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Marr's Tri-Level Framework Integrates Biological Explanation Across Communication Subfields

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In this special issue devoted to speaking across communication subfields, we introduce a domain general explanatory framework that integrates biological explanation with communication science and organizes our field around a shared explanatory empirical model. Specifically, we draw on David Marr's classical framework, which subdivides the explanation of human behavior into three levels: computation (why), algorithm (what), and implementation (how). Prior theorizing and research in communication has primarily addressed Marr's computational level (why), but has less frequently investigated algorithmic (what) or implementation (how all communication phenomena emerge from and rely on biological processes) explanations. Here, we introduce Marr's framework and apply it to three research domains in communication science—audience research, persuasion, and social comparisons—to demonstrate what a unifying framework for explaining communication across the levels of why, what, and how can look like, and how Marr's framework speaks to and receives input from all subfields of communication inquiry.

Keywords: Communication Neuroscience, Communication Theory, Computational Theory, Marr, Subfields

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Special issues in the *Journal of Communication*, including the original "Ferment in the Field" (Fuchs & Qiu, 2018; Gerbner & Siefert, 1983), "Future of the Field" (Levy & Gurevitch, 1993), and "Getting the Discipline in Communication with Itself" (Vorderer & Weinmann, 2016) have taken up the question: Is there a unified theory of communication, or are we a field destined for what Craig (1999) called "productive fragmentation" (p. 122)? This issue begins from the premise that our field is fragmented and lacks integration across communication subfields.

In this manuscript, we argue that biological explanation in communication is not just another subfield, but instead an integral component to forming a complete explanation of human communication and, as such, may integrate existing communication science subfields. To make this argument, we draw from David Marr's tri-level framework (1982), which illustrates how behavior requires three levels of explanation to be fully understood: (a) computation, or why does a given behavior exist; (b) algorithm, or what mathematical rules govern the behavior; and (c) implementation, or how is the behavior physically implemented. Communication scientists have implicitly engaged in all three of Marr's levels in their theoretical and empirical efforts (Weber, Sherry, & Mathiak, 2008). However, the field has primarily focused on Marr's first level of explanation. Inquiry at the second and third levels is not yet mainstream (Chung, Barnett, Kim, & Lackaff, 2013). Research in cognate disciplines (i.e., the cognitive, social, and behavioral neurosciences), by comparison, largely focuses on Marr's second and third levels, such that many excellent descriptions of physical systems exist, but *why* explanations are largely missing (Krakauer, Ghazanfar, Gomez-Marin, Maciver, & Poeppel, 2017).

This bifurcation is problematic for two reasons (Krakauer et al., 2017). First, explanations at Marr's first level are powerful in that they offer an answer to why a mechanism exists. Many, if not most, communication theories operate at this explanatory level. Communication theories often assume processes at Marr's second and third levels and some communication scientists have spent their careers investigating the biological, psychophysiological, and neural basis of communication processes (for reviews, see, Bolls, Weber, Lang, & Potter, 2019; Floyd, 2014; Schilbach et al., 2013; Schmälzle, & Meshi, 2020; Weber, Eden, Huskey, Mangus, & Falk, 2015; Weber, Sherry, & Mathiak, 2008). Such research has, in many ways, laid the foundation on which this manuscript builds. Nevertheless, biological inquiry is not yet mainstream in the field. As a consequence, we lack sufficient empirical evidence demonstrating if many of our theories are biologically plausible, or not (Geiger & Newhagen, 1993).

Many communication theories are built on assumptions that we leave to other disciplines to test. This has important consequences. When our theoretical assumptions are falsified, and we fail to notice, our capacity for theory building suffers (see, e.g., Fisher, Huskey, Keene, & Weber, 2018). In addition, the focus on specific *why* explanations for a behavior may exacerbate the fragmentation of communication science by rooting investigations firmly within their context (e.g., organizational or political) or method (e.g., computational or neuroscientific), while ignoring underlying processes and biological structures that may help explain behaviors across contexts.

Second, explanation at Marr's second and third levels describes a process; not why it occurs. For instance, heart rate—observed through mathematical modeling of the sinus wave collected using an electrocardiogram—temporarily decelerates when audiences orient to new information (Potter & Bolls, 2011). This second- and third-level description of a system does not explain *why* heart rate does not uniformly decelerate at the onset of new information. Only by combining Marr's three levels do we learn that deceleration indicates that an individual is taking in new information and that deceleration magnitude indicates which aspects of a message were attended to (Potter & Bolls, 2011). For this reason, communication scientists have long argued that inquiry beyond Marr's first level improves explanatory power (Bolls et al., 2019).

In this article, we show that the benefit of adopting Marr's framework is a richer and more complete explanation of communication that integrates a diverse array of subfields around a common explanatory framework. Our manuscript is subdivided into three sections. First, we focus on how Marr's framework offers a unified explanatory approach across communication subfields. Next, we articulate Marr's "three levels of explanation" framework and the way it intersects with an interdisciplinary communication science. From there, we sketch how insights from a diversity of communication science subfields are poised to make important scientific breakthroughs. We conclude with a general outlook on applying Marr's framework across communication as a scientific discipline, and the challenges and opportunities this idea presents.

