing information visualization research papers," in *Information Visualization: Human-Centered Issues and Perspectives*, A. Kerren, J. T. Stasko, J.-D. Fekete, and C. North, Eds., Berlin, Germany: Springer, 2008, pp. 134–153. [Online]. Available: https://doi.org/10.1007/978--3-540-70956-5_6

[136] F. Amini, N. H. Riche, B. Lee, A. Monroy-Hernandez, and P. Irani, "Authoring data-driven videos with DataClips," *IEEE Trans. Vis. Comput. Graph.*, vol. 23, no. 1, pp. 501–510, Jan. 2017.

[137] Z. Chen et al., "Augmenting sports videos with VisCommentator," *IEEE Trans. Vis. Comput. Graph.*, vol. 28, no. 1, pp. 824–834, Jan. 2022.

[138] M. Shin et al., "Roslingifier: Semi-automated storytelling for animated scatterplots," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 6, pp. 2980–2995, Jun. 2023.

[139] Z. Chen et al., "Sporthesia: Augmenting sports videos using natural language," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 1, pp. 918–928, Jan. 2023.

[140] T. Tang, J. Tang, J. Hong, L. Yu, P. Ren, and Y. Wu, "Design guidelines for augmenting short-form videos using animated data visualizations," *J. Visualization*, vol. 23, no. 4, pp. 707–720, 2020. [Online]. Available: https://doi.org/10.1007/s12650--020-00644-z

[141] T. Lin, Z. Chen, Y. Yang, D. Chiappalupi, J. Beyer, and H. Pfister, "The quest for: Embedded visualization for augmenting basketball game viewing experiences," *IEEE Trans. Vis. Comput. Graph.*, vol. 29, no. 1, pp. 962–971, Jan. 2023.

[142] M. Wattenberg, "Baby names, visualization, and social data analysis," in *Proc. IEEE Symp. Inf. Visualization*, 2005, pp. 1–7.

[143] B. Lee, E. K. Choe, P. Isenberg, K. Marriott, and J. Stasko, "Reaching broader audiences with data visualization," *IEEE Comput. Graph. Appl.*, vol. 40, no. 2, pp. 82–90, Mar./Apr. 2020.

[144] B. Lee, A. Srinivasan, J. Stasko, M. Tory, and V. Setlur, "Multimodal interaction for data visualization," in *Proc. Int. Conf. Adv. Vis. Interfaces*, 2018, Art. no. 11. [Online]. Available: https://doi.org/10.1145/3206505.3206602

[145] B. Lee, A. Srinivasan, P. Isenberg, and J. Stasko, "Post-WIMP interaction for information visualization," *Found. Trends Hum.-Comput. Interact.*, vol. 14, no. 1, pp. 1–95, 2021.

[146] S. Reeves, S. Benford, C. O'Malley, and M. Fraser, "Designing the spectator experience," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2005, pp. 741–750. [Online]. Available: https://doi.org/10.1145/1054972.1055074

[147] Q. Zhi, S. Lin, P. T. Sukumar, and R. Metoyer, "GameViews: Understanding and supporting data-driven sports storytelling," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2019, pp. 1–13. [Online]. Available: https://doi.org/10.1145/3290605.3300499

[148] C. Görg, Z. Liu, J. Kihm, J. Choo, H. Park, and J. Stasko, "Combining computational analyses and interactive visualization for document exploration and sensemaking in Jigsaw," *IEEE Trans. Vis. Comput. Graph.*, vol. 19, no. 10, pp. 1646–1663, Oct. 2013.

[149] C. Görg, Z. Liu, and J. Stasko, "Reflections on the evolution of the Jigsaw visual analytics system," *Inf. Visualization*, vol. 13, no. 4, pp. 336–345, 2014.

[150] Y.-A. Kang, C. Görg, and J. Stasko, "How can visual analytics assist investigative analysis? Design implications from an evaluation," *IEEE Trans. Vis. Comput. Graph.*, vol. 17, no. 5, pp. 570–583, May 2011.

[151] T. Erickson and W. A. Kellogg, "Social translucence," *ACM Trans. Comput.-Hum. Interact.*, vol. 7, no. 1, pp. 59–83, 2000.

