NORTHWESTERN UNIVERSITY

From the History of Network Visualization, Indicators of Interdisciplinarity, to the Career of Metaphor: Formal and Computational Methods and the Illumination of Patterns Otherwise Unknowable

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

DOCTOR OF PHILOSOPHY

Field of Sociology

By

Vincent Yung

EVANSTON, ILLINOIS

March 2021

ABSTRACT

From visualizing thousands of social relationships, operationalizing measures that offer us insight into our theories, to characterizing cultural change over the span of centuries, computational methods appear to provide sociology a means to reveal patterns otherwise unknowable. While these methods are persistently critiqued for their inability to generate social theory, some contemporary scholars have argued that computational methods may even change how we theorize social life. My dissertation takes inspiration from these debates. I offer three self-contained studies that demonstrate how various forms of formal and computational analysis, including early forms, permit us to advance social theory in a variety of ways.

My first chapter shows the importance network visualization. Existing historical accounts of the origins of Social Network Analysis tend to emphasize the foundational role of mathematics in unifying otherwise isolated approaches to the study of social structure. Visualization, a cornerstone of contemporary network research, has a relatively understated role in these accounts. Through an archival analysis of three early precursors of network research, I demonstrate how network visualizations impacted how each thought about, theorized, and communicated ideas about social structure.

My second chapter compares two divergent approaches to interdisciplinarity. The *Mertonian* approach assesses interdisciplinarity through the intermixing of disciplinary actors, while the *Geertzian* approach assesses it through the intermixing of ideas across disciplinary actors. Using the case of higher education scholarship, I use co-citation network analysis and topic modelling to operationalize each approach into complementary indicators of interdisciplinarity. My findings provide systematic evidence in support of the disciplinarity of higher education scholarship, but with a few complications. More broadly, my findings

demonstrate that the Mertonian and Geertzian approaches offer complementary insights and indicators that may be used to more consciously define, assess, and facilitate interdisciplinary scholarship.

Finally, my third chapter examines the evolving use of the network metaphor. I offer a formal model for visualizing and interpreting what metaphors describe and do and how they change and conventionalize. Specifically, I characterize the *career of metaphor* in the context of the network metaphor, which I leverage as both a revelatory case for evaluating my model and a critical case for deepening our historical understanding of the network. Using computational techniques based on co-occurrence, I find that the network metaphor underwent significant changes in use over the first half of the 19th century, stood in for anatomical structures of the body in the mid-19th century, and conventionalized prior to the start of the 20th century.

I use my dissertation to reflect on how computational methods may be used to theorize systematically and may impact how we theorize. I argue that, in some respects, computational methods supplement rather than succeed conventional approaches to theorizing. In other respects, however, computational methods impact how we theorize in ways that are genuinely unprecedented.

ACKNOWLEDGEMENTS

A quote I came across while researching the connections between scholars involved in early social network research is etched into my permanent memory. In a letter to a colleague, Jacob Moreno described Kurt Lewin in what some might consider unkind terms: “he did not appear to me like an originator of new ideas, but rather like a ‘feminine talent[’], like a man who knows hot [sic] to take ideas from others [and] tries to develop them further”.[1]

I find myself questioning why one would ever want to develop their own ideas when the alternative is so much more rewarding. All of what may be my best ideas in this dissertation would not exist if not for the ideas, comments, criticisms, and commiserations of the people who have helped me in my graduate school career (my worst ideas, which are many, are my own careless creations).

My graduate cohort was a lifeline. Sakhile Matlhare helped me be present in the process (because the process is a present). Robin Bartram, on numerous occasions, provided thoughtful feedback and also entrusted me with the livelihoods of Franny and Frère. Jess Meyer and Stefan Vogler will be the only people I ever wine and whine with. My friends, particularly Amelia Nguyen and Carly Chubak, gave me endless encouragement.

The Culture and Society Workshop at Northwestern provided invaluable feedback on multiple versions of each chapter. Chas Camic and Quincy Thomas Stewart offered clarifying and detailed comments on an earlier version of my chapter on interdisciplinarity. The discussant and presenters for the Social Theory and Social Data session of the Theory Section at ASA

---

[1] Correspondence from Jacob L. Moreno to Pierre Renouvier, Undated, Box 104, Folder 1742, Jacob L. Moreno Papers, Harvard Medical Library, Francis A. Countway Library of Medicine, Boston, Massachusetts.

provided helpful remarks on an earlier version of my chapter on the history of social network analysis.

For assistance obtaining materials I used to research the history of social network analysis, I would like to thank the archivists and librarians of the Baker Library at Harvard Business School, the Bentley Historical Library at the University of Michigan, the Center for the History of Psychology at the University of Akron, the Francis A. Countway Library of Medicine in Boston, the MIT Institute Archives, the Special Collections Research Center at the University of Chicago, and the University Archives at Harvard. None of my archival work would have been possible without the generous support of a Northwestern University Graduate Research Grant.

My dissertation committee, which includes Jeannette Colyvas, Wendy Espeland, Steve Epstein, and Wendy Griswold, offered grounding guidance. My dissertation co-chairs, Jeannette and Wendy, provided both extensive comments and invaluable instruction on how to think and write. They continue to push me to express my ideas with more clarity. If any of the ideas here are muddled, it is because I still have much to learn.

Ashwin Shahani was preternaturally patient as I talked through every single chapter in every iteration. My sisters only ever asked for what I needed. Lastly, my parents provided unconditional love and support.

Any child of immigrants will be familiar with the quiet patience required of someone who commits their life to a land that makes them into a stranger. In writing my dissertation, I have come to see this as an act of strength rather than a sign of submission. So, I dedicate this dissertation to my parents.