Communication, its subfields, and Marr

Craig (1999) argues for seven communication traditions: rhetoric, semiotics, phenomenology, cybernetics, social psychology, sociocultural, and critical theory. Rogers (1994) argues that the field is rooted in evolutionary, psychoanalytic, and critical theories. Others have articulated that the field can be divided by communication channel (e.g., interpersonal, mass; Weimann, Hawkins, & Pingree, 1988). Today, the International Communication Association (ICA) has 23 divisions and another 10 interest groups. Some of these are organized by channel (e.g., Interpersonal Communication, Mass Communication), others by topic area (e.g., Health Communication, Political Communication), epistemological perspective (e.g., Feminist Scholarship), or methodological approach (e.g., Computational Methods).

What then, is a communication subfield? Network analysis of ICA membership (Barnett & Danowski, 1992) suggests that the field is organized along three dimensions: scientific–humanistic, interpersonal–mass, and theoretical–applied. This structure was also replicated when examining ICA submission titles (Doerfel & Barnett, 1999).[1] Therefore, an empirical definition is that a communication subfield can be plotted within this three-dimensional space. This solution is elegant as it empirically organizes channel, topical area, epistemological orientation, and methodological approaches into a coherent framework. Importantly, and as we will show below, Marr can be applied to subfields that map onto any point along the interpersonal–mass and theoretical–applied continua so long as these points adopt a scientific epistemology.[2]

The power of Marr's framework is not that it dictates what questions are interesting or important to a given subfield. The power of Marr's three levels is that they represent a framework for organizing inquiry that is applicable to all scientifically oriented communication subfields. We will show that Marr offers a framework that helps advance communication theory while also providing a more complete explanation of human communication behavior.

Marr's three levels of explanation

Human communication is a complex phenomenon that necessitates explanation at multiple levels. This claim is not controversial and we are not the first to make it. Tinbergen's (1963) four questions (what is it for, how did it evolve, how does it develop, and how does it work) have been applied to communication research (e.g., Huskey, Craighead, & Weber, 2017). Aristotle famously described four causes (what is the material, what is the form, what agent produces it, and what is its final form) that must be specified in order to completely explain a "why" question. The "Engine Perspective" advanced by Weber et al. (2008) called for studying and integrating explanations for communication at a number of different levels, including biological, interpersonal, mass, organizational, and cultural.

Marr's tri-level framework also emphasizes the importance of explanation at multiple levels: computation (why), algorithm (what), and implementation (how). The computational level organizes questions related to an observable behavioral process. Specifically, it asks: why does a given behavior exist and what problem does the behavior solve? Explanation within Marr's framework is sufficiently general that it can apply to any information processing system. To demonstrate, Marr (1982) uses the example of a cash register. How much does a customer buying a loaf of bread and a package of butter owe? A cash register uses addition to solve this computational problem. Why does the cash register use addition rather than say, multiplication? Constraints provide an answer. If a customer chooses to buy bread and butter but not buy milk (a value of zero), multiplication would dictate that the customer owes zero dollars, which is incorrect. According to Marr, "the reason is that the rules we intuitively feel to be appropriate for combining the individual prices in fact define the mathematical operation" (p. 22).

Marr's second level of explanation, the algorithmic level asks: What representation of mathematical rules governs a given process? Should the numeric costs be represented as Roman numerals? Such representations make mathematical operation cumbersome in comparison to Arabic numerals. If we select Arabic numerals "for the algorithm we could follow the usual rules about adding the least significant digits first and 'carrying' if the sum exceeds 9" (p. 23).

Finally, Marr's third level asks how a given operation is physically implemented. In the case of a child using an abacus, the child might add numbers by sliding beads from left to right; digits exceeding nine might by "carried" to the next row. By comparison, electronic cash registers might use a computer processor to execute this algorithm. The outcome of the computation is the same, "but the physical realization of the algorithm is quite different in these two cases" (p. 24).

By explicating these levels, conceptual overlaps and gaps in current communication science become clear. Prior theorizing and research in communication have primarily addressed Marr's computational level (why). Similarly, the biological tradition in communication research has investigated Marr's third level. Yet Marr's second level—the crucial bridge between the first and third levels—is largely absent from these other approaches to explanation.

Marr's three levels as applied to communication theory

As an example of Marr's three levels applied to communication, consider a dyadic interpersonal interaction (Figure 1). Expectancy violation theory (EVT; Burgoon, 1978) offers a theoretical framework for studying the rules that govern such interactions. One rule is Hall's (1966) regions of interpersonal space. According to this rule, casual interpersonal interactions typically occur with a physical distance of 1.5–4 feet. Imagine that the conversational partner violated this rule by entering the message sender's personal space (less than 1.5 feet). If this interpersonal distance negatively violated the message sender's expectations, then EVT would predict that this would likely lead to cognitive (the message sender forms a negative evaluation of the communicative partner) and behavioral (the message sender steps backward to increase interpersonal distance) outcomes. This example demonstrates explanation at Marr's first level: what is the computational problem and why does a given behavior exist.

