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The Carrier Wave Principle

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In this article, we propose a new theoretical premise called the "carrier wave principle." It holds that there is no fixed limit to the amount and variety of knowledge that may be produced from a given cultural artifact. This can be understood in relation to the exponential growth in the power and ubiquity of computational processing, which has reduced the procedural distance between cultural production, transmission, archiving, reception, and analysis. The resulting cascade of new interpretive epistemes has challenged the capacity of individuals, communities, and institutions to adapt, posing real-world challenges for privacy, identity, and subjectivity. We conclude that this principle will be integral to developing media, policies, and technologies that empower individuals and communities as computational processing continues to expand in adoption and scope.

Keywords: media studies, science and technology studies, information science, surveillance, privacy, authorship, affordances, computational analysis, forensics, epistemology

> The saddest aspect of life right now is that science gathers knowledge faster than society gathers wisdom. —Isaac Asimov (Asimov & Shulman, 1988, p. 281)

Hidden figures long buried beneath classic paintings by Rembrandt, Bruegel, and Picasso are revealed through infrared and x-ray imaging, changing our understanding of cultural and social history (Bradshaw, 2018; MacLennan et al., 2019; Rice, 2018). Researchers point a camera at a bag of potato chips stored behind a wall of soundproof glass, and "eavesdrop" on the people in the room with it by resynthesizing sound waves from the microscopic ripples on the bag's surface (Davis et al., 2014). Police arrest former police officer Joseph James DeAngelo as the alleged Golden State Killer, decades after his horrific crimes, based on a match between DNA samples and an open source genealogy website (Kaiser, 2018). Analysis of public data from a fitness app reveals the location and movements of secret military bases in war zones such as Syria and Afghanistan (Pérez-Peña & Rosenberg, 2018). A state judge orders online retail titan Amazon to hand over recordings of a private citizen's household collected by its Echo "smart device" as evidence in a murder trial (Ferguson, 2018).

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Each of these stories has something in common: cultural and technological artifacts (a painting, an app, a bag of chips), placed into new social and institutional contexts, and with the aid of computational technologies, end up revealing far more than their creators originally intended them to and, in many cases, more than they could have imagined.

Anecdotes such as these are often treated as *sui generis* novelties, strange episodes at the periphery of normal social, cultural, and technological processes. When they are discussed within a broader context, the scope of discussion is typically limited to the particularities of the case: The forensic analysis of old paintings is presented as an unalloyed benefit to art historians; the fitness app data are interpreted as a cybersecurity threat with consequences for America's strategic military interests; the use of Amazon Echo recordings in a murder case revives longstanding debates about the relative social benefits of surveillance and privacy. Not only are these contexts wholly separate from one another, each is framed as contiguous with predigital practices and concerns. The addition of computational analysis, therefore, is relegated to little more than a new twist on an old story: Forensic art history adds a new tool; military security faces a new threat.

Although each of these contexts is certainly appropriate for the case study in question, and each site-specific discussion deserves merit in its own right, we argue in this article that the broader principle that unites them is also worthy of investigation, and may have profound implications for media studies as a field of research and for media as a site of social action. Individually, the examples we cite may represent historical continuity within their separate spheres, but collectively they represent a distinct rupture in the relationship between media and society, and require us to reinvestigate our assumptions about culture, technology, and policy, as well as the interdependencies among them.

Specifically, we argue that, although anecdotes such as those we have cited are commonly understood and presented as proverbial "exceptions that prove the rule," or what are often referred to as "edge cases," in the parlance of engineering and law (Powell, 2015), and therefore notable for their ambiguous ethics or interpretive valence, they are actually exemplary of a much broader principle that applies to all cultural artifacts, which for reasons that will become clear, we refer to as the "carrier wave principle." The rudiments of this principle can be summarized thus:

- There is no fixed limit to the amount and variety of knowledge that may be produced[1] from a given cultural artifact. This may be understood via the concept of "*n*-way,"

[1] We intentionally use the verb *produced* in this framing to emphasize that knowledge is not an inherent quality of a text or artifact, but something derived from it. This framing draws on Machlup (1962), for whom the term refers to something "socially new" (p. 145) generated—and, more importantly, shared—by researchers and creators. We also use it to invoke Foucault (1995), for whom the production of knowledge is inherently an act of power. Finally, in this article, we take pains to differentiate among terms such as *data*, *information*, and *knowledge*, adhering to the accepted categorical delineations outlined in the field of information science (see Zins, 2007), while bearing in mind that the very subject of our article—the epistemological disruptions engendered by computational processing—demands a reinvestigation of these categorical differences (Kitchin, 2014).

used in mathematics and computer science (e.g., Carroll & Chang, 1970; Kolda & Bader, 2009), to describe the greatest number of possible relationships among elements within or between data sets.

- As a given artifact is displaced temporally, geographically, and/or culturally from its origins, the tacit assumptions and omissions intrinsic to the circumstances of its production become increasingly evident, an epistemic shift that reframes the artifact not merely as a transmissive vessel for information, but as a site of inquiry itself. This *n*-way process is iterative and lateral, and as one episteme gives way to or competes with another (Foucault, 2005), multiple "layers" of knowledge may be produced from the same artifact.

- These two interrelated conditions (*n*-way potential meanings, generated via epistemic displacement) are immanent to mediated culture, and have been discussed, in various ways, by social theorists for thousands of years. Historically, the production of knowledge has been premised on a dialectical relationship between technology, on the one hand, and culture on the other.