[152] M. Eslami et al., ""I always assumed that I wasn't really that close to [her]": Reasoning about invisible algorithms in news feeds," in *Proc. 33rd Annu. ACM Conf. Hum. Factors Comput. Syst.*, 2015, pp. 153–162. [Online]. Available: https://doi.org/10.1145/2702123.2702556

[153] J. Choo and S. Liu, "Visual analytics for explainable deep learning," *IEEE Comput. Graph. Appl.*, vol. 38, no. 4, pp. 84–92, Jul./Aug. 2018.

[154] W. Samek, T. Wiegand, and K.-R. Müller, "Explainable artificial intelligence: Understanding, visualizing and interpreting deep learning models," 2017, *arXiv: 1708.08296*.

[155] F. Hohman, M. Kahng, R. Pienta, and D. H. Chau, "Visual analytics in deep learning: An interrogative survey for the next frontiers," *IEEE Trans. Vis. Comput. Graph.*, vol. 25, no. 8, pp. 2674–2693, Aug. 2019.

[156] Z. J. Wang et al., "CNN explainer: Learning convolutional neural networks with interactive visualization," *IEEE Trans. Vis. Comput. Graph.*, vol. 27, no. 2, pp. 1396–1406, Feb. 2021.

[157] J. Burrell, "How the machine 'thinks': Understanding opacity in machine learning algorithms," *Big Data Soc.*, vol. 3, no. 1, pp. 1–12, 2016. [Online]. Available: https://doi.org/10.1177/2053951715622512

[158] M. T. Ribeiro, S. Singh, and C. Guestrin, ""Why should I trust you?": Explaining the predictions of any classifier," in *Proc. 22nd ACM SIGKDD Int. Conf. Knowl. Discov. Data Mining*, 2016, pp. 1135–1144. [Online]. Available: https://doi.org/10.1145/2939672.2939778

[159] D. Lupton, "Feeling your data: Touch and making sense of personal digital data," *New Media Soc.*, vol. 19, no. 10, pp. 1599–1614, 2017. [Online]. Available: https://doi.org/10.1177/1461444817717515

[160] G. Lupi, S. Posavec, and M. Popova, *Dear Data*. New York, NY, USA: Princeton Architectural Press, 2016. [Online]. Available: https://books.google.com/books?id=YorTDAAAQBAJ

[161] J. Kastrenakes and J. Peters, "Webby awards 2020: The complete winners list," The Verge, May 2020. [Online]. Available: https://www.theverge.com/2020/5/20/21263445/2020-webby-awards-winners-lil-nas-x-nasa-jon-krasinski

[162] Story portrait, The New York Times, 2020. [Online]. Available: https://help.nytimes.com/hc/en-us/articles/6921803704468

[163] S. Munson, S. Lee, and P. Resnick, "Encouraging reading of diverse political viewpoints with a browser widget," in *Proc. Int. AAAI Conf. Web Social Media*, 2021, pp. 419–428.

[164] G. R. Hayes, "The relationship of action research to human-computer interaction," *ACM Trans. Comput.-Hum. Interact.*, vol. 18, no. 3, pp. 1–20, 2011. [Online]. Available: https://dx.doi.org/10.1145/1993060.1993065

[165] G. Hayes, *Knowing by Doing: Action Research as an Approach to HCI*. New York, NY, USA: Springer, 2014, pp. 49–68.

[166] VisualizeNews, "India goes to polls," Indian General Elections 2019, 2019. [Online]. Available: https://india.visualize.news/

[167] N. Nigro, "Hamilton 2.0 dashboard," Alliance For Securing Democracy, 2022. [Online]. Available: https://securingdemocracy.gmfus.org/hamilton-dashboard/

[168] L. Nicoletti and S. Sarva, "When women make headlines: A visual essay about the (mis)representation of women in the news," The Pudding, 2021. [Online]. Available: https://pudding.cool/2022/02/women-in-headlines/

[169] N. McCurdy, J. Dykes, and M. Meyer, "Action design research and visualization design," in *Proc. 6th Workshop Beyond Time Errors Novel Eval. Methods Visualization*, 2016, pp. 10–18. [Online]. Available: https://doi.org/10.1145/2993901.2993916