EVT makes formal mathematical predictions about the magnitude of deviation of a given behavior from an expectation. Indeed, EVT's second proposition specifies that "The communication outcome of an interaction is a function of the reward value of the initiator, the direction of deviation from expectations, and the amount of deviation" (Burgoon, 1978, p. 133). This means that the violation (the difference between expectation and actuality) might be of lower magnitude if the message receiver is a friend rather than an adversary. The difference between expectation and actuality, also known as a reward prediction error, can be mathematically formalized (Schultz, Dayan, & Montague, 1997), and prediction error has been shown to shape cognition and behavior (Shohamy & Adcock, 2010). This represents Marr's second level: algorithm, or what mathematical rules govern the behavior.

Reward prediction error is well-studied and its neurochemical and neurobiological substrates are increasingly understood. One physical component of this process

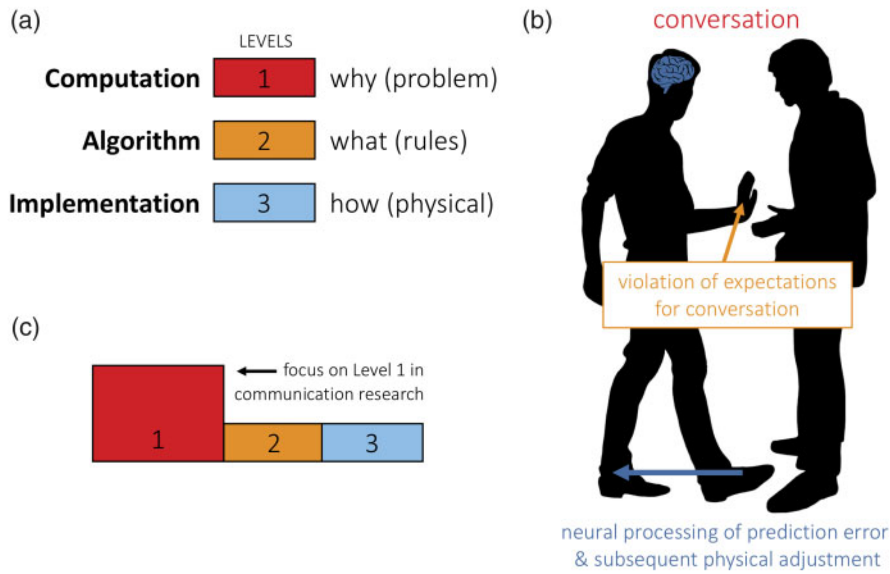

Figure 1 Marr's framework as applied to a dyadic interpersonal interaction. (a) The levels as represented in Krakauer et al. (2017). (b) Communication example: A message sender attempts to share information with a conversational partner while following a set of socially constructed rules that govern the interpersonal interaction (goal). Here, the interaction partner stands too close, which triggers a violation between expectation and actuality, also known as a prediction error (algorithmic realization) that is cognitively processed in the brain and results in a physical adjustment of the body positioning (physical implementation). (c) Historically, communication research emphasizes the computational level of communication phenomena.

is the striatum. The striatum is deep brain structure that is located below the cortex (the outer layer of neural tissue). The striatum can be spatially subdivided into at least two subregions, the dorsal (or top) and ventral (or bottom) striatum. A large body of research demonstrates that the ventral striatum (VS) processes information about expectation and the dorsal striatum processes information about actuality—both of which are crucial to reward prediction error calculations (O'Doherty et al., 2004). Although no specific study has investigated the neural basis of EVT, its second-level mathematical formalism leads to falsifiable predictions at the Marr's third level: implementation.

Together, these three levels offer a more complete explanation of communication than each on its own. Explanation at one level informs explanation at the other levels as there is a crucial dependency between all three levels (Marr, 1982). In the EVT example, explanation at the first level (rule-based communication patterns) suggests algorithmic implementation at the second level (the mathematical quantification of rule violation magnitude), which should predict biological processes at the third level (the neural hardware that encodes this violation).

This process also operates in the reverse direction. Third-level mechanisms confirm second-level algorithmic processes which are ultimately explained by the first level (Krakauer et al., 2017). Intervention on a third level causal mechanism should trigger a cascade of changes at the second and first levels (Craver & Darden, 2013). If the striatum is causally involved in reward prediction error, then lesions or neurological disorders that disrupt striatal processing (e.g., schizophrenia) should blunt the brain's capacity to compute prediction errors, which should result in different cognitive and behavioral outcomes during the communicative interaction.

Moreover, Marr offers clear benefits to communication theory. Canonical readings (Chaffee & Berger, 1987) as well as more contemporary articles (DeAndrea & Holbert, 2017; Slater & Gleason, 2012) articulate the criteria for making an important theoretical contribution to communication science. Below, we demonstrate how the Marr and EVT example used above can be used to illuminate a number of these criteria (*listed in italics*).

Turning first to the Chaffee and Berger (1987) criteria, the EVT example above demonstrates that Marr's framework is capable of producing new hypotheses (*heuristic provocativeness*) that can be proven false (*falsifiability*). Similarly, the EVT example demonstrates that Marr's framework is useful for integrating seemingly disparate literatures (*organizing power*) related to nonverbal communication, interpersonal communication, mathematical modeling of reward prediction, and the biological substrates of reward prediction.