- The addition of ubiquitous computational processing to a globally networked communications infrastructure has collapsed this dialectic, drastically reducing the latency among production, transmission, archiving, reception, and analysis. The sociotechnical affordances of this newly synthetic cultural infrastructure have catalyzed a cascade of new epistemes, which are so numerous, diverse, and irreconcilable that they challenge the capacity of individuals, communities, and institutions to adapt.

The challenges precipitated by the digitization of culture have been discussed extensively in terms related to crises of social institutions and power, including the need for "big data ethics" (boyd & Crawford, 2012; Richards & King, 2014; Zwitter, 2014), the disruptions to traditional media and communications industries (Craig & Cunningham, 2019; Wikström & DeFillippi, 2016), and the dangers of algorithmic governance (Gillespie, 2018; Sinnreich, 2018). Our aim in this article is to raise an additional crisis, which we view as causally proximate to the others: namely, that as the cultural infrastructure has become increasingly reliant on computational processing, everyday users have become commensurately less capable of understanding the consequences of their actions and interactions. Specifically, they are largely unaware, and uninformed, about the layers of knowledge that may be produced by any number of third parties from their creative, consumptive, and communicative practices (Gehl, 2011).

In short, digital technology—marketed to consumers as a tool of social progress and individual empowerment (Banet-Weiser, 2012; Wright, Pires, Stanton, & Rita, 2006)—has for the most part been designed and deployed to achieve fundamentally different ends. Primary among these is the production, stockpiling, synthesis, and commercial and political exploitation of data about users (Vaidhyanathan, 2018; West, 2019). In this article, we argue that, to develop cultural competencies, practices, and institutions necessary for digital technology to deliver on its promises, we must first theorize the conditions under which it has failed to do so.

Carrier Waves: A Brief Political History

Around the turn of the 20th century, researchers and inventors such as Morse, Marconi, and Tesla discovered that electromagnetic waves—a ubiquitous property of the natural world whose existence had been proven by Hertz in the 1880s—could be used to carry encoded information over long distances. This process built on principles explored by such researchers as Fourier, Germain, and Maxwell, who demonstrated that the qualities of waves in any medium may be described arithmetically, and that electromagnetic waves in particular may be transformed through the application of these mathematical principles.

Today, television, radio, and Wi-Fi transmissions all make use of this process. Using common standards, they encode information by modulating a given "carrier" waveform mathematically and transmit the encoded data via "channels" using designated frequency bands. This information is then decoded upon reception by extracting it from the carrier wave and making it legible via those same common standards. The 20th-century conceit of the broadcast channel may therefore be understood as the result of the commercial exploitation and consequent popular imaginary of the carrier wave as an engineering principle.

In classical engineering, as well as 20th-century broadcast industries and governance bodies, carrier waves were typically thought of as "neutral"—arbitrary and passive carriers of information. However, communication studies and science and technology studies (STS) scholarship (Dunbar-Hester, 2014; Slotten, 1995) has long argued that the establishment of carrier frequencies and encoding standards, as well as the laws, technologies, and economic relations that regulate and exploit the electromagnetic spectrum, are anything but neutral. In fact, the channelization of the spectrum can be understood as a map of the asymmetrical power relations between the multiple sets of stakeholders, such as programmers, manufacturers, rights holders, advertisers, audiences, and regulators themselves, who benefit from its commercial and governmental uses.

In a digital, networked context, the paradigm of the "neutral" medium—never more than a convenient (for some) fiction—becomes even more unsustainable. With the geometric growth in computational power and the ubiquity of data transmission across a range of different infrastructures, any media artifact or communication platform may be employed as a carrier wave by encoders and/or decoders, building on available conceptual and technological toolsets. In fact, the translation, manipulation, and synthesis of data as they move from one infrastructure to another, and one level of abstraction to another, are fundamental to all computational communications media, including but not limited to the Internet. This process is typically discussed in terms of moving data up and down "the stack" (Bratton, 2016; Farrel, 2004).

The carrier wave principle, as we postulate it, holds that every sociotechnical artifact, regardless of its intended or manifest cultural meaning, can be understood—not merely metaphorically, but with the same technosocial specificity that applies to carrier waves deployed in the context of radio or television broadcasts—as a carrier wave for *n*-way other potential meanings. These may be decoded with or without the knowledge (or, more significantly, the consent) of the artifact's creator(s), through the exploitation of a range of technological affordances (Gibson, 1979; Norman, 2013) both engineered (such as metadata fields in the case of a digital file) and environmental (such as sonic microvibrations in the case of a bag of chips).

In other words, given enough time and computational power, every material and informational object or assemblage may be added to the stack.

Just as a radio receiver must apply proper arithmetic and electronic transformations to successfully decode the audio signal carried on a given broadcasting channel, the *n*-way layers of information that may be derived from other sociotechnical artifacts become culturally legible only when new paradigms of reception, often accelerated by developments in computational analysis, allow investigators to parse their signals from the carrier in question. This is why the analytical framework of the carrier wave is so useful: It emphasizes that the ability to produce knowledge is both reliant on a set of technosocial standards and, as a result of that, is unequally distributed among social stakeholders (a consequence that is not lost on end users and data subjects themselves, as demonstrated in Andrejevic, 2014). It also helps us understand the commercial, regulatory, and political apparatuses that are emerging around computational processing within a historical context: The new modalities of knowledge production may use different tools than broadcast industries, but they involve a similar set of actors with similar agendas. To put it simply, just as the exploitation and regulation of electromagnetic carrier waves created communications industries a century ago, the crystallization of standards around the *n*-way possible modalities of knowledge production in a digital, networked context is fundamental to the consolidation of industrial and political power in the present day.