[170] J. Zhou, Y. Zhang, Q. Luo, A. G. Parker, and M. De Choudhury, "Synthetic lies: Understanding AI-generated misinformation and evaluating algorithmic and human solutions," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2023, Art. no. 436. [Online]. Available: https://doi.org/10.1145/3544548.3581318
[171] K. Shu, D. Mahudeswaran, and H. Liu, "FakeNewsTracker: A tool for fake news collection, detection, and visualization," *Comput. Math. Org. Theory*, vol. 25, no. 1, pp. 60–71, 2019.
[172] A. Karduni et al., "Vulnerable to misinformation? Verifi!," in *Proc. 24th Int. Conf. Intell. User Interfaces*, 2019, pp. 312–323. [Online]. Available: https://doi.org/10.1145/3301275.3302320
[173] A. Karduni et al., "Can you verifi this? Studying uncertainty and decision-making about misinformation using visual analytics," in *Proc. Int. AAAI Conf. Web Social Media*, 2018, pp. 151–160. [Online]. Available: https://ojs.aaai.org/index.php/ICWSM/article/view/15014
[174] S. Lee et al., "MisVis: Explaining web misinformation connections via visual summary," in *Proc. Extended Abstr. CHI Conf. Hum. Factors Comput. Syst.*, 2022, Art. no. 228. [Online]. Available: https://doi.org/10.1145/3491101.3519711
[175] D. Lazer et al., "Combating fake news: An agenda for research and action," 2017. [Online]. Available: https://apo.org.au/node/76233
[176] H. Rashkin, E. Choi, J. Y. Jang, S. Volkova, and Y. Choi, "Truth of varying shades: Analyzing language in fake news and political fact-checking," in *Proc. Conf. Empirical Methods Natural Lang. Process.*, 2017, pp. 2931–2937. [Online]. Available: https://aclanthology.org/D17--1317
[177] E. Wall, A. Narechania, A. Coscia, J. Paden, and A. Endert, "Left, right, and gender: Exploring interaction traces to mitigate human biases," *IEEE Trans. Vis. Comput. Graph.*, vol. 28, no. 1, pp. 966–975, Jan. 2022.
[178] A. Narechania, A. Coscia, E. Wall, and A. Endert, "Lumos: Increasing awareness of analytic behavior during visual data analysis," *IEEE Trans. Vis. Comput. Graph.*, vol. 28, no. 1, pp. 1009–1018, Jan. 2022.
[179] A. D. Holan, "The principles of the Truth-O-Meter: PolitiFact's methodology for independent fact-checking," Politifact, 2020. [Online]. Available: https://www.politifact.com/article/2018/feb/12/principles-truth-o-meter-politifacts-methodology-i/
[180] C. R. Sunstein, S. C. Lazzaro, and T. Sharot, "How people update beliefs about climate change: Good news and bad news," *SSRN Electron. J.*, 2016.
[181] A. V. Pandey, K. Rall, M. L. Satterthwaite, O. Nov, and E. Bertini, "How deceptive are deceptive visualizations? An empirical analysis of common distortion techniques," in *Proc. 33rd Annu. ACM Conf. Hum. Factors Comput. Syst.*, 2015, pp. 1469–1478. [Online]. Available: https://doi.org/10.1145/2702123.2702608
[182] A. Fan, Y. Ma, M. Mancenido, and R. Maciejewski, "Annotating line charts for addressing deception," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2022, pp. 1–12. [Online]. Available: https://doi.org/10.1145/3491102.3502138
[183] A. McNutt, G. Kindlmann, and M. Correll, "Surfacing visualization mirages," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2020, pp. 1–16. [Online]. Available: https://doi.org/10.1145/3313831.3376420
[184] A. K. Hopkins, M. Correll, and A. Satyanarayan, "VisuaLint: Sketchy in situ annotations of chart construction errors," *Comput. Graph. Forum*, vol. 39, no. 3, pp. 219–228, 2020.
[185] The White House, "We just learned that President Biden's first year in office was the strongest year for economic growth since 1984," 2022. [Online]. Available: https://twitter.com/WhiteHouse/status/1486709480351952901
[186] B. E. Rogowitz, L. A. Treinish, and S. Bryson, "How not to lie with visualization," *Comput. Phys.*, vol. 10, no. 3, 1996, Art. no. 268.
[187] E. R. Tufte, *The Visual Display of Quantitative Information*, 2nd ed. Cheshire, CT, USA: Graphics Press, 2001.
[188] M. A. Borkin et al., "Beyond memorability: Visualization recognition and recall," *IEEE Trans. Vis. Comput. Graph.*, vol. 22, no. 1, pp. 519–528, Jan. 2016.