Using the Slater and Gleason (2012) criteria, the EVT example demonstrates how prediction error might explain expectancy violations (*elucidating the mechanism*). The EVT example also shows how Marr's framework is useful for testing EVT in new contexts (*extending the range of existing theory*) by specifying what neural structures should be active when processing expectancy violations. The EVT example shows how Marr's framework is useful for integrating explanations that have previously been evaluated using distinct theories (*theoretical synthesis*). Finally, scholars interested in developing new theories (*theory creation*) should consider how their theoretical model accounts for all three of Marr's levels of explanation. The EVT example shows how the theory implicitly considers Marr's first and second levels. We show that, with a little extra work, EVT can be easily modified to include all three of Marr's levels.

Communication neuroscience: Examples across subfields

With these considerations in mind, we now turn to more extended applications of Marr's framework in communication science. In doing so, we demonstrate how Marr's framework helps build and test communication theory in a variety of disciplinary subfields.

Audience responses to messages

The concepts of *audience* and *message* are integral to communication science. As one of the earliest introductory textbooks puts it, "Any communication situation involves the production of a message by someone, and the receipt of that message by someone." (Berlo, 1960, p. 16). Or as Shannon once said, "The fundamental problem of communication is that of reproducing at one point, either exactly or approximately, the message selected at another point." (Shannon, 1948, p. 369). In the following section, we examine the concepts of audience and message reception using Marr's three levels, with a specific focus on Shannon's (1948) *Mathematical Theory of Communication*, to illustrate how Marr's framework applies to communication science.

Situating audiences within Marr's three levels

To situate the topic within Marr's framework, we must first understand why different means of communication exist, and what problem we are trying to solve by communicating. Perhaps the most basic answer is that humans are not perfect information senders or receivers, and must therefore use some kind of protocol to transmit information. Often, messages are sent with the intention of acting as an agent of change—be it by providing knowledge or to persuade—the receiver (Berlo, 1960). However, given that all communication intentions are mediated by the message construction and transmission process, the message a speaker believes they are creating and sending out to an audience may not be the one that is received. Errors in the fidelity of message transmission are introduced, which interfere with the transmission and reception. Thus, the speaker fails to influence the audience as intended, leading to a need to understand why message transmission is successful, why it fails, and why constraints on the system produce specific communicative behavior. Answers to these questions represent Marr's first level of explanation. To address such problems, let us start at the computational level, and use theory to make sense of the kind of protocols humans adopt to better communicate with audiences and how audiences make sense of the messages they receive.

Perhaps the clearest example of a theory that addresses these fundamental elements of communication is Shannon's (1948) *Mathematical Theory of Communication*, commonly known as information theory (IT). IT describes communication in terms of mathematical theorems focusing on the transmission of messages from one place to another, with five key elements: an information source, which produces a message; a transmitter, which encodes the message into signals; a channel, to which signals are adapted for transmission; a receiver, which decodes (reconstructs) the message from the signal; a destination, where the message arrives. A sixth element, noise, is a dysfunctional factor: any interference with the message traveling along the channel (such as static) which may lead to the signal received being different from that sent.

Although proposed primarily to describe communication in technical systems regardless of the content, the model at the root of IT was widely adopted by the fledgling discipline of communication (Rogers, 1994), particularly in the sender-message-channel-receiver model (SMCR; Berlo, 1960), which reframes IT in order to explain how and when messages may be understood by audiences in the way they were intended by senders. In terms of Shannon's model and the SMCR, the audience can be understood as the message destination or receiver. Applying Shannon's model to mass communication, for example, Schramm (1955, p. 132) notes that "Communication occurs when two corresponding systems, coupled together through one or more non-corresponding systems, assume identical states as a result of signal transfer along the chain. . . . Unless the concept in the semantic system of Mr. A. is reproduced in the semantic system of Mr. B., communication has not taken place." Thus, message transmission and reception are central concepts when IT is adapted to audience research. Importantly, IT addresses Marr's first and second levels: The problem at the root of communication is defined clearly (the *why* of communication) and mathematical formulae are introduced to account for the transmission of information from a sender to an audience (the *what* of communication).

Shannon's model can be mathematically formalized as follows (Rogers, 1994, p. 421):

$$\int_1 (t) \rightarrow T \rightarrow F(t) \rightarrow R \rightarrow \int_2 (t)$$

Where $\int_1 (t)$ is the message to be transmitted as a function of time, T is the transmitting element, $F(t)$ represents what is actually transmitted, R is a receiving element, and $\int_2 (t)$ should be similar to $\int_1 (t)$ but for noise or static (Rogers, 1994). In a landmark paper, Schramm applied IT concepts to mass communication processes (Schramm, 1955).

One way to investigate the physical implementation of this "semantic system" would be to study the neural basis of sensory and perceptual systems. Indeed, many careers have been dedicated to doing exactly this, and such inquiry is among the oldest in the cognitive neurosciences (Gazzaniga, Ivry, & Mangun, 2013). However, if we are interested in studying how not only the information of a message is transmitted from one mind to another, but the *meaning* of a message is transmitted, then we also need to study higher-order neural processes. Therefore, we turn to something known as intersubject correlation (ISC; Hasson et al., 2004), which assesses the degree to which the neural time series in the brains of message receivers (i.e., the audience) are correlated (Schmälzle et al., 2013). In brief, ISC analysis reveals the extent to which message-induced brain responses become correlated as the members of an audience receive and attend to the same stimulus. This analysis accounts for Marr's third, implementation level, in that a large magnitude ISC indicates that a message has arrived in a brain, that specific states are shared, or are at least common across audience members.