Although we credit ubiquitous computational analysis as a catalyst for the carrier wave principle, predigital precursors abound. In fields ranging from police work to theology to natural and social sciences, practitioners have frequently reexamined existing corpuses—evidence kits, ancient libraries, and archaeological artifacts, for instance—to seek secondary and tertiary layers of information that may add to, or conflict with, the original interpretive paradigm. Frequently, the innovations contributing and/or resulting from these reinvestigations (e.g., carbon dating, textual exegeses) have been foundational to the development of new theories and fields of scholarship (e.g., paleopathology, social history).

Claude Shannon's work at Bell Labs in the 1940s, leading to the publication of his "mathematical theory of communication" (Shannon, 1948), also proved fundamental to the development of computing as a malleable, efficient information space. In particular, Shannon's quantization of information entropy and its relationship to the emergent bandwidth or carrying capacity of a communications medium proved fundamental to the development of modern telecommunications infrastructure, all of which was incorporated directly into the various forms of digital signal processing and error correction routines that have enabled the Internet, mobile telephones, and other 21st-century communication networks. Shannon's premise, which takes the noise signature (inherent entropy) of a medium as a given, gave computer scientists a powerful framework for improving the speed and accuracy of a communications technology using that medium.

Our argument builds on these foundations, emphasizing the role of computation in expanding the scope, speed, and scale of knowledge production (Hilbert & López, 2011) in a way that qualitatively changes the social and cultural role of information.

While we propose the carrier wave principle as a new theoretical formulation regarding the relationship between sociotechnical artifacts and cultural meanings, our analysis draws heavily from several

branches of research and scholarship, including media studies, information science, cultural studies, STS, and critical data studies. Next, we briefly review some relevant themes among these disparate scholarly strands before weaving them together to explore the ramifications of the carrier wave principle in practice.

Encoding Media, Decoding Messages

A central aspect of the carrier wave principle is its reinvestigation of one of the foundational conceits of communication theory: the distinction between what are typically referred to as *media* and *content*. Traditional communication scholarship treated communications platforms and the messages they carry as two distinct and discrete elements of the communication process. In Lasswell's (1948) oft-quoted formulation, all communication may best be described by answering the following compound question: "Who says what, in which channel, to whom, with what effect?" (p. 117).

Of course, this model of communication has been problematized by scholars almost from the instant it was proposed. McLuhan (1994) famously argues that "the medium is the message" (p. 7)—more precisely, that media shape and constrain the messages they carry and the experiences of the communicants who engage with them in ways that are themselves communicative. Writing a few decades later, Carey (2008) argues that Lasswell's "transmission view" overlooks another important aspect of communication, namely, its cultural dimensions. Although Carey does not share McLuhan's interest in blurring the lines between medium and content, his "ritual view of communication" (p. 12) holds that the social structures and practices surrounding the act of information sharing often have greater communicative capacity than the information itself.

Birmingham School scholars such as Hall (1980) and McRobbie (1990) import articulation theory from sociology to cultural studies, helping to further transform the field "from a model of communication . . . to a theory of contexts" (Grossberg, 1993; quoted in Slack, 1996, p. 113). In an explicitly political analog to Carey's (2008) argument, they demonstrate that "active audiences" are not merely interpreting cultural artifacts independently of the intentions of creators, but are deliberately resisting and negotiating with hegemonic social institutions through the act of "decoding" mass mediated texts. Any given text has multiple potential meanings, they argue, and active audiences, especially within a subcultural context, work to "exploit its polysemic values" (Hall, 1980, p. 169).

This analysis has a parallel in STS, which treats all sociotechnical artifacts in much the same way that the Birmingham School scholars treat media texts: as nexuses of power whose contours and patterns of cultural adoption reflect the interplay of the various social stakeholders involved in their production and reception (Bijker & Law, 1992). Actor–network theory (Latour, 1996) goes a step further, arguing that "the gap in between the text and the context" (p. 378) does not exist, and "extending" semiotic analysis beyond cultural texts to "any assemblage of heterogeneous entities," (p. 374) including science and technology.

These perspectives have gained increasing traction in media studies and communication studies in recent years. An excellent example is Sterne's (2012) recent work on "format theory." He adopts this approach in his social and industrial history of the MP3 format, demonstrating that the engineering decisions that went into the codec (uncoincidentally, a contraction of coder–decoder), as well as the commercial and cultural decisions that led to its widespread diffusion, were rooted in fundamentally value-laden notions of

what constitutes legitimate music, idealized performers, and privileged listeners. Along similar lines, but using different theoretical foundations and methodologies, Balsamo (2018) examines the digitization of a tactile work of activist art (the AIDS quilt) to show how "forms of culture are literally held in place by numerous organizations, institutions, and social practices, historically rooted and ideologically reproduced at every turn" (p. 150), privileging hegemonic modes of knowledge production and technological adoption while precluding more resistant forms of engagement.

The carrier wave principle reflects and extends this set of scholarly concerns. Like McLuhan (1994) and the STS and actor–network theory scholars, we see the affordances of media platforms—and the assemblages of actants that surround, compose, and perpetuate them—as integral to the nature of the messages they carry. And, like Carey (2008) and the Birmingham School scholars, we see active audiences as integral to the interpretation of those messages. Our premise puts these two dynamics into dialogue, by arguing that an underappreciated dimension of audience agency is not merely choosing among polysemous readings of a given text, but rather interpreting a text through the *n*-way affordances of its sociotechnical infrastructure. To put it another way, audiences may exercise agency not only by assigning new significations to mediated texts, but also by using the textual artifacts as a site to investigate (and, potentially, to critique and surveil) the circumstances of production.