[189] H.-K. Kong, Z. Liu, and K. Karahalios, "Frames and slants in titles of visualizations on controversial topics," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2018, pp. 1–12.
[190] H.-K. Kong, Z. Liu, and K. Karahalios, "Trust and recall of information across varying degrees of title-visualization misalignment," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2019, pp. 1–13. [Online]. Available: https://doi.org/10.1145/3290605.3300576
[191] P.-M. Law, A. Endert, and J. Stasko, "Characterizing automated data insights," in *Proc. IEEE Visualization Conf.*, 2020, pp. 171–175.
[192] C. Oh et al., "Understanding user perception of automated news generation system," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2020, pp. 1–13. [Online]. Available: https://doi.org/10.1145/3313831.3376811
[193] Y. Wang et al., "DataShot: Automatic generation of fact sheets from tabular data," *IEEE Trans. Vis. Comput. Graph.*, vol. 26, no. 1, pp. 895–905, Jan. 2020.
[194] C. Bryan, K.-L. Ma, and J. Woodring, "Temporal summary images: An approach to narrative visualization via interactive annotation generation and placement," *IEEE Trans. Vis. Comput. Graph.*, vol. 23, no. 1, pp. 511–520, Jan. 2017.
[195] D. Shi, X. Xu, F. Sun, Y. Shi, and N. Cao, "Calliope: Automatic visual data story generation from a spreadsheet," *IEEE Trans. Vis. Comput. Graph.*, vol. 27, no. 2, pp. 453–463, Feb. 2021.
[196] A. Srinivasan, S. M. Drucker, A. Endert, and J. Stasko, "Augmenting visualizations with interactive data facts to facilitate interpretation and communication," *IEEE Trans. Vis. Comput. Graph.*, vol. 25, no. 1, pp. 672–681, Jan. 2019.
[197] I. Bogost, S. Ferrari, and B. Schweizer, *Newsgames: Journalism at Play*. Cambridge, MA, USA: MIT Press, 2012. [Online]. Available: https://books.google.com/books?id=JrK2CAAAQBAJ
[198] N. Diakopoulos, F. Kivran-Swaine, and M. Naaman, "Playable data: Characterizing the design space of game-y infographics," in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2011, pp. 1717–1726.
[199] P. Isenberg, B. Lee, H. Qu, and M. Cordeil, "Immersive visual data stories," in *Immersive Analytics*, K. Marriott, F. Schreiber, T. Dwyer, K. Klein, N. H. Riche, T. Itoh, W. Stuerzlinger, and B. H. Thomas, Eds., Cham, Switzerland: Springer, 2018, pp. 165–184. [Online]. Available: https://doi.org/10.1007/978--3-030-01388-2_6
[200] M. Broussard, "Archiving data journalism," O'Reilly Media, 2012. [Online]. Available: https://datajournalism.com/read/handbook/two/organising-data-journalism/archiving-data-journalism
[201] K. Boss and M. Broussard, "Challenges of archiving and preserving born-digital news applications," *IFLA J.*, vol. 43, no. 2, pp. 150–157, 2017.
[202] R. Kosara, "The bits are rotting in the state of data journalism," eagereyes, Jul. 2016. [Online]. Available: https://eagereyes.org/blog/2016/the-bits-are-rotting-in-the-state-of-data-journalism
[203] M. Broussard, "Preserving news apps present huge challenges," *Newspaper Res. J.*, vol. 36, no. 3, pp. 299–313, 2015.
[204] M. Broussard and K. Boss, "Saving data journalism," *Digit. Journalism*, vol. 6, no. 9, pp. 1206–1221, 2018.
[205] L. Ahva and S. Steensen, "Journalism theory," in *The Handbook of Journalism Studies*, K. Wahl-Jorgensen and T. Hanitzsch, Eds., 2nd ed. Evanston, IL, USA: Routledge, 2019, pp. 38–54.
[206] E. M. Peck, S. E. Ayuso, and O. El-Etr, "Data is personal: Attitudes and perceptions of data visualization in rural pennsylvania," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2019, pp. 1–12. [Online]. Available: https://doi.org/10.1145/3290605.3300474
[207] B. Alper, N. H. Riche, F. Chevalier, J. Boy, and M. Sezgin, "Visualization literacy at elementary school," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2017, pp. 5485–5497. [Online]. Available: https://doi.org/10.1145/3025453.3025877
[208] M. Correll, "Position paper: Are we making progress in visualization research?," in *Proc. IEEE Eval. Beyond - Methodological Approaches Visualization*, 2022, pp. 1–10.

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