Supporting this theorizing, it has been shown that, when there is no common message, brain activity between audience members remains uncorrelated (e.g., Hasson et al., 2004). When a message is incomprehensible, or otherwise compromised in its 'meaning', then the ISC between audience brains is also uncorrelated (Schmälzle et al., 2015). Moreover, the degree to which a speaker and a listener exhibit ISC during communication predicts how well the information was transmitted (Stephens et al., 2010). Lastly, several recent studies suggest that manipulations of message-sided factors (e.g., message topic, quality; Schmälzle et al., 2015; Imhof et al., 2017), receiver-sided factors (e.g., audience attention, previous knowledge; Ki, Kelly, & Parra, 2016), or message–receiver interactions (e.g., topical fit between message and receiver-sided variables; Schmälzle et al., 2013), affects the magnitude of ISC that is observed. The central point is that the correlated brain responses revealed by ISC analysis indicate that a message has been transmitted into the brains of audience members and that the message evokes shared informational states among and across audience members. In this way, Marr's third level of *how* communication occurs in the brain can be understood via ISC.

What audience research gains from adopting Marr's framework

By using Marr's framework we can build on the foundations at Levels 1 and 2 in order to better understand audience message processing. Although the neuroscience of sensory and perceptual aspects of information reception and processing is well developed, knowledge gaps exist with regard to processes pertaining to the conceptual and semantic aspects of information reception. Beyond studying how individual messages and specific subaspects of meaning are transmitted and decoded in the brains of individual audience members, we can study this process at a collective level via the ISC approach. By linking Marr's three levels of inquiry, we can better refine fundamental applications at Levels 1 and 2. For example, using ISC, it may be possible to model the fidelity of specific types of messages when transferred from sender to receiver, or better model the effects of specific types of interference (e.g., noise, sender characteristics, audience composition) on information decay. Even more fundamentally, we can study how information is transmitted from the semantic system of Mr. A to Mr. B, and build more functional *why* explanations at Marr's Level 1.

Persuasion

Persuasion is a change in attitude or behavior as a result of free choice following an intentional communicative act (e.g., Perloff, 2014). The idea that attitudes and behavior can be altered intentionally through communication alone is fundamental to human society and highly attractive to any goal requiring change without the possibility or desire for physical or structural intervention. Consequently, persuasion has been a central element of communication science from early Greek rhetoric (Golden, Berquist, & Coleman, 2000), to the foundation of the field of (Berlo, 1960), to the contemporary, somewhat fragmented research across communication subfields. Here, we showcase how Marr's framework unifies and increases the efficiency of persuasion research by moving beyond a focus on context-specific effects. This process develops a common language that shapes and connects communication science subfields.

Situating persuasion within Marr's three levels

Persuasion research exists at all three of Marr's levels, yet is focused disproportionately on first-level *why* explanations. Such research charts why persuasion occurs as a function of variation in persuasive appeals (J. Hornik, Ofir, & Rachamim, 2016), situations (Hullett, 2005), and populations (Prochaska, Redding, & Evers, 2015), among others. These types of investigations can be inefficient on their own because their contextualized nature hinders them from building on and learning from one another.

Consider two examples of mere exposure effects studies. Grinsven and Das (2016) observed stronger positive effects of more compared to less frequent exposure to logos on brand attitudes and recognition when logos had higher compared to lower complexity. McAfee, Davis, Shafer, Patel, Alexander, and Bunnell (2017) found that the dose–response relationship between exposure to antismoking campaigns and message effects was moderated by audience characteristics like race, education, and mental health status. Both studies concern mere exposure effects. But the moderating role of complexity or demographics on mere exposure effects remains unclear because the two studies describe one concept in two languages (both in terms of methodology and terminology) without a clear translation. A common language is needed, and can be found in existing first-level persuasion research that uses common concepts (e.g., attitudes) and theoretical approaches (e.g., the elaboration likelihood model [ELM]; Petty & Cacioppo, 1986).

It is hard to generalize common, context-independent rules on the basis of first--level evidence alone. This is because detailed descriptions of specific effects in specific contexts often lead to multiple plausible explanations for a behavior. Nevertheless, a context-independent framework is necessary. Why? Put simply, humans do not have specialized "persuasion systems" that govern responses to persuasive appeals according to completely separate rules in different contexts. Research at Marr's second and third levels can determine which context-independent explanations are biologically plausible, and therefore help eliminate alternative explanations. Such a cross-level approach supports more efficient first-level research by specifying the context-independent biological and algorithmic basis for persuasion.

The field of computational persuasion (Marr's second level) developed from early argumentation research and was largely focused on parameters such as argument strength, sequence, and logic (Hunter, 2018). Contemporary examples include the use of automated persuasion systems that apply messaging strategies informed by algorithmic models of persuasion. Examples include a virtual nurse based on a formalization of the ELM (Kang, Tan, & Miao, 2015), the use of reinforcement learning models to predict the success of an agent that negotiates for resources (Keizer et al., 2017), and using an algorithmic model to test if cognitive processing is required for mere exposure effects to occur (Fink, Monahan, & Kaplowitz, 1989). Studies such as these demonstrate how context-general concepts (reinforcement learning, mere exposure) are applied to specific contexts to test second-level hypotheses. An added advantage of these types of mathematical models, as compared to more classic statistical tests like analysis of variance that are often used in research at Marr's first level, is their generalized capacity to evaluate a model's ability to predict out-of-sample outcomes. This allows researchers to evaluate if, and to what extent, an effect generalizes to novel contexts (Jolly & Chang, 2019).