On the other hand, to echo and extend Balsamo's (2018) argument, because these techniques frequently require expertise and resources associated with advanced computational analysis, as well as the institutional leverage to build consensus around a set of standards, the ability to produce new knowledge from sociotechnical artifacts is restricted disproportionately to those who already wield a degree of power. In fact, in some cases, tacit or explicit coordination between the engineers of a platform and the hegemonic institutions that subsidize or support it may serve to exploit the carrier wave principle in ways that directly undermine user agency and privacy. For instance, many commercial printers use invisible ink to encode details about their users directly onto the pages they print without their knowledge or consent. These affordances have been exploited by law enforcement and other institutional powers to hold individuals accountable for what would otherwise have been anonymous forms of information sharing. One notable recent example is the American government whistleblower Reality Winner, who unwittingly included metadata that could be used to identify her, such as her printer's model, serial number, and time of printing, on the top-secret paper documents she leaked to the news media (Collins, 2017).

Thus, although the carrier wave principle offers some promise of resistant or liberatory potential for marginalized or repressed actors and communities, it may also be exploited to strengthen a hegemonic actor's dominant discursive position. Our principle holds that "medium" and "message" are positional rather than absolute designations, and that the power to encode and decode—and to designate one assemblage as a "carrier" for another—is itself an act of power.

Authorship and Identity

Although the carrier wave principle draws on longstanding scholarly debates about the nature of audiences and reception, it also requires us to rethink the circumstances of production, specifically the concept of *authorship* and the definition of a cultural *work*. Can an author be credited for work that she did

not intend to communicate? Can we ever fully understand, let alone evaluate, a work if we cannot confidently say we have extracted all of the information it may contain? How should we balance the intentional versus unintentional communicative aspects of a work in trying to understand the culture and identity of the person or people who created it?

The modern concept of authorship has been linked with the construction of identity since its first emergence during the Renaissance (Baxandall, 1988). During this era, cultural works began to be evaluated not merely for the quality of their materials, or even for the skill evident in their construction, but as evidence of an artist's unique vision and interiority. This change, as Woodmansee (1984) and Decherney (2013) argue, was not merely an update to the philosophy of art: It was the dawn of a new, humanistic approach to understanding the operation of culture. The birth of the modern author was the birth of the modern individual, and therefore integral to the modern social order. This syllogism was acknowledged by contemporary philosophers, as well: As Thomas Hobbes argued in 1651 in his book *Leviathan*, "He that owneth his words and actions, is the AUTHOR" (2012, Chapter 16, para. 4).

Yet, this conceit has also been questioned and challenged as long as it has existed. Even the earliest works of modern literature, such as *Don Quixote* and *Tristram Shandy*, actively play with the concept of authorship and creative authority. By the 20th century, works exploring what Barthes (1977) refers to as "the death of the author" had become virtually synonymous with avant-garde experimentation, from the collage techniques of Hannah Höch to the Dadaism of Marcel Duchamp to the nonlinear narratives of such authors as James Joyce and Brion Gysin to the *musique concrète* of composers such as John Cage and Pierre Henry. At the same time, postmodern literary criticism increasingly sought to deconstruct what Foucault (1977) calls the "author-function" (p. 125), and to demonstrate that it was both necessitated by the industrialization of cultural production (exemplified by the printing press) and necessary to the production of the modern Western state (Kittler, 2015).

These critiques led to a reinvestigation of the text as a communicative artifact. Eco (1989) argues that all works are open to continuous reinterpretation, and that the presumed interactivity between reader and text must always be a fundamental aspect of its meaning. Similarly, Gross (1985), working with Sol Worth, proposes a distinction between "natural" events, which are not perceived to be inherently communicative, and "symbolic" ones, which are. As they argue, this distinction does not inhere in the event or object itself, but is entirely reliant on the circumstances of reception. In Gross's words, "all mediated events are to some degree symbolic" (p. 10). In other words, the cultural definition of a "natural" event, free of authorial intent, is a conceit that varies widely over time and space.

The contemporary era of digital media has added new twists to this continuing dynamic. As Internet cultural scholars ranging from Gunkel (2016) to Miltner (2014) to Sinnreich (2010) chronicle in recent work, such digital cultural forms as memes, mashups, and remixes introduce new challenges to post-Romantic conceptions of authorship, requiring us to rethink how identity is established and expressed in the era of digital networked communications. Along parallel lines, law scholars such as Bridy (2012) and Kaminski (2017) explore the implications of artificial intelligence for our legal conception of authorship; for instance, if a piece of computer software algorithmically generates a visual image, does it warrant copyright protection? If so, for whom?

The carrier wave principle suggests an additional process by which digital media and networked communications further complicate the relationship between authorship and identity. While collective online creativity and algorithmic production problematize the premise of authorship as the act of a discrete and unique individual, our principle shows that even a sole author cannot necessarily "own her works and actions," as Hobbes (2012) might say, because we can never anticipate the *n*-way variety of knowledge that may be derived from them in the future.

Even this article, which was written collaboratively by two authors, in dialogue with peer reviewers and journal editors, and published in the form of a PDF produced by the journal, has the capacity to serve as the basis for knowledge produced by third parties about the authors themselves. It is not merely that text such as this may be "mined" for evidence regarding our political ideologies, implicit biases, and cultural values (Chen, Fraiberger, Moakler, & Provost, 2017; Magua et al., 2017) or for metadata embedded in the digital file, but more significantly, it may be used in conjunction with other data sets (including our social media profiles, our broader written corpuses, or even those of our professional and social peers) to develop conclusions about us and our work that bear little relation to the manifest content of the article itself. It is ultimately irrelevant whether the knowledge produced via this process is "true" in an objective or essential sense. Our point is that these new regimes of knowledge production, and the standards that emerge around them, are themselves constituent of new technosocial relations, and may be used by third parties to exert power over us or over others.