LIST OF ABBREVIATIONS

SNA: social network analysis

MIT: Massachusetts Institute of Technology

RCGD: Research Center for Group Dynamics

JHE: *The Journal of Higher Education*

RHE: *Research in Higher Education*

RevHE: *Review of Higher Education*

EC: eigenvector centrality

BC: betweenness centrality

CC: closeness centrality

OLS: ordinary least squares

ML: multinomial logistic

LDA: latent Dirichlet allocation

JSD: Jensen-Shannon divergence

SGNS: skip-gram with negative sampling

t-SNE: t-distributed neighbor embedding

For my parents, Benny and Virginia

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ARTICLE 1

ARTICLE 2

ARTICLE 3

INTRODUCTION

My dissertation takes inspiration from debates over the theory-method relationship in formal and computational analysis. I demonstrate how various forms of formal and computational analysis, including early forms, permit us to advance social theory in a variety of ways: by showing the importance of visualizing social structure, by comparing divergent approaches to interdisciplinarity, and by examining the evolving use of the network metaphor. Each chapter is a self-contained study that situates an idea in its lineage to illustrate how formal and computational methods may reveal patterns otherwise unknowable.

My first chapter situates early studies of *social structure* in a shared historical milieu in order to reevaluate the roles of mathematics and visualization in the emergence of Social Network Analysis [SNA]. Current historical accounts of SNA tend to reiterate a common story: the relational approach to social structure emerged in isolated fragments. According to this origin story, what unified these independent approaches in the 1970s was mathematics, which offered a formal vocabulary that left little ambiguity and provided a portable, reusable form of reasoning whenever structurally similar problems emerged. I challenge this account on the basis of an archival analysis of three American precursors of SNA during and following the Interwar period.

By situating precursors of SNA in a shared historical milieu, I suggest that it was not simply mathematics but network visualizations that were crucial in establishing the emergence of a new approach to social structure. I show that these precursors were recognized by individual adherents and colleagues as shared efforts to explain behavior through concrete relationships. Each approach vastly diverged in how it theorized, visualized, and formalized social structure. Yet network visualizations impacted how each thought about, theorized, and communicated ideas about social structure in common ways. Through visualization, early network-theoretic research encouraged new forms of representation for engaging with structural research that enabled communication across different audiences.

My second chapter situates ideas about *interdisciplinarity* against traditional approaches for its assessment in service of theorizing the measurement of interdisciplinarity. Interdisciplinarity is often hailed as a panacea for practical and innovative discoveries, yet there is little consensus over how to define and assess it. I argue that the way scholars theorize interdisciplinarity can be divided into two conceptually complementary but methodologically divergent approaches that I call the Mertonian and Geertzian approaches to interdisciplinarity. In the former, interdisciplinarity arises through the intermixing *of disciplinary actors*. In the latter, interdisciplinarity arises through the intermixing *of ideas across disciplinary actors*. I use each approach to develop two indicators for assessing interdisciplinarity: Mertonian intellectual canons and Geertzian cognitive frames. The former assesses interdisciplinarity through the integration of canonically cited disciplinary actors. The later assesses interdisciplinarity through the integration of the cognitive content of research across disciplinary actors.

To operationalize my indicators, I define a Mertonian intellectual canon as a co-citation network and a set of Geertzian cognitive frames as a set of topics in a linguistic topic model. I demonstrate the distinction between each indicator in the context of higher education scholarship. My findings provide insights that critically re-evaluate the interdisciplinarity of higher education scholarship. In doing so, they demonstrate how two divergent approaches can offer complementary insights and indicators that can be used to more consciously define, assess, and facilitate interdisciplinary scholarship.

My third and final chapter situates the use of the *network metaphor* against histories of the network concept in service of theorizing the career of metaphor. Metaphors evolve, shifting in meaning in undesired or unexpected directions, posing a challenge to sociological studies that seek to examine how metaphors can both anchor meaning in language yet evoke associations that enable cultural change. To account for the dynamics of metaphor over time, I propose a systematic analysis of metaphor anchored around four core questions. What do metaphors describe? How do metaphors change over time? What do metaphors do? And how do conventional metaphors emerge?

I address my questions by offering a formal model of the career of metaphor. Drawing on cognitive linguistics and sociological theories of public ideas and professional careers, I theorize that the career of a metaphor can be interpreted with respect to four core constructs: its *jurisdiction*, *periodicity*, *ecology*, and *conventionality*. I operationalize each construct using computational techniques that leverage co-occurrence and the Google Books Ngram corpus as my source of data. I apply and evaluate my constructs using the case of a persistent and prolific metaphor with a dynamic history that spans several centuries: the network metaphor. By comparing the career of the network metaphor to historical appraisals of the network concept, I both illustrate and evaluate my model of metaphor and deepen our historical understanding of the network.

ARTICLE 1

Visualization and the Origins of Social Network Analysis: Early Visions for the Quantification of Social Structure

1. Introduction

"A general yet powerful means of representing patterns" (Newman, 2010: 3). "One of the most potent ideas in the social sciences" (Borgatti et al., 2009: 892). A "powerful perspective for studying relational systems quite generally" (McCulloh et al., 2013: xvii). Social network analysis [SNA] is a mode of inquiry motivated by an interest in explaining the behaviors or processes of various systems, from kinship networks, corporate interlocks, social movements, to scientific collaborations, among others, through patterns of relationships. Along with providing a perspective for representing abstract ideas, it succeeded in making the intangible concept of social structure observable and subject to empirical investigation. This was by no means an ordinary scientific achievement. As Durkheim famously insists in the programmatic *Elementary Forms of Religious Life*, abstract concepts can feel so powerful and authoritative because they are made real, material, and tangible through collective representations of society. It was one thing to represent structure in everyday life. But a different question faced the earliest practitioners of this approach to the study of society, and that was how to present social structure in its complexity to other social scientists.

Three of the earliest exemplars of the visual approach to structure emerged during the Interwar period: Jacob Moreno's *Sociometry*, Kurt Lewin's *Group Dynamics*, and the approach recognized as *Positional Analysis* attributed to W. Lloyd Warner.[2] All three efforts are widely

[2] I term Warner's approach as Positional Analysis following Warner's description of his relational system in his *Yankee City* studies as a "positional system" and Arensberg's (1942) description of Warner's methods to the *American Sociological Society* as "position-analysis".

recognized as foundational attempts to analyze social structure that used tools distinct from those employed by their statistical, case-study, and interview-oriented peers (Coleman 1986; Scott 2000; Hanneman and Riddle 2005). Notably, each "precursor" engaged in techniques to visualize social structure. Moreno used sociograms to depict patterns of likes and dislikes, Lewin used field diagrams to represent interrelations between empirical facts, and Warner used positional charts to present patterns of interaction. This legacy carries on in the form of network visualizations that simplify a vast array of relationships into the most dazzling and elegant explanations of behavior (see Lima 2011).