Computational models at Marr's second level are inherently simplifications of reality, which reduce the feature space of relevant concepts and hypotheses that are identified in contextualized studies at the first level to a few key parameters with formalized relationships. Kaplowitz and Fink (1982, p. 365) made this point elegantly: "By contrast [to persuasion research] with just three principles and two fundamental variables (length and time), Newton was able to explain phenomena as diverse as planetary motion, falling objects . . ., and the motion of a pendulum." But what are the relevant context-independent variables? We argue that persuasion research at Marr's third level can efficiently narrow the feature space of concepts to a few key variables that are implemented biologically and drive context-independent persuasive effects.

Persuasion research at Marr's third level is concerned with identifying the biological bases of persuasive processes. There is a relatively long-standing tradition of applying physiological measurements to study persuasive effects (e.g., Clayton, Lang, Leshner, & Quick, 2018) and communication neuroscientists have begun using functional neuroimaging to study neural structures and signal that support persuasion (for a review, see Falk & Scholz, 2018). This work intersects with research at other levels and contributes to the efficiency of persuasion research in several ways. Specifically, cross-level knowledge creation can occur in a top-down (from the first level to the third) and a bottom-up fashion (from the third level to the first).

In top-down persuasion research, questions at Marr's third level examine the biological implementation of first- and second-level concepts. Identifying the physical systems that implement a certain process can help to specify boundary conditions that govern the functioning of that system and, thereby, the behavior in question. For instance, knowledge about physical limitations has helped researchers to distinguish concepts such as subliminal and supraliminal priming (Kouider, Dehaene, Jobert, & Bihan, 2007). Likewise, in situations where similar concepts are studied using context-specific methodologies and terminologies (see the mere exposure examples above), biological explanation can help to understand whether these processes are indeed separate, context-dependent concepts or whether they are implemented by the same, less context-dependent biological systems and functions (Lieberman, 2010).

For instance, neuroimaging research on persuasion has consistently identified brain regions in which activity correlates with the subjective valuation of a wide range of stimuli, including the VS and ventromedial prefrontal cortex (VMPFC;

Bartra, McGuire, & Kable, 2013). The VS is thought to encode relatively low-level judgments about the rewarding nature of a stimulus, whereas the VMPFC is thought to encode deliberate thought processes that compute value based on diverse relevant inputs (Knutson & Genevsky, 2018). Interestingly, although VS activity is often found to be the strongest correlate of persuasion in marketing-related work (Genevsky, Yoon, & Knutson, 2017; Knutson & Genevsky, 2018), health communication research more often identifies strong relationships between persuasion and VMPFC activity (Falk & Scholz, 2018). This work suggests systematic differences in persuasive processes across two prominent subfields, but does not yet explain why these differences occur. Such insights may direct further inquiry at other levels. In this case, observations and algorithms at Marr's first and second levels, respectively, may not be generalizable from one subfield to the next. This calls for explorations of why and when different biological systems drive persuasion.

In bottom-up cross-level knowledge creation, researchers working at the third level can start with knowledge about a physical system and investigate its involvement in certain first- and second-level processes. For instance, after identifying neural correlates of persuasion, researchers can make novel predictions about processes at the second level which are driving persuasion (see e.g., Meshi, Biele, Korn, & Heekeren, 2012). We can illustrate this process using our mere exposure case study. As described above, communication neuroscientists have reliably identified regions within the brain's subjective valuation system (VS/VMPFC) as key structures involved in persuasion. One common second-level model that is often used to describe brain activity in these regions and to predict decision-making (Basten, Biele, Heekeren, & Fiebach, 2010) is the drift diffusion model (DDM). According to the DDM, decision-makers accumulate evidence over time until a certain threshold is reached after which a decision can be made (Ratcliff & McKoon, 2007). One can therefore use a DDM as a source of algorithmic hypotheses at Marr's second level—parameters such as the accumulation of subjective value and the threshold at which a decision is reached may be used to model a viewer's response to repeatedly watching a persuasive ad, as well as their neural responses to repeated exposure in the VS and VMPFC.

What persuasion research gains from adopting Marr's framework

Building holistic, generalizable models of persuasion require regular knowledge transfer between communication subfields and between Marr's levels of inquiry. This goal requires distinguishing between context-general and context-specific concepts, that is those that do or do not share biological and algorithmic foundations. Finally, and as demonstrated above, biological explanation increases the efficiency of and highlights novel avenues for research across Marr's levels of inquiry.