In light of this potentiality, and given the argument that "authorship" has never signified anything beyond a presumption of authority regarding the meanings derived from a text, to what degree can we justifiably call ourselves the authors of this article? The more of the *n*-way potential meanings that are ultimately produced, the less authority we exert, and the less applicable that title becomes. This point is not merely rhetorical or "academic" in nature; the global intellectual property system is founded on the premise of individual authorship, and innumerable economic, technical, and institutional systems rely on a similarly unitary vision of cultural expression (Sinnreich, 2019).

Privacy and Surveillance

Another consequence of the carrier wave principle is the challenge it poses to our expectations of privacy, and the opportunities it suggests for state, commercial, and/or criminal surveillance. Like the notions of authorship and audience discussed above, the concept of privacy—always a fluid and contingent value (B. Moore, 2018; Westin, 1967)—has been thrust to the forefront of public consciousness and debate in the wake of digital media's disruptions to our communication practices and technologies. As Papacharissi (2010) argues, it is fast becoming a "luxury commodity" (para. 6), available only to elites with the resources and expertise to prevent their personal data from spreading across networks and markets.

Privacy is not solely conceptualized as a personal "commodity," however. Scholars such as Andrejevic (2002) and Balkin (2008) write extensively about the role of new technologies in supporting the rise of the "surveillance state," and Zuboff (2015) has been instrumental in popularizing the critique of "surveillance capitalism," parallel institutional processes in which individual and collective identity and

sovereignty are circumscribed by the voracious data collection practices of state and commercial actors. Nissenbaum's (2004) concept of "contextual integrity" further complicates the definition of privacy, arguing that the de- and recontextualization of data by surveillants poses as much of a threat as its collection and dissemination. And nearly all recent scholarship on the subject references Foucault's (1995) premise of "panopticism," based on Bentham's infamous architecture for a surveillance-based prison, which posits that the production of knowledge through surveillance serves as a broad organizing principle for social power relations, rather than a challenge that may be reduced to a classic "two body problem." As these critiques suggest, the precipitous rise of data collection in our social environment does not merely pose an obstacle to the exercise of free speech, free thought, and free agency, but fundamentally undermines the legitimacy of the concepts themselves, by requiring citizens and communities to naturalize and internalize surveillance by powerful and unaccountable institutions.

Yet, despite (or in response to) these critiques, scholars across a range of disciplines have sought to identify spaces of agency with respect to new surveillance practices and architectures. Marwick and boyd (2014) argue that surveilled communities engage in "networked privacy," a state of relations in which "shared social norms and social ties" (p. 1064) serve as a bulwark against the incursions of surveillants. Similarly, Bossewitch and Sinnreich (2013) argue that, although we can no longer reasonably expect personal data collected by institutions to decay—heralding an era called "the end of forgetting"—individuals and communities may still exercise agency through tactical approaches to the production and collection of data, thus shaping the net "information flux" of a communications system. And Lingel (2019) theorizes extensively the politics of negotiated visibility, arguing, for instance, that countersurveillance among queer communities online amounts to a form of "dazzle camouflage."

The carrier wave principle aims to intervene in this scholarly conversation, and in the public awareness of surveillance and the potential for its mitigation, by providing a broadly applicable framework for understanding one of the principal vectors for the dissemination and collection of potentially sensitive data. Although much of the public debate has centered on the distinction between *data* and *metadata* (already a somewhat spurious dichotomy when it comes to analyzing the social consequences of data collection, as Schneier [2014] argues), we argue that the manifest data contained in both corpuses are dwarfed by the *n*-way varieties of knowledge that may be produced from each.

For instance, the audio of an intercepted phone call may yield immediate data regarding the subject of a given interlocutor's conversations, but over time, further analyses of these recordings may yield information about the subject's medical condition, about her material environment, or about additional conversations taking place in the space around her (Krouse, 2019). By the same token, that same interlocutor's phone records (the sought-after metadata) may provide immediate details about her network of contacts or the specific times, durations, and locations of her interactions with them, but further analyses of these logs may produce additional knowledge, such as the phone company's technological, structural, and administrative features, or the target user's unconscious cultural biases and social preferences.

The Carrier Wave Principle in Context

In the introduction, we cited a handful of seemingly disconnected case studies—each of which, we argue, exemplifies the carrier wave principle in its own way. For the remainder of this article, we attempt to document some real-world implications of the principle a bit more methodically. Although a comprehensive catalog of every potential implication is beyond our present scope, we hope this review will lay the groundwork for future research and investigation.

Squeezing Data From a Stone

Above, we alluded to the study in which researchers used high-definition videography, in conjunction with computational analysis, to resynthesize the sound waves of human speech based on the microscopic vibrations on a bag of potato chips. This technique, which is called "Eulerian video magnification," has a far broader range of potential forensic uses, including inferring the vector of an object's motion from still images, the flow of blood through the capillary veins in a person's face from a selfie, and the material properties of a textile from a short video clip (Wadhwa et al., 2016). Similarly, new lighting detection and range technology (LIDAR) is being used by law enforcement to capture three-dimensional models of crime scenes for the purpose of reconstructing the crimes in question (Agosto, Ajmar, Boccardo, Tonolo, & Lingua, 2008; Barazzetti et al., 2012).

Along parallel lines, a relatively new species of machine learning algorithms called "generative adversarial networks" (GANs) has been used successfully to infer missing data from existing data sets, with applications ranging from creating high-resolution versions of low-resolution images (Ledig et al., 2017) to assessing the dimensions of a three-dimensional object from a two-dimensional image (Wu, Zhang, Xue, Freeman, & Tenenbaum, 2016).