In contemporary histories of the emergence of SNA, however, visualization occupies a position overshadowed by formal measurement. The most comprehensive accounts of the origins of SNA suggest that mathematical formalization was what united scattered strands of network research. In these accounts, visualization offered a tool that could communicate and perhaps reveal insights implicit in relational data. In contrast, mathematics by all accounts offered a precision that cut through the use of vague metaphors. It unified what were largely isolated research programs that shared a common "structural intuition"(Freeman 2004).

I problematize this origin story and examine the role of visualization by asking three questions. *How did visualization enable new ways of thinking about social structure? How did visualization impact how scholars theorized social structure? And how did visualization facilitate the communication of ideas about social structure across different audiences?* To do so I critically reevaluate the origins of SNA using the cases of Sociometry, Group Dynamics, and Positional Analysis. I analyze primary correspondences, published works, and other archival documents surrounding each research program. I use these documents to trace connections between each program, examine how each developed forms of mathematics and measurement, and compare how visualization impacted their research.

Contrary to contemporary historical accounts, I find that these programs were far from isolated developments. Rather, they were viewed by their contemporaries and each other as cut from the same cloth: shared efforts to explain behavior through concrete relationships. Each program offered theories that engaged with the contemporary network paradigm, which as I define includes a focus on relations, an analytical emphasis on structure, and a central yet malleable concept of a network. Yet each program operated on vastly divergent ideas of what constituted a relation, structure, and a network. Furthermore, each developed formal concepts and measurements that were in no way commensurate. What united these efforts was how they used network visualizations to think, theorize, and communicate ideas about social structure. For all three programs, visualization enlarged the possibilities for making social structure both empirical and engaging.

First, visualizations encouraged both readers and researchers to think about social structure through visual imagery. Network visualizations contained a variety of features, from circles, pointed arrows, to dotted lines, that signified different concepts for each program. Readers used these features to decode and interpret visualizations that were rarely if marginally explained by text. Researchers found visualizations useful for enabling thinking and exploration in the process of conducting research.

Second, visualizations offered each program a way to theorize and generate conceptual distinctions by visualizing "concrete" empirical situations. By simultaneously representing both abstract concepts and situations drawn from contemporary life, such as "sociometric stars" that identified popular girls among a group of friends or "behavioral situations" that predicted interactions at a tea party, visualizations tied the theorization of social structure to empirical research.

Lastly, visualizations provided an emblem of structural research that captured the imagination of the public and enabled communication across linguistic, disciplinary, and professional divides. What mattered were not the particularities of constructing a visualization, but the idea that social structure could be visually expressed. Beyond social scientists, journalists, muckrakers, and novelists, among others, could use visualization to engage with and critique the science of social structure.

I speculate on why visual approaches to structure emerged during the Interwar period. Furthermore, I use my findings to discuss the benefits of articulating the role of visualization in the origins of structural research. Far from rudimentary attempts to establish a structural paradigm, SNA's precursors offer rich resources for rethinking contemporary network theory.

2. Visualization in Origin Stories of SNA

The visualization of relational structures in everyday life is a practice time immemorial. From fifteenth century genealogical trees (Klapisch-Zuber 1991), nineteenth century organizational charts (McCallum, Henshaw, and New York and Erie Railroad Company 1855), to modernist flow diagrams of influence in art (Barr 1936), structural imagery offers a familiar visual language for making sense of the social world through relationships. Nowhere is this more apparent than in the study of social structure. If the history of scientific observation is a history of how the "private experiences of individuals have been made collective and turned into evidence" (Daston and Lunbeck 2011: 2), network visualizations have had an important role in making social structure both empirical and engaging. From snapshots of social networks that illustrate the spread of obesity (Christakis and Fowler 2007), red and blue hairballs of interconnected websites that capture polarization in the political blogosphere (Adamic and Glance 2005), to biennial congressional voting patterns that demonstrate a significant rise in partisanship (Andris et al. 2015), network visualizations both reveal scientific insights and captivate the imagination of audiences beyond the academy.[3]

Despite its importance, contemporary accounts for the emergence and adoption of SNA downplay the role of visualization and overemphasize the role of mathematics. These histories tend to reiterate a common story: the relational approach to social structure, based on the ties between actors rather than their attributes, emerged in isolated fragments, like "random pieces sitting out in the desert" (Mullins and Mullins 1973: 264) that failed to capture the attention of the wider social science community (Freeman 2004: 118). What unified these independent programs was mathematics (Wolfe 1978; Hummon and Carley 1993; Freeman 2004: 135). Scholars with degrees in mathematics filled SNA's earliest ranks, offering a formal vocabulary that unified the many isolated research programs that shared a common structural intuition. Formal concepts provided precise descriptive tools that avoided the misunderstandings invited by the use of linguistic metaphors (Freeman 1960; 1984: 126; 2004: 136; Leinhardt 1977: xiv; Holland and Leinhardt 1979: 2; Wasserman and Faust 1994: 11). Mathematics provided a form of reasoning that was "portable" and reusable whenever structurally similar problems emerged (Freeman 1984: 127). Visualizations offered insights about network structures and helped communicate those insights (Freeman 2000; 2004). But they were more important for inspiring mathematicians to apply lessons learned in graph theory to problems of social structure. "The

---

[3] Network visualizations from Christakis and Fowler (2007) were covered by the *New York Times* ("Study Says Obesity Can Be Contagious"), from Adamic and Glance (2005) in *Science* on the emergence of computational social science (Lazer et al. 2009), and from Andris et al. (2015) in *The Washington Post* ("A stunning visualization of our divided congress").

whole meaning in a graph is in its structure" (Freeman 2004: 24), and that structure was best if formally determined.[4]

I critically reevaluate this origin story and examine the role of visualization in three of the earliest exemplars of the visual approach to structure: Jacob Moreno's Sociometry, Kurt Lewin's Group Dynamics, and the approach recognized as Positional Analysis attributed to W. Lloyd Warner.