Social comparison

We interact with others on a daily basis, both in person and via mediated environments. As we interact, our brains process a wide array of social information that guides our communication and behavior. A well-established theory from psychology, social comparison theory (Festinger, 1954) has been widely adopted by the field of communication to explain how we compare ourselves to relevant others to assess our own opinions and abilities. To elaborate, Festinger proposed that social comparisons can be categorized into three types: (a) upward comparisons, in which we compare ourselves with others who we perceive as doing better in a given domain (e.g., a task or goal), (b) lateral comparisons, in which we compare ourselves with similarly performing individuals, and (c) downward comparisons, in which we compare ourselves with others who we feel are performing worse in a given domain. Downward and lateral comparisons with others may provide reassurance that we are performing well in a particular domain, and typically lead to positive feelings (Gibbons & Gerrard, 1989). In contrast, although upward social comparisons have the potential to inspire individuals to improve their own performance, scholars have found that upward comparisons often lead to feelings of discouragement and reduced well-being (Appel, Gerlach, & Crusius, 2016).

Communication researchers have made great progress in their respective fields by capitalizing on social comparison as a cognitive mechanism to explain myriad communication phenomena. For example, communication scholars have investigated social comparison as it affects various aspects of interpersonal communication (Berger & Calabrese, 1974) as well as mediated contexts (Knobloch-Westerwick & Romero, 2011) and most recently social media (Johnson & Knobloch-Westerwick, 2014). An exhaustive review of these contributions is beyond the scope of this article, however, as we will demonstrate below, these contributions by communication scholars have, by and large, focused on explaining Marr's first level.

Situating social comparison within Marr's three levels

Considering Marr's first level, communication research has explored why individuals conduct social comparisons and how the cognitive process of comparing oneself to others may lead to specific behaviors and outcomes. For example, natural selection has resulted in the modern human having a need to connect with and manage their reputation with others (Baumeister & Leary, 1995). Engaging in social comparison helps to fulfill these needs by allowing individuals to figure out how they compare to others on a similar domain (i.e., self-evaluation). In addition, engaging in upward social comparisons motivates individuals to reduce discrepancies between the self and others that improves performance and subsequent social standing.

Festinger (1954) described the social comparison process in interpersonal contexts, but communication researchers have also applied social comparison theory to mediated contexts, examining how comparisons made in these environments relate to psychological outcomes, such as body dissatisfaction, depression, and well-being. Within the context of body image research, scholars have used social comparison as a cognitive mechanism to describe body dissatisfaction following exposure to idealized media images, both in mass media (e.g., Knobloch-Westerwick & Romero, 2011) and social media platforms (e.g., Hendrickse, Arpan, Clayton, & Ridgway, 2017). A related line of research has used social comparison as a cognitive mechanism to describe the use of online social media platforms (Meshi, Tamir, & Heekeren, 2015) and how this use may lead to decreased affect and well-being (Appel, Crusius, & Gerlach, 2015).

With regard to Marr's second, algorithmic level, scholars have attempted to outline the mathematical parameters under which social comparisons take place. For example, parameters could include (a) the discrepancy between oneself and the other within the comparison domain, (b) the direction (upward or downward) of the discrepancy between the self and other within the comparison domain, (c) the overall similarity of the comparison target to oneself across other domains, and (d) one's intrinsic drive to conform to the group that they belong to. These potential parameters could be included in an algorithm that would describe the human process of social comparison. For example, Fridman and Kaminka (2007) used social comparison theory to develop a cognitive model of crowd behavior, which is the behavior of groups of people in close geographical or logical states who are influenced by each other's presence and/or actions. The first computation in their overall crowd behavior model calculates comparison similarity to another on a single factor *s(x)* using a weighted linear sum:

$$s(x) = \sum_{i=0}^{k} w_i f_i$$

In this equation, k represents the feature index, or the particular domain of comparison (e.g., is this individual a similar age, ethnicity, education); f_i is the perceived similarity, and w_i is the order of importance of each factor (e.g., prioritizing similarity in age over similarity in ethnicity). The individual chosen for comparison (i.e., target) is the one that is the most similar to the agent (within specified bounds). In this way, Fridman and Kaminka (2007) incorporate computational aspects of social comparison into an overall algorithmic model that describes and predicts crowd behavior. This example demonstrates that the cognitive process of social comparison can be mathematically formalized at Marr's second, algorithmic level.

With regard to Marr's third, physical implementation level, work in the field of cognitive neuroscience has provided the neural substrates involved in making social comparisons. This research has examined the brain regions involved in both downward and upward social comparisons. A recent meta-analysis of 72 of these studies (Luo, Eickhoff, Hétu, & Feng, 2018) has revealed that the VS and VMPFC are active when making downward social comparisons. As discussed above, these regions are part of the brain's subjective valuation system and are active when people experience or anticipate experiencing situations that they value (Bartra, McGuire, & Kable, 2013). For example, reward system activation occurs when individuals receive positive social feedback online, such as obtaining "likes" on social media (Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016). Conversely, the meta-analysis by Luo et al. also revealed that the anterior insula and dorsal anterior cingulate cortex are active when making upward social comparisons (Luo et al., 2018). These regions are well-known to be involved in situations of social loss or social pain (Rotge et al., 2015).