These two varieties of computational analysis are very different: Eulerian video magnification and LIDAR modeling amplify or preserve hidden data in a cultural artifact to make it legible, and GANs extrapolate missing data from their context. Yet, from a social and cultural standpoint, they both have similar implications: The boundless archive of photos, videos, texts, sound recordings, and other media assets in libraries, homes, and computer servers around the globe may be mined, both singly and collectively, to generate new modalities of knowledge production that were not assumed possible when they were first captured and stored.

When this type of sociotechnical analysis was predicted in speculative fiction, such as the "Esper" device in Ridley Scott's *Blade Runner* (1982), it was widely viewed by information scientists and media studies scholars as a "fallacy" (Manghani, 2013, p. 153) because the existing resolution of an image or work was understood as the upper boundary for retrievable information. That assumption itself is now revealed as fallacious; as the carrier wave principle argues, any perceived "upper boundary" is a contingent limitation, imposed by a temporary state of technosocial relations, rather than a fixed attribute of a cultural artifact's *n*-way information layers. This does not necessarily mean that the knowledge produced via such techniques is either infinite or accurate: Under the new conditions of ubiquitous computation, the upper limit of

knowledge production is primarily a social and epistemological challenge rather than a procedural or technological one.

What are the implications of Esper-style technology in institutional hands today, and (presumably) in the hands of the general public in the not-so-distant future? One can easily imagine socially beneficial effects, such as a research project reconstructing the sonic environments of early silent film or even efforts to make history more accessible via augmented documentary footage, such as Peter Jackson's *They Shall Not Grow Old* (2018). However, it is just as plausible to imagine this technology applied to the massive archive of photos and videos uploaded to social media platforms, and used by commercial entities to commodify customer data, by states for warrantless policing, and by criminal enterprises for blackmail, extortion, identity theft, or character assassination. The interpersonal dimensions of these capacities are also problematic: When we "share" snapshots of our lives with friends and family via commercial platforms, what else may we reveal over the longer term, once third parties can "Esper" their way through those photos and videos?

It is important to acknowledge that, no matter how sophisticated GANs or similar algorithms become, there are always bound to be instances in which the data they add through extrapolation are erroneous, and therefore risk distorting the knowledge produced through this process, or worse, providing a mechanism for opportunistic actors to legitimize false or misleading information. This may undermine socially agreed upon factuality, potentially exacerbating existing power differentials between those who possess the authority and technological capacity to generate such data and those who do not. Furthermore, as these tools become increasingly commonplace, their conclusions will become more embedded in the operational regimes of social institutions such as schools, financial services, and health care providers, increasing the gravity of any errors or biases they introduce. Lastly, as GANs become increasingly sophisticated, it is likely that the data they infer will become integrated ever more seamlessly into the original data sets, making it more difficult to identify errors and biases, and to challenge the social and political frameworks that arise from them.

Informatic Subjectivity

It has long been theorized in the social sciences that our subjectivities and epistemologies—our sense of who and what we are, the nature of our relationships to one another, and our models for making sense of the world around us—are shaped and circumscribed by the social institutions and power dynamics that surround us (Foucault, 1995; Longino, 1993). Consequently, as scholars across a range of fields have argued, we shape our personae, and orient our self-presentation, around the specificities of our technosocial milieux (Giddens, 1986; Goffman, 1978; Turkle, 2005). In a large and complex society, media play a central role in this process, and therefore, their affordances are integral to how we see ourselves and one another. This can generate a feedback loop in which the idiosyncrasies of those media are exaggerated in the images we present of ourselves and see in others. In McLuhan's (1994) poetic formulation, humans are captivated by the "mirror" of media interfaces until we become "the servomechanism of [our] own extended or repeated image" (p. 41).

More recent research has focused on the role of the Internet and other digital media in shaping our subjectivities and reflecting our self-presentations. Because of their newness, these cultural behaviors are often described via neologisms, such as "selfie" and "blackfishing" (the term itself is a portmanteau of "black" and another neologism, "catfishing"). These new modes of self-presentation have clearly been internalized by many Internet users to a degree that the logic of the networked eye is inscribed onto the physical body. Examples include an uptick in elective plastic surgery so subjects can look better for digital photos, or even match their computer-generated or -augmented avatars (Reaney, 2014; Rees, 2014); "pro-ana" communities on social media, where anorexics encourage one another to continue losing weight through self-imposed starvation (Boero & Pascoe, 2012; Ging & Garvey, 2018); and even cyborgian enhancements such as machine-readable tattoos (Barfield & Williams, 2017; for those who want to increase their data legibility) and surveillance-blocking makeup (Joh, 2013; for those who want to decrease their data legibility).

What these examples share is the dynamic of the "real-time" feedback loop: Users see themselves being seen through the camera of a mobile phone or an environmental surveillance device and alter their self-images and self-presentations accordingly. Yet, the carrier wave principle suggests that, as data subjects become increasingly aware of the less immediate and visible forms of information they produce, they may also begin to adjust their perspectives and personae in a way that anticipates those *n*-way modalities of knowledge production, as well.

We can already see nascent forms of this dynamic in emerging cultural practice. "Quantified self" applications and self-tracking devices such a Fitbit and the Apple Watch have become commonplace in recent years, and have given rise to a firestorm of debate within scholarly circles, between those who decry them as an instrument "data fetishism" and creeping neoliberalism (P. Moore & Robinson, 2016; Morozov, 2013) and those who hail them as emancipatory instruments of self-knowledge and self-determination (Sharon & Zandbergen, 2017)—as well as those, like Crawford, Lingel, and Karppi (2015) and Humphreys (2018), who argue that contemporary digital self-chronicling can best be understood as a new variation on centuries of predigital self-investigation through mechanical and analog media.