On one hand, these three exemplars are regarded as central figures in the emergence of SNA. Moreno is largely credited as the "father" of SNA. Lewin, through his students, is credited for adapting the mathematics of graph theory upon which contemporary network methods are based. And Warner, who oversaw studies such as the *Yankee City* project and the Bank Wiring Observation Room experiments of the famous *Hawthorne* studies, is credited for instigating a tradition of research at Harvard that inspired Harrison White to study social structure.

On the other hand, these three exemplars are historically unprecedented for their analytical focus on relationships instead of individual attributes. All three efforts analyzed social structure using tools distinct from those of their peers (Wasserman and Faust 1994; Freeman 2011; Scott 2017), diverging from the survey-based "variables paradigm" and qualitative community studies that dominated sociology from the 1940s and onward (Emirbayer and Goodwin 1994; Abbott 2001b).

[4] Contemporary appraisals of network imagery echo this sentiment and focus on how graphs can be effectively used to communicate data (Ding and Mateti 1990; Battista et al. 1994; McGrath, Blythe, and Krackhardt 1997; Purchase 1997; 2002; Butts 2008; Newman 2010; Krempel 2011). Network visualizations are "effective" if they can "highlight the key features of interest" (Healy and Moody 2014: 123), emphasize the "structural features" of interest (McGrath, Blythe, and Krackhardt 1997) or can be quickly interpreted or "decoded" (Krempel 2011). Here, the visual is a means of achieving what Lynch and Edgerton (1988: 212) term representational realism: "composing visible coherences, discriminating differences, consolidating entities, and establishing evident relations." Much less is said about network visualizations beyond their instrumental use for identifying structural patterns.

Contrary to the belief that they were isolated and ignored by the wider social sciences, I find that these precursors were both aware of their shared approach to the study of groups and publicly recognized for it. Despite sharing common intellectual interests, however, they engaged with radically distinct theories of social structure. This included different ideas of what constituted a relationship, structure, and a network and different forms of mathematics and measurement.

3. Sociometry, Group Dynamics, and Positional Analysis

3.1. Shared Connections in the Study of Group Behavior

Jacob Moreno was a psychiatrist who viewed the development of group therapy as fundamentally intertwined with the study of group interaction. Moreno contributed to both by creating Psychodrama and Sociometry: the former instructed patients to act out and resolve internal conflicts through improvisational theater, while the latter provided a way to chart and measure group interaction. For some such as Gardner Murphy, Sociometry was “the beginning of a new way of viewing human relationships” (Murphy 1955: 37). Moreno received his medical degree at the University of Vienna in 1912 and practiced as a psychiatrist in Austria before emigrating to the United States in 1925. While Moreno taught classes as a clinician at Columbia University, he largely conducted his work in Beacon, New York where he founded the Beacon Hill Sanitarium (later renamed the Moreno Institute) in 1936.

Kurt Lewin, a fellow Jewish refugee of Nazi Germany and a professor of psychology, conducted ground-breaking work on child psychology at the State University of Iowa prior to establishing the Research Center for Group Dynamics [RCGD] at the Massachusetts Institute of Technology [MIT]. In contrast to his Gestaltist contemporaries at the Berlin Psychological Institute, Lewin was interested in bridging the divide between human perception and human behavior.[5] However, he was interested in a much wider variety of behaviors than studied by behaviorists.[6] Lewin's field theory offered a conceptual language lacking in the Gestaltist and behavioral approaches that could handle the interdependence of the persona and environment. Lewin sought to refine field theory through the RCGD but died from a heart attack less than two years after its inception.

W. Lloyd Warner left a failed career in acting to become an anthropologist, conducting fieldwork in Australia at the suggestion of Alfred Radcliffe-Brown. He eventually pursued a doctorate in anthropology at Harvard while overseeing the Bank Wiring Observation Room experiments of Roethlisberger and Dickson's (1939) *Hawthorne* studies and the *Yankee City* studies. The latter ran for five years and employed numerous students from Harvard, including Elliot Chapple, Allison and Elizabeth Davis, and Conrad Arensberg, among others.

Historical accounts treat Moreno's Sociometry and Lewin's Group Dynamics as largely independent (Freeman 2011; Scott 2017). Moreno and Lewin's colleagues, however, saw them as interchangeable. Esteemed scholars, such as Ernest W. Burgess, viewed both as one new development in the study of groups. Burgess (1945), in an editorial for the fiftieth anniversary of the *American Journal of Sociology*, identified Sociometry as one of five techniques that came to the fore in American sociology since 1920.[7] For Burgess, Moreno provided the earliest systematic presentation of Sociometry: a method of defining and charting the relationships

---

[5] Character evaluation of Kurt Lewin by Robert R. Sears, 19 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[6] Character evaluation of Kurt Lewin by Leon Festinger, 15 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[7] The other methods included statistics, the personal document and case study, typology, and interviewing.

between people in a way that made interpersonal relations measurable. Burgess acknowledged Lewin's contributions to *sociometric research* (and not Group Dynamics) in a footnote.[8]

Moreno himself considered Group Dynamics to be a "succession from the Sociometric Movement" (Moreno 1953: 101). Publicly, Moreno accused not Lewin but Lewin's "Machiavellian" students of poor imitation. Colleagues took notice of these accusations. Pitirim Sorokin, for example, assured Moreno that he and his colleagues would "invite the master and not his imitators" at MIT for a series of lectures and consultations on group methods at Harvard.[9] Privately, Moreno dismissed Lewin as "rather a 'feminine talent['], like a man who knows hot [sic] to take ideas from others [and] tries to develop them further".[10]

It is unclear whether Lewin regarded Moreno in such an adversarial manner, but he engaged with scholars from across the aisle. For example, Helen Hall Jennings participated in Lewin's Topology Group, an informal forum for exchanging intellectual ideas that began in 1933 (Marrow 1969: 260). Jennings was Moreno's uncredited collaborator on the studies used to outline the foundations of Sociometry (Moreno 1934). Her training in research design and statistics is likely what grounded Sociometry's foundational studies in systematic empirical research (Freeman 2011: 36), given that Moreno had no formal training in social science. Despite her affiliation, Lewin considered Jennings to be a promising candidate for hire on studies of

---

[8] Similarly, Cottrell (1950), in a Presidential Address to the American Sociological Society, noted that his formative understanding of human behavior in groups was greatly influenced by Moreno and Lewin.