Importantly, communication scholars have begun to investigate the role of social comparisons in regard to communication topics. For example, a study by Meshi, Morawetz, & Heekeren (2013) assessed the role of social comparison in driving social media use. To do this, the authors provided participants with reputation-related social rewards, and participants also saw another person receive social rewards. When the authors examined activation of participants' nucleus accumbens (a structure in the VS implicated in processing rewards), they found that greater activity in response to seeing self-related social rewards, relative to seeing social rewards given to another person, correlated with Facebook use intensity across participants. Notably, self-related social reward activity alone was not associated with intensity of social media use, only the socially compared social reward activity was associated with intensity of social media use. Therefore, with regard to social neurocognitive processes and social media use, the bigger the difference in an individual's reward system response to self- versus other-related social rewards, the more that individual uses Facebook.

What social comparison research gains from adopting Marr's framework

As described above, different research fields have made great strides investigating the cognitive process of social comparison. Importantly, however, there is still much to be gained from applying Marr's conceptual framework within each field. For example, at Marr's third level, recent neuroimaging work has focused overall on social comparisons after receipt of monetary rewards, neglecting to examine brain activity in contexts other than monetary gain (Kedia, Mussweiler, & Linden, 2014). Therefore, research at Marr's third level could benefit from incorporating a broader range of contexts, which are provided by research at Marr's first level. Communication scholars hold much potential in this regard, as the field explores situations of social comparison across many contexts. In other words, the advances of communication theory at Marr's first level could provide a wealth of contexts in which to examine social reward processing at Marr's third level, whereas algorithmic information from Marr's second level could afford scholars the opportunity to see if (quantifiable) individual differences in social comparison correlate with brain activation or behavioral outcomes. In addition, the domain generality of social comparison research at Marr's second and third levels may help communication scholars identify processes common across Marr's first level. Thereby offering communication researchers more powerful, and less contextually bound, theorizing.

Conclusion

In this manuscript, we introduced Marr's three levels of explanation, situated them within communication science, and demonstrated how they can be applied across a number of research areas that transcend communication subfields. Along the way, we have argued that what looks like fragmentation in the absence of a formal framework begins to look like an integrated line of inquiry once a framework, such as Marr's, is in place (Pfaff, Tabansky, & Haubensak, 2019).

Some readers might wonder if adopting Marr's framework requires them to develop specialized skills in computational modeling or biological inquiry such as psychophysiology or neuroimaging. In short, the answer is no. Truly specializing in inquiry at one level represents a lifetime of training and work and communication scientists should not be expected to specialize in all three levels. The important point is that a common framework toward shared empirical inquiry allows specialists at one level to communicate across all levels. Naturally, this creates opportunities for collaboration between specialists at each level who are, nevertheless, interested in a shared fundamental question of communication processes.

Fully implementing Marr's framework requires overcoming a number of challenges that cut across multiple domains central to communication science. First, constructs like *understanding* and *meaning* are often only loosely defined and carry a lot of surplus implications. As a result, we lack sufficient detail to mathematically model these constructs at the second level or to precisely identify their implementation in the brains of audience members. Although recent advances in natural language processing now make it possible to quantify aspects of meaning that were previously considered elusive (e.g., Mikolov, Corrado, Chen, & Dean, 2013), it is still the case that many layers of information that are relevant for human communication remain insufficiently specified at all three of Marr's levels. This does not mean that progress is impossible, quite the opposite. A growing handful of theories has pinned down higher-order communication processes with sufficient specificity to be tractable across all three of Marr's levels (see e.g., Fisher et al., 2018).

A second reason is that our understanding of higher-order cognitive processes remains incomplete given that cognitive and social neuroscience—the two closest relatives of communication neuroscience—are themselves relatively young disciplines. Gaps regarding conceptual and semantic aspects of information transmission are an opportunity for future research. Indeed, there is reason to believe that communication science can become a testbed for cutting-edge research given its focus on realistic and relevant messages as opposed to stale or otherwise reductionistic "stimuli" (Krakauer et al., 2017).

A third reason why we do not yet fully understand communication processes across Marr's three levels is that most communication research cuts across numerous topical subfields that are currently divided. Thus, the conceptual space is very large and complex and encompasses widely distributed knowledge domains. For instance, a complete understanding of the processes engaged during the reception of a public speech, a radio program, or a TV show, would not only involve all the auditory and visual processes, but also diverse content areas that are being communicated, and various social processes pertaining to nonverbal levels of information, the context, and so on. These concerns are not new and the field has wrestled with them since inception (Berlo, 1960; Rogers, 1994). We assert that Marr's framework helps tackle these issues across domains and levels of inquiry in a parsimonious, yet heuristic, manner.

On a final note, Marr's framework does *not* argue for the primacy of one level of explanation. It clarifies the explanatory bounds any level can claim while demonstrating how each level is crucially dependent on all other levels. If a goal of this special issue is to speak across subfields, Marr's framework is an excellent starting point for initiating these discussions.

Notes

1. A recent network analysis of ICA and the Korean Society of Journalism and Communication Studies (KSJCS) found a similar structure for ICA but with just two major dimensions: scientific–humanistic and interpersonal mediated. KSJCS, by comparison, had just one major dimension: media-journalism (Chung, Lee, Barnett, & Kim, 2009).
2. Marr's framework might also inform researchers who adopt a humanistic epistemology, however, we humbly admit that we are not experts in this area. We have endeavored to present Marr's ideas clearly and hope that humanities scholars might find connections between Marr's framework and their own research. We are eager to participate in discussions organized around this effort.

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