Although we are not taking sides in this debate in the present article, we observe that implicit in all of these arguments is the premise that quantified self technology requires its users to see themselves not merely through the lens of a webcam, but through the algorithm's-eye view of data analysis. This is a second-order abstraction, because the end user is adjusting her presentation of self not based on what she sees reflected on the screen, but rather based on what she anticipates might be compiled through the aggregation and synthesis of information about her over time. This is no mere speculation on end users' parts; in fact, a growing number of industries, from higher education (Costello, McNiel, & Binder, 2016) to job placement (Jeske & Schultz, 2016) to insurance (Scism, 2019), are now explicitly telling their customers that the rates and opportunities they are offered will be based, at least in part, on their visible social media activity.

These new modalities of informatic subjectivity (or, as Hong, 2016, calls it, "machinic sensibility") have begun to inscribe themselves into users' bodies as well. It is now a common trope, for instance, for wearers of self-tracking devices to wave their arms as a way of tricking the devices into recording steps

walked toward the fulfillment of a daily goal. An entire thread of user commentary on the Fitbit Community website was recently devoted to discussing whether this activity constitutes "cheating"—with mixed responses.[2] In other words, the presence and authority of the algorithmic eye is now so widely recognized that ethical debates regarding the responsibility to yield accurate data have emerged among the general public (Andrejevic, 2014). This phenomenon is exemplary of the carrier wave principle's social implications: The iterative generativity of computational processing has catalyzed rapid shifts in behavior, which in turn require new collective cultural modalities. Much as Schrödinger's cat provided a material visualization of natural phenomena at the subatomic level, these emerging tropes can be understood as a human-scale attempt to make sense of computational processes that can only be inferred through their effects, although never witnessed directly by the people whose lives they transform.

Easter Eggs and Modulated Malware

"Easter eggs"—bits of rogue code hidden within software programs—have been used for purposes ranging from playful (e.g., games hidden in productivity applications) to criminal (e.g., password sniffers hidden in financial applications) nearly since the dawn of computing (Bogost, 2011). Nearly all are created intentionally by their programmers, but many are released without the knowledge or consent of either their publishers or their end users. Many examples of the carrier wave principle in action rely on forensic approaches to reveal *n*-way meanings encoded into media artifacts, but Easter eggs point to another vector: the deliberate multiplex encoding of separate meanings intended for separate audiences. Thus, the process of decoding such artifacts both signifies and reifies group identity affiliation, similar to the subcultural dynamics discussed in Hall (1980) and especially relevant to Marwick and boyd's (2014) concept of "social steganography."

Easter eggs illustrate an important point about software or any medium that may potentially serve as a carrier wave for hidden messages: They are a security risk. To put it simply, because we can never predict how the data we are sharing or accessing may be exploited or interpreted, let alone understand the architectures of the media that carry them, total information security is an unrealistic expectation.

In recent years, the threat of malware (one of the less playful forms of Easter eggs) hidden inside of "benign" apps by malicious actors has become a recurring theme in the news and a part of the popular consciousness (Cimpanu, 2019). However, these stories rarely reveal that, in some cases, malware can serve as a vector for information that even its creators did not plan, and may be used to produce knowledge they could not have anticipated. This is exactly what happened with the infamous Stuxnet worm, which was first discovered in 2010 infecting industrial control systems operated by Siemens (McMillan, 2010). Cybersecurity researchers found that Stuxnet piggy-backed on the Windows operating system, taking advantage of a previously unrecognized vulnerability in its code. Ultimately, however, the episode revealed far more than the existence of the worm. Researchers traced its origins back to American and Israeli government efforts to disrupt Iran's uranium enrichment program, revealing both the program's existence and the coordinated cyber warfare efforts of the United States and Israel to the general public for the first time. In other words, the carrier wave principle applies doubly to the Stuxnet case: Not only was Windows

[2] https://community.fitbit.com/t5/Ionic/Waving-arms-counting-as-steps-what-to-do/td-p/3006844

a carrier for Stuxnet, but Stuxnet was a carrier for highly sensitive political information, all of which ultimately became legible to the general public via media accounts of the incident (Zetter, 2014).

The second part of the Stuxnet story points to an essential consequence of the carrier wave principle: The knowledge produced from a given artifact may be completely decoupled from its original context. The social impact of this decoupled knowledge may be observed in different media, different narratives, and different contexts than the artifact itself, and therefore may not be readily apparent to the people who originally created, used, or interpreted it. This is the case with many cybersecurity threats, which rely on "social engineering," for instance, getting someone to click a link in an e-mail they believe is legitimate, in conjunction with the malicious code buried within the link, for the exploit to work. This was also the case with the recent Cambridge Analytica scandal, in which social media platforms were used maliciously as a carrier wave, both for the collection of data related to millions of individual users and for the targeting of disinformation tailored to the individual vulnerabilities and biases revealed through analyses of those data (Cadwalladr & Graham-Harrison, 2018).

Yet, although social networks are a common, and effective, medium used in conjunction with computer code for the encoding and decoding of hidden messages, they are not the only ones. The 1980s New Wave band Information Society included an audio track on a vinyl record that, when played back through a modem, would generate a plaintext file on the computer at the other end, telling a convoluted story about the band being extorted by the Brazilian government. Similarly, alt rock band Aphex Twin included a track on a 1999 CD that, when played through a spectrograph, would generate nightmarish image files (Weinel, Griffiths, & Cunningham, 2014; Yezpitelok & Cantrell, 2010).