[9] Correspondence from Pitirim A. Sorokin to Jacob L. Moreno, 25 April 1948, Box 31, Folder 498, Jacob L. Moreno Papers, Harvard Medical Library, Francis A. Countway Library of Medicine, Boston, Massachusetts.

[10] Correspondence from Jacob L. Moreno to Pierre Renouvier, Undated, Box 104, Folder 1742, Jacob L. Moreno Papers, Harvard Medical Library, Francis A. Countway Library of Medicine, Boston, Massachusetts.

group problems while he was at the State University of Iowa.[11] Lewin permitted his students to drift[12] and explore projects in other schools of psychology[13], and the Topology Group encouraged collaboration over adversarial conflict (Marrow 1969: 112). If Lewin was as aggrieved as Moreno to have the provenance of his ideas questioned, he did not express it.

Connections drawn between Positional Analysis and the others were generally less contentious. Reviewers of Warner's Yankee City studies considered its interrelational approach to society as originating from "fashionable" (Mills 1942: 270) part-whole, or gestaltist assumptions (Arsenian 1943: 400), of which Lewin was typically associated.[14] After moving from Harvard to the University of Chicago, Warner served on the advisory council of the Commission of Community Interrelations (a group that conducted research on ethnoracial conflict and discrimination) under Lewin's leadership (Marrow 1969: 195).

Warner's students drew more explicit ties between Sociometry and Positional Analysis. Conrad Arensberg believed that both engaged in the same goal: dealing with the continuum of industry and community (Arensberg 1942). The positional approach used "devices adopted by the sociometrists" to characterize the networks of interpersonal relationships of the community

---

[11] Correspondence from Kurt Lewin to Roger Barker, 13 July 1943, Box M946, Folder 24, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[12] Character evaluation of Kurt Lewin by Donald MacKinnon, 8 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[13] Character evaluation of Kurt Lewin by Alexander "Alex" Bavelas, 31 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[14] It is unclear if Warner saw parallels between his approach to structure and the work of Lewin and Moreno, but it was certainly acknowledged by his students and those influenced by his students. For example, Siegfried Frederick Nadel, whose work was influential to the development of blockmodels (White, Boorman, and Breiger 1976: 733), cited Moreno and Warner's student Eliot Chapple as exemplars for abstracting relationships from concrete data (Nadel 1957: 107-14). Nadel's treatment of Sociometry and specifically sociograms as "geometricized representations" suggests an appraisal of Lewinian research as merely a type of sociometric research.

(12). William Foote Whyte similarly viewed the sociometric method, Warner's technique, and Roethlisberger and Dickson's (1939) studies on informal organizations as involved in the same endeavor: explaining behavior on the basis of groups (Whyte 1941). Moreno's student, Maria Rogers, echoed these views. Rogers (1946: 351) considered Roethlisberger and Dickson's (1939) studies and Sociometry to be engaged in parallel efforts to study the social structure of human institutions.

3.2. Divergent Theories, Visualizations, and Mathematics

Overall, Sociometry, Group Dynamics, and Positional Analysis were recognized by individual adherents and colleagues as shared efforts to explain behavior through concrete relationships. This shared status is puzzling if one only takes the content of their ideas into account. Each offered an approach to behavior that vastly diverged in how it theorized, visualized, and formalized social structure. Despite these differences, however, each offered a theory that engaged with the contemporary network paradigm, which as I define revolves around three distinct but interrelated features: a focus on relations, an analytical emphasis on structure, and a central yet malleable concept of a network.[15]

First, the network paradigm seeks to explain human behavior or social processes through patterns of objective (i.e., operationalized and observed) *relations*. While capacious in terms of theoretical orientation (reviewed in Erikson 2013) or approach to theorizing (reviewed in Pachucki and Breiger 2018), the fundamental unit of analysis of SNA is relations.[16] The concept

---

[15] Despite its "formal roots" (Abbott 1997: 1153), SNA does not represent a unified theoretical system organized around a common set of laws or logically consistent propositions (Emirbayer and Goodwin 1994; Erikson 2013; 2017). Rather, SNA represents more of a paradigm (Leinhardt 1977) or loose federation of approaches (Burt 1980) organized around several basic assumptions.

[16] Who or what defines an actor or relationship varies. Relationalists may define relationships by interactions (e.g., Padgett and Ansell 1993; White 2008; Pachucki, Jacques, and Christakis 2011), while formalists rely on pre-given forms such as familial ties or friendships that presuppose interaction (e.g., Christakis and Fowler 2007; Baldassarri

of a relation takes on a broad definition: from a shared group membership (Breiger 1974) to a "transaction" (Emirbayer 1997: 287) or interaction (J. L. Martin 2003) between concrete entities, among others. Because this definition is so broad, the concept of a relation is perhaps best understood in terms of what it is not: a categorical attribute of an individual (e.g., "middle-class") or categorical aggregate (e.g., "classes").

Second, the network paradigm treats regularities in patterns of relations as a form of social *structure* (H. C. White, Boorman, and Breiger 1976; Laumann and Knoke 1986; Pachucki and Breiger 2010). Inspired by Simmel's (1972: 14) argument that "[t]he a priori of social life consists of the fact that it is not entirely social", this approach views patterns of relations as distinct from the content of those relations.[17] Contemporary network research offers a sophisticated vocabulary for describing these patterns: from dyads or triads of people; to structural equivalence (Lorrain and White 1971), or similarity in patterns of relationships; to structural holes (Burt 1995), or gaps where no direct or indirect connections exist; to network clustering, or groups of tight-knit connections, among many others. Structure, in whatever form it takes, makes the analysis of relations methodologically actionable and insightful for the study of social life.

---

and Diani 2007); ontological individualists tend to represent actors as individuals (e.g., Bearman, Moody, and Stovel 2004; Hedström and Ylikoski 2010; Pachucki, Jacques, and Christakis 2011), while formal cultural sociologists have been more receptive to representing actors as ideas or concepts (e.g., Carley and Kaufer 1993; Mohr 1998; Mohr et al. 2013; Powell and Oberg 2017; Hoffman et al. 2018). In approaches where the unit of analysis shifts from actors to positions or roles (H. C. White, Boorman, and Breiger 1976; Burt 1980; Padgett and Powell 2012), aggregated sets of multiplex relationships between actors form the basis for constructing roles, and it is the relationship between roles that forms the basis for explanation.

[17] Simmel did not offer a consistent definition of what constitutes a social form. There are a variety of competing interpretations that identify contradictory elements of Kantian formalism and phenomenological relationalism in Simmel's work (see Erikson 2013). However, it is clear that Simmel regarded social forms as distinct from content.

Third, SNA concerns itself with the study of *networks*. The proliferation of the network paradigm across the sciences has expanded our understanding of what can be a network: from kinship networks, corporate interlocks, co-citation networks, to animal sociality networks, to name a few. This diversity reflects the variety of individuals, organizations, and other concrete entities empirically investigated in network analysis. But it also reflects the variety of conceptual constructs represented by the network concept. Thus, for example, networks vary based on whether they represent an entire population (whole networks) or only a sample (ego networks). Networks can also vary by the breadth of data analyzed, such as multidimensional networks that include more than one type of relation, multimodal networks that include more than one type of entity (such as individuals and organizations), or hypergraphs that include relations that may connect more than two entities (to represent, for example, relations between groups or teams). And networks can vary by degree of conceptual abstraction, from concrete trade networks that represent globalization in the market based on East India Company voyage logs (Erikson and Bearman 2006), semantic networks that represent the meaning of symbols based on their co-occurrence with other symbols (Lee and Martin 2015), to abstract network domains (H. C. White 2008) that represent identities we switch between as we move across different social environments. I make this point to emphasize that the network concept has the capacity to represent many different ideas. While networks are fundamentally about relations, and while structure offers patterns for understanding how relations impact social life, the network concept is malleable and not necessarily bounded by fixed methodological distinctions.

Despite sharing a status as new developments in the study of groups, Sociometry, Group Dynamics, and Positional Analysis elaborated wide variations of these three features (**Table 1**), including forms of visualization, formal concepts, and measurements that were in no way comparable or commensurate.

	Sociometry	Group Dynamics	Positional Analysis
Relations	Flows of feeling, of *tele*, between individuals.	Mutually interdependent facts.	Interaction between individuals within and across social institutions.
Structure	Patterns in relations that recurred with regularity.	A representation of the interrelations between facts for a given individual or group with regard to a given behavioral outcome.	An organizational institution (e.g., the family, party, church, clubs, etc.). Later, patterns of interaction between individuals.
Network	A system of relationships between individuals included in a network.	Relationships between facts, concepts, and theories (Lewin 1938: 16-18).	A system of relationships based on recurrent/repetitive patterns of interaction.

Table 1. Similarities in network analytic form, by how each precursor defined relations, structure, and network.

3.2.1. Sociometry, Sociograms, and Classificatory Counts

Sociometry argued that relations were the flows of feeling, of *tele*, between individuals. In practice, these "emotional cross-currents" were essentially ranked lists (recorded by a survey called the sociometric test) of who one liked or disliked with regard to a certain criterion, such as who one would prefer to work with, marry, adopt, or live with. The term "structure" denoted patterns in relations that recurred with regularity, and these patterns could include, for example, patterns that identified popular sociometric stars, lonely isolates, friendship triangles, or linked chains. Moreno's network resembled what we recognize today as ego-centric networks: a system of relationships between each individual included in the network. However, because they arose from flows of feeling, Moreno emphasized that these networks were psychological in origin.

Sociometry as developed by Moreno provided a way to both quantify and visualize relationships using sociograms. In his foundational study of the New York State Training School for Girls ("Hudson"), for example, Moreno (1934) used sociograms to illustrate feelings of like and dislike between girls living in different cottages. The sociogram for the cottage on the left in

Figure 1 visualized the greater degree of friendship and integration that the one on the right notably lacked: far more mutual red lines of attraction were visible for the former than mutual black lines of repulsion.

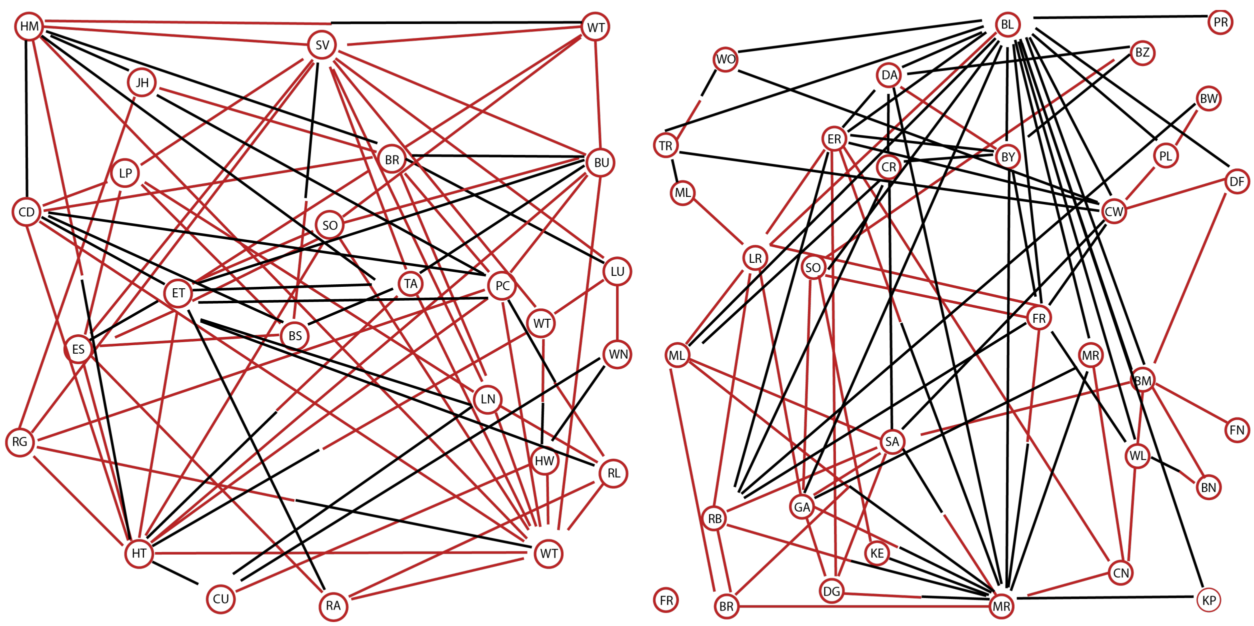

Figure 1: Two Hudson cottage families (Moreno 1934: 121-123). Individuals are represented by circles. Likes are colored as red and dislikes as black. If an individual listed another but was not reciprocated, their preference is identified as a single-pointed arrow. If both individuals listed the other but the feeling was not mutual, the line will be half red and half black. The lone individual at the center bottom of the figure listed no one and wasn't listed by anyone.

		in	out
WL			L
	sent	2 — 1	3 — 1
	received	3 — 0	4 — 0

Figure 2. Moreno's (1934: 80) formula for representing the likes and dislikes (separated by a dash) sent to and received from individuals in and outside a girl's (identified as WL) cottage.

For Moreno, counts of likes and dislikes offered a way to classify and compare groups or individuals on the basis of their relationships with others. When converted into a "formula" that took the form of a matrix, these counts could be used to identify, compare, and classify individuals who presented striking cases (80). The matrices presented in Moreno's study were not formal equations, but two-by-two tables summarizing the series of likes and dislikes sent and received by a girl from girls inside and outside of her cottage. For example, a relatively positive, attractive, and extroverted girl identified as "WL" (see **Figure 2**) sent and received more likes inside (2 and 3, respectively) and outside (3 and 4, respectively) her cottage than dislikes (1 sent inside and outside, 0 received whatsoever). Moreno compared WL's formula to the formula of "TL", a relatively isolated and rejected girl who received far more dislikes, to argue that these classificatory counts were "able to differentiate the position of any individual" in practice (82).

3.2.2. Group Dynamics, Field Diagrams, and Topology and Geometry

Field Theory, formally branded as Group Dynamics when Lewin established the RCGD at MIT, established relationships between mutually interdependent "facts." Here, facts represented what Lewin considered expressions of a concrete situation – in short, anything that had a direct and recognizable effect on observed behavior in the life space, be it an individual's physical location, cognitive state of development, or who one was interacting with. This was a broad approach to behavior. But for Lewin, if behavior was a function of the person in their environment, $B = f(P,E)$, then it needed to approximate both person and environment without undue simplification. Unfortunately for Lewin after his untimely death, his students narrowed their focus onto a specific kind of fact: communication between individuals. Furthermore, Lewin used the term "structure" in reference to the differentiation of the life space. But unlike Moreno or Warner, he strongly emphasized that structure was a theoretical construct. Structure for Lewin was a representation of the interrelations between facts for a given individual or group with regard to a given behavioral outcome. Rather than a general set of patterns that recurred with regularity, structure could be elaborated upon with the discovery of more interrelated facts about a given concrete situation.

Finally, Lewin's network consisted of relationships between facts, concepts, and theories. Establishing relationships between facts required the use of concepts, such as dynamic concepts like force or static concepts like boundaries or regions, in service of theorizing behavior. Lewin's definition of a network was much broader than the definitions offered by Sociometry or Positional Analysis, for it could include facts such as feelings and interactions between individuals. Lewin's definition of a network was perhaps best illustrated in an unsent letter Lewin addressed to his colleague and friend, Wolfgang Köhler. In explaining his hesitation to leave Germany despite the rise of anti-Semitism and the Nazi Party, Lewin described a network that kept him anchored to the country: "Vital bonds with the landscape, the house in which one grew up, childhood friends, the language, the thousand little events of growing up, create ties that are stronger than we are and ultimately unbreakable" (Lewin [1933]1986: 41). In Lewin's own network for explaining his behavior (his inclination to stay in Germany), ties between such facts such as childhood friends and his upbringing directed him to stay.

Lewin adapted the mathematics of topology and geometry to develop his theory of psychological fields and forces in what he termed, respectively, topological and vector psychology. Topological psychology provided a mathematical representation of the life space that was non-metrical and visual in nature. The benefit of a topological approach was that it could be used to represent the life space as a series of regions of behavior that could be visualized using field diagrams. Field diagrams provided a visual space that represented both the structural characteristics of a given situation (i.e., all the interrelations between the relevant facts) and the relationship between regions against a whole (i.e., environment). They were used to theorize behavior in any situation, from approximating a child's behavior eating an unwanted food (**Figure 3**), to representing the process of communication across social groups (**Figure 4**).

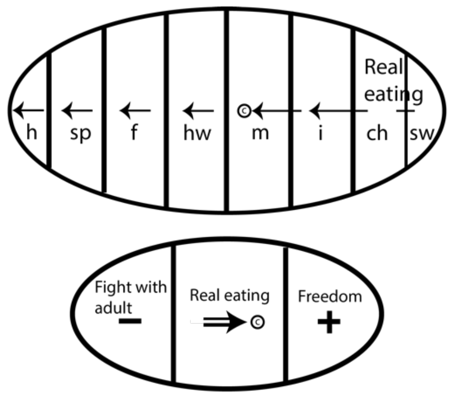

Figure 3. A Lewinian field diagram of the position of a child in the act of being fed unwanted food: from an adult putting a hand on the table (h), taking the spoon (sp), spooning the food (f), inserting (i) the food into the mouth, and having the child chew (ch) and swallow (sw) the food (Lewin 1936: 97). Forces are represented by arrows and here denote forces directed by the child (a). Desires or "valences" are designated by positive and negative signs and here represent what the child wants (b).

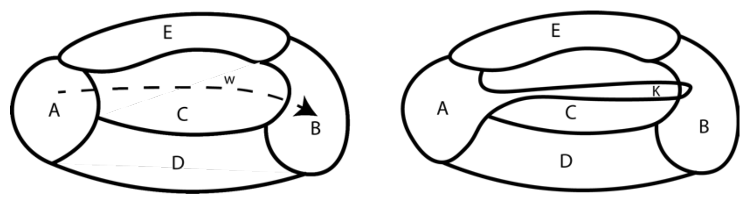

Figure 4. A Lewinian field diagram of an individual from region A making contact with region B (a) and establishing communication between the two regions (b) (Lewin 1936: 100).

Whereas topological psychology was non-metrical, vector psychology intended to establish a system for measuring psychological forces on the basis of a geometry Lewin termed hodological space. Hodological space offered a complement to topology by offering a vocabulary for representing the application of forces, be they physical or psychological, in terms of direction, distance, and distinguishable paths. However, Lewin refrained from imposing measures for these conceptual features. His first (and only) treatise on vector psychology argued that one needed an adequate theory that justified numerical measurement. To proceed without would risk the use of measures that were irrelevant to a given empirical situation.

3.2.3. Positional Analysis, Positional Charts, and Combinatorial Algorithms

Finally, in Positional Analysis, relations were interactions between individuals that occur within and across social institutions. In Warner's *Yankee City* studies, however, relations connoted a second sense: relations between *positions* or "behavioral situations," stratified by an individual's social class and the institutional structural types the individual interacted within.

“Structural types” were combinations of social institutions, such as families, churches, schools, political parties, and clubs, that shared unique social class compositions. Thus, the term “structure” for Warner as used in the *Yankee City* studies had an institutional connotation. In studies overseen by Warner (Roethlisberger and Dickson 1939) or research proposals by his students (Arensberg 1942), however, relations were simply treated as interactions between individuals, and structure had to more do with patterns of interaction between individuals. Furthermore, the term “network” denoted a system of relationships based on interactions between individuals (Roethlisberger and Dickson 1939). Warner’s students (Chapple and Arensberg 1940; Arensberg 1942) acknowledged Sociometry’s use of the term to denote networks of interpersonal relationships, but described networks as “recurrent patterns of action taking place through time in a definite sequence, with definite repetitions of ascertainable frequency” (Arensberg 1942:11).

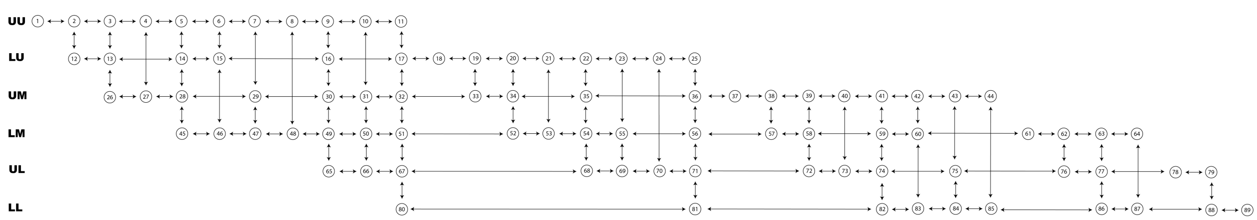

Figure 5. Warner and Lunt's (1942: 17) general system of positions for Yankee City.

Warner’s study of Yankee City used a complex combinatorial process to sort a town of some 17,000 people into one of 89 behavioral situations. **Figure 5** illustrates a positional chart depicting Warner’s general system of positions for Yankee City. The vertical and horizontal axes separate positions by class standing (from upper-upper to lower-lower class) and structural types, respectively. Numbered circles represent positions individuals inhabited as they moved across social institutions. Vertical and horizontal lines between adjacent circles are stylistic. Given that Warner classified individuals by class standing, however, circles connected by horizontal lines imply positions an individual of a particular class standing could occupy across Yankee City. For example, a lower-lower ("LL") class individual could occupy positions 80-89 depending on his social situation. Circles connected by vertical lines imply interactions between positions individuals across classes could occupy as they interacted in the same social institutions. For example, any U.S. war veteran who was a member of the American Legion could potentially interact with anyone across the class spectrum (positions 11, 17, 32, 51, 67, and 80). These interactions corresponded to social interactions Warner and his team recorded in Yankee City using "personality" interview punch cards.

Additionally, Warner computed the degree of "influence" between any two positions by counting the number of "incoming" and "outgoing" connections between them in a given social class, net of all individuals in Yankee City (200-201).[18] Applying this algorithm was a sizable computational task, and the tables containing tallies of these connections spanned 86 pages.

Yankee City did not appear to inspire others to adopt its specific method for computing behavioral situations. Proponents of Positional Analysis did not share a unified mathematical system. What was shared, however, was an emphasis on using combinations of interactions in order to identify positions that explained behavior. How proponents of Positional Analysis combined interactions varied in complexity. Warner identified behavioral situations across Yankee City by combining multiple social institutions where one could observe interactions between groups that shared the same class composition. Roethlisberger and Dickson (1939), in

---

[18] Since each position represented combinations of multiple social institutions, an individual could have multiple "memberships" in each position depending on what was listed in their personality card. For each Yankee City inhabitant, Warner tallied their memberships in each position and generated pairwise comparisons between each position on the basis of these tallies. Next, Warner tallied comparisons that demonstrated some degree (i.e., nonzero) of influence across all inhabitants. The net sum for each pairwise comparison represented the degree of influence between each position. In contemporary SNA, this measure might represent mutual directed, weighted edges.

contrast, identified “the group in the front” and the “group in the back” by simply recording several types of interaction (i.e., friendships, antagonisms) between workmen in their study. Conversely, Warner’s students Chapple and Arensberg (1940) proposed what some considered an excessively formal approach (Homans 1