The Future of Weak Ties[1]

"The Strength of Weak Ties" (Granovetter 1973) arguably contains the most influential sociological theory of networks. Granovetter's subtle, nuanced theory has spawned countless follow-on ideas, many of which are immortalized in the 35,000 manuscripts that cite the original work. Among these are notable theories in their own right, such as Ron Burt's structural holes theory (Burt 1992), which itself has generated a sizable body of knowledge about the social structure of competition.

The central argument of this line of theory is that contacts maintained through weak ties are more likely to be bridges to socially distant network cliques, which provide access to novel information and resources.[2] Novelty is thought to be valuable because of its local scarcity. Those with access to scarce novelty are better brokers, make better decisions, and innovate more effectively, it is argued, by leveraging novel information to solve problems that are intractable given local knowledge.[3] Since this theory was elucidated, the empirical evidence has accumulated both for and against the strength of weak ties. In some cases, weak bridging ties are advantageous (e.g., Hargadon and Sutton 1997; Reagans and Zuckerman 2001; Burt 2004; Rodan and Gallunic 2004); in other cases, however, strong cohesive ties seem to provide more advantage (Coleman 1988; Uzzi 1996, 1997; Hansen 1999; Reagans and McEvily 2003; Obstfeld 2005; Uzzi and Spiro 2005; Lingo and O'Mahony 2010).

In 2011, Marshall Van Alstyne and I proposed the diversity-bandwidth trade-off theory to help rationalize this apparent contradiction (Aral and Van Alstyne 2011). We argued that as ego networks become more struc-

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[2] Bridges are made possible by the "small world" nature of human social networks, which simultaneously exhibit high clustering and low average path length, creating dense cliques connected by weak ties (Watts and Strogatz 1998).

[3] There is also a power argument embedded in this theory, but much (though not all) of this power emanates, theoretically, from differential access to novel information and resources. I therefore focus here exclusively on novelty, rather than on power.

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turally diverse (accumulating weak bridging ties and forgoing strong cohesive ties), the bandwidth of their communication channels should contract, reducing information flow through the network. We showed, through textual analysis of email content, that the diversity-bandwidth trade-off regulates access to novel information because, all else equal, greater channel bandwidth delivers more diverse information and more total nonredundant information. The diversity-bandwidth trade-off helps resolve the apparent contradiction in weak tie theory because while greater network diversity (sparse networks with weak ties) and greater channel bandwidth (found in cohesive networks with strong ties) *both* provide access to novel information, determining *which* provides *more* novelty depends on the information environments in which brokers are situated. We showed that in information environments with rapidly changing information, many topics, and overlapping information between actors, strong cohesive ties deliver more novel information. In information environments with few topics, slowly changing information, and less information overlap between actors, on the other hand, diverse networks with weak ties provide more novelty. In essence, the strength of weak ties and the strength of strong ties are both theoretically sound arguments, but which prevails depends on the informational context in which individuals are embedded.

In "The Strength of Varying Tie Strength," Bruggeman (2016) provides strong confirmatory evidence for the diversity-bandwidth trade-off in an entirely different empirical context: knowledge flows in a data set containing 2 million U.S. patents over 24 years. This confirmation of the diversity-bandwidth trade-off is important, especially as several scientific disciplines are facing expanding replication controversies (Open Science Collaboration 2015), both because of the strength of the replication in a large data set and because it confirms the broad applicability of the theory across institutional, organizational, and knowledge contexts. In this way, Bruggeman's comment adds to the growing evidence replicating and supporting the diversity-bandwidth trade-off (Wu et al. 2008; Grabowicz et al. 2012; Aral and Dhillon 2015).

Bruggeman's main contribution, however, is to make two extensions to the theory by emphasizing differences between simple and complex knowledge and, more important in my view, by theorizing that the benefits of bandwidth are maximized when tie bandwidths are matched to the quality of the information sources transferring complex knowledge.

The first extension is not new. Szulanski (1996), Argote (1999), Hansen (1999, 2002), Uzzi (1996, 1997), Reagans and McEvily (2003), and Wu et al. (2008) have all argued that complex knowledge is transmitted more effectively through strong ties. Wu et al. (2008) go so far as to connect this argument to the diversity-bandwidth trade-off by showing that diverse networks of weak ties perform better when simple knowledge is being transferred and that cohesive networks of strong ties perform better when complex knowledge is being transferred.

Bruggeman's second extension, however, is both novel and subtle. He argues that, given the high cost of transmitting and processing complex information, individuals should avoid spending resources on maintaining high bandwidth ties with every contact, but rather should vary their tie bandwidths in proportion to the value of the information coming from a particular source. This reasoning is in line with our *AJS* article (Aral and Van Alstyne 2011), which focused on the second moment of the bandwidth distribution: we argued that *on average* higher bandwidth will be beneficial for accessing novelty. Bruggeman extends the argument by focusing on the contours of the distribution of bandwidth over ties. Not only should higher average bandwidth be beneficial, he argues, but the distribution of bandwidth should vary such that high bandwidth ties are maintained with high-value information sources, while lower bandwidth ties are maintained with lower-value information sources (see fig. 1). His analysis supports *both* arguments: higher average bandwidth is beneficial, as is maintaining a distribution of ties with bandwidths proportional to information value.

A modern weak tie theory—made possible by access to more granular, large-scale, microlevel data on networks, communication content, and knowledge transfer—is emerging from the most recent research in this area. This modern weak tie theory is an extension of the pillars of classical weak tie theory, including the strength of weak ties (Granovetter 1973), social cohesion (Coleman 1988), and structural holes (Burt 1992), which rely mainly on survey and interview data to support their theses. Modern weak tie theory, in contrast, relies on new sources of fine-grained data such as nationwide call log records (Eagle, Macy, and Claxton 2010; Miritello et al. 2011), email networks with content data (Iribarren and Moro 2009; Aral and Van Alstyne 2011), social media networks (Grabowicz et al. 2012), and large networks of manuscript or patent citations (Vilehena et al. 2014; Bruggeman 2016) to flesh out the details of precisely how network structure, information flows, and nodal outcomes coevolve.

Although modern weak tie theory is still in its infancy, several of its intellectual arcs are now coming into focus. At the heart of the movement is a deep examination of the coevolution of networks and the information and knowledge content that flows through them (Carley [1997], Diesner and Carley [2005], Yang and Counts [2010], and Lu, Kinshuk, and Singh [2013] provide some examples; for a detailed review see Sundararajan et al. 2013). There is a focus on the micromechanisms that govern network dynamics in context: the diversity-bandwidth trade-off which regulates access to novel information (Aral and Van Alstyne 2011), the differences between local and global structural holes (Reagans and Zuckerman 2001), secondhand brokerage (Burt 2007), and the decay of weak bridges (Burt

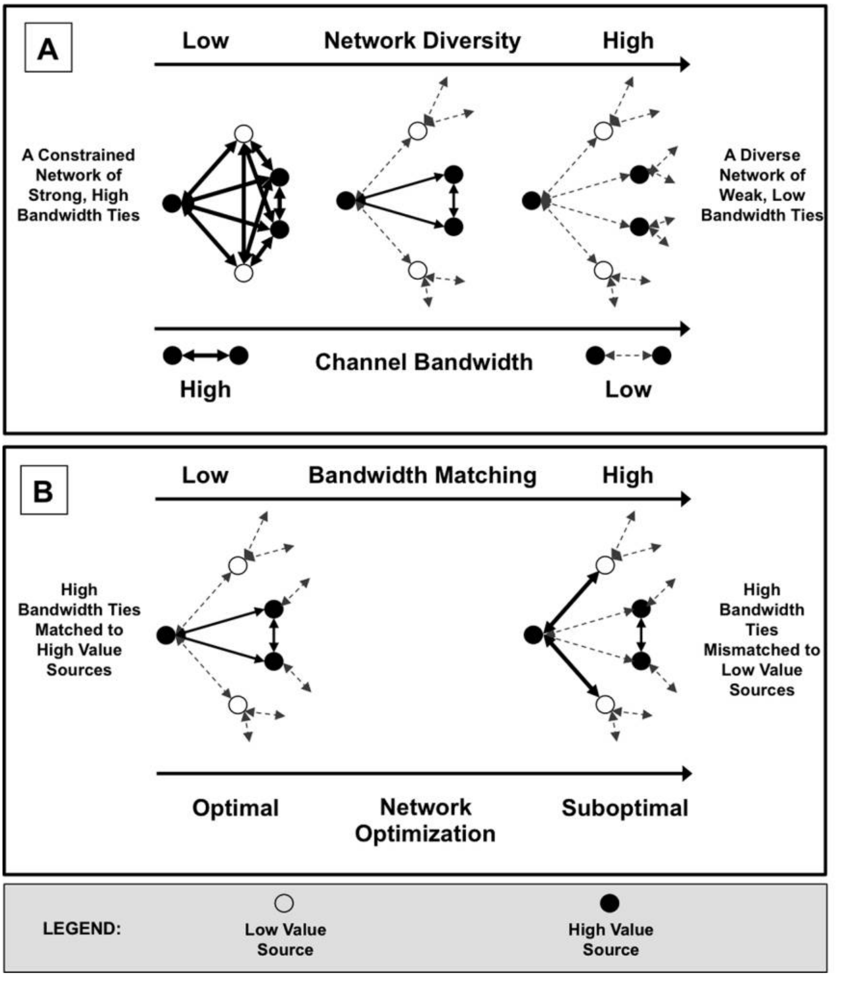

FIG. 1.—This image displays the mechanics of the diversity-bandwidth trade-off and the strength of varying tie strength. Part A replicates the relationship between network diversity and channel bandwidth displayed in Aral and Van Alstyne (2011), but also colors alters by whether they are high value (solid circles) or low value (hollow circles) sources of information. Part B displays the process of bandwidth matching suggested by Bruggeman (2016). In optimized networks, high bandwidth ties are maintained with high-value sources of information, while low bandwidth ties are maintained with low-value sources of information.

2002) are good examples of the focus on micromechanisms. There is also a focus on the sociology of information itself (Burt 2008), which is defining and examining relevant theoretical dimensions of information and knowledge content that flow through networks. For example, recent research examines the coevolution of network structure and knowledge content by combining citation networks with topic modeling of scientific publications (e.g., Vilhena et al. 2014), examining variation in the flow of simple versus complex information (e.g., Hansen 1999; Wu et al. 2008), and metaknowledge in the production of science (e.g., Evans and Foster 2011). Finally, there is a focus on the critical task of integrating network dynamics and information flow: the diversity-bandwidth trade-off proposes a contingency theory of vision advantages in which informational context determines whether weak or high bandwidth ties deliver more novel information; the strength of varying tie strength extends this idea by examining "bandwidth matching" for targeted knowledge acquisition; and Aral, Brynjolfsson, and Van Alstyne (2012) examine the productivity effects of information flow in email networks and multitasking behavior.

Access to new large-scale, microlevel data presents a tremendous opportunity to modernize and improve the explanatory power of weak tie theory. However, several critical challenges remain. In particular, three unresolved issues suggest clear directions for future research toward creating a more rigorous, robust, and reliable weak tie theory.

First, we must address the endogeneity inherent in these relationships. Understanding the causal dynamics of networks, information and node outcomes will be critical to developing accurate knowledge on how weak ties "work" and how networks provide advantages. Some recent work has taken causal network dynamics seriously, using natural experiments (Sacerdote 2001; Hasan and Bagde 2013, 2015; Phan and Airoldi 2015; Aral and Nicolaides, in press), instrumental variables (Bramoullé, Habiba, and Fortin 2009), actor-oriented models (Snijders, Steglich, and Schweinberger 2006), matching estimators (Aral, Muchnik, and Sundararajan 2009), and randomized controlled experiments (Leider et al. 2009; Aral and Walker 2011, 2012; Centola 2010; Bond et al. 2012; Bakshy et al. 2012) to measure the causal effects of networks on performance and other outcomes. However, surprisingly little of this work has focused on weak ties, social cohesion, or structural holes specifically, testing the causal hypotheses implied by this theory. More work on the econometric identification of network effects will be essential to our understanding of how and why network structures cause nodal outcomes and how these structures and outcomes coevolve.

Second, we must be more specific and rigorous in defining the measurable dimensions of information content that matter. For example, what exactly is novelty? Readers of the last four decades of weak tie theory are left with only a vague understanding of what novel information is and how to measure it. Is novel information that which resolves the most uncertainty, that which is the most different than what is already known or locally available, that which is the most unique, or that which is the most diverse or varied? How can we theoretically and mathematically characterize these different dimensions of novelty? Clearly, the roots of such mathematical formalism exist in information theory, work on entropy, and other mathematical models of communication that date back at least to Claude Shannon (1948). But, without precision in our formulation of exactly what novelty is (and is not) we will have difficulty making reliable arguments about how it behaves or how it affects productivity, innovation, or performance (Aral and Dhillon 2015). The same thing could be said of information complexity, information "overlap," the density of information, how contextual it is, or its relevance, timeliness, or essentiality. We have much work to do to become more precise in how we conceptualize and formalize information in weak tie theory.

Third, we must examine the micromechanisms that explain the networked outcomes we observe. The diversity-bandwidth trade-off was an initial attempt to propose a structural explanation of how novel information moves through networks. The theory explains why and when novelty is more likely to flow through weak or strong ties. We precisely defined and measured novelty and tested whether the mechanisms we proposed held true in a rich data set. However, much remains unknown about how we dynamically distribute information, knowledge, and other resources through networks and how these distributions in turn affect outcomes. I believe there is a vast untapped potential for networks to explain many of our most pressing societal challenges. For example, the uneven distribution of information, knowledge, and resources surely explains part of the variation in globally accelerating inequality, but economic (Piketty 2014) and technological (Brynjolfsson and McAfee 2014) explanations currently dominate the debate. A focus on micromechanisms could help weak tie theory contribute to a broader intellectual milieu by becoming more precise, contextual, and rigorous.

A modern weak tie theory is emerging to strengthen and broaden one of the most impactful sociostructural intellectual traditions in recent memory. If more attention is paid to the key challenges preventing its ascendance, this modern theory could become one of history's most influential.

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