These examples are on the playful end of the Easter egg spectrum, but there are more troubling examples, as well. For instance, researchers recently reported success editing a strand of DNA so that when it is analyzed by a gene-sequencing software on a computer, the resulting data would become self-executing malware attacking the sequencing software itself and ultimately taking over the computer it runs on (Greenberg, 2017). Although this is still a novelty and largely the stuff of speculative fiction (in fact, there was a 1993 episode of the television show *Star Trek: The Next Generation* entitled "The Chase" in which a very similar mechanism served as a crucial plot point), the growing accessibility and power of DNA-editing technologies such as CRISPR (Doudna & Charpentier, 2014) suggest that our own biological code may soon become a viable medium for carrier wave principle phenomena as well.

Conclusion: Second Guessing the Recording Angel

In this article, we have introduced the carrier wave principle, supported it with analysis linking it to several scholarly fields, and offered evidence that it is a widely applicable phenomenon, with far-ranging implications related to our identities, our politics, and our security. We also have argued that its impact will most likely increase precipitously as the catalyzing power of computational processing continues to grow at an exponential rate (Denning & Lewis, 2017). Whereas some cultural artifacts will continue to degrade and become lost to the ages, aided by the "planned obsolescence" of digital media (the recent inadvertent deletion of MySpace's library of millions of songs by independent musicians [Van Sant, 2019] demonstrates how fragile digital archives can be, especially prior to contemporary models of redundancy via "cloud"

computing), our principle holds that we cannot reasonably expect data to disappear or anticipate the knowledge that may be derived from them over time.

In fact, the near future likely holds the potential for a highly transformative and disruptive event that will significantly reshape our cultural, economic, and institutional landscape, what some commentators have already dubbed the "quantum apocalypse" (Dolev, 2018). Much of today's Internet traffic is protected by various forms of encryption, so that if it is intercepted by a third party without the decryption key, it will be illegible and inactionable. We rely on this assurance of security for commerce, banking, privacy, identity verification, and innumerable other essential functions in our daily lives, business dealings, and government and military communications. Yet, quantum computing, which has made significant strides in recent years, may have the capacity to easily break such encryption, leaving our Internet traffic as open to investigation as if it had not been encrypted in the first place (Heath, 2016).

Intelligence organizations are taking this possibility very seriously, and are acting both to (a) collect as much encrypted data as possible, in the hopes of decrypting it in the future, and (b) build encrypted communication systems that will be resilient to quantum computers (Johnson, 2019). The result will likely be that, in the nearer term, wealthy and powerful institutions such as national governments and large corporations will have the capacity to unmask and analyze decades of Internet traffic for billions of users. In the longer term, if the social history of technology is any guide, this power will likely be democratized, and much of today's hidden data will be available widely for search, retrieval, and processing to any number of curious investigators.

We must prepare, both in our cultures and our politics, for this eventuality and for the continuing effects of the carrier wave principle as technology and culture continue to coevolve, leaving an ever widening trail of cultural artifacts and digital records in their wake. This need will become ever more dire, as the "Internet of things," cyborgian implants, DNA editing, and other, increasingly intimate and granular forms of data collection and manipulation continue to pervade our individual and collective lives. We must understand, as a society, that nearly everything we do or say in proximity to a networked sensor, including actions and words we are not even aware of, may be archived and searchable for perpetuity.

In Judeo-Christian religions, there is a "recording angel" tasked with tracking every detail of every human's life and weighing our souls in the balance. We are not here suggesting that judgment is the ultimate goal, or even the necessary consequence, of the carrier wave principle as applied to personal data. But a wide range of interested parties, from states to commercial entities to malicious actors, certainly have goals of their own, and there will inevitably be consequences. Above, we described how a futuristic plot device from a television show a quarter century ago is now a technosocial feasibility. Today, such shows as *Westworld* and *Black Mirror* feature plots in which data harvested from social media sites are used to reconstruct artificially intelligent simulations of individual human beings. Although we cannot confidently predict that this will be feasible in another quarter of a century, we cannot rule it out either.

Scenarios such as this raise a final key point: The growing reliance on computational processing as a foundation of knowledge production and social governance makes public oversight and development of best practices for data collection, management, and processing imperative for a functional civil society.

Incomplete or inaccurate data sets can yield incorrect conclusions, leading to potentially dire outcomes. In Terry Gilliam's classic dystopian film *Brazil* (1985), one data error introduced by an insect's carcass falling into a typewriter sets off a deadly and destructive "butterfly effect" chain of events that upturns and threatens the protagonist's life. Today, computer scientists and critical technologists frequently demonstrate the fallibility of our data regimes and their potentially lethal effects (such as the inherent racial biases in computer vision that make self-driving cars more apt to strike dark-skinned pedestrians than light-skinned ones [Samuel, 2019]). This suggests the need for new systems of governance and open discussions among stakeholders to ensure that these consequences are mitigated within frameworks that balance our desire for knowledge with an acknowledgment of the potential risks.

If there is one thing we can predict confidently based on our analysis, it is that our media will have meanings and applications in future societies that far exceed our understanding or anticipation today. Yet, we can play a more proactive role in shaping that future by being more deliberate now about what kinds of media we build, what kinds of messages we send, and what kinds of laws and ethics we embrace to guide their development and deployment. We believe it is essential to recognize, and account for, the carrier wave principle when crafting those technologies, messages, laws, and ethics, and to think beyond the narrow range of "use cases" envisioned in today's board rooms, laboratories, and policy institutions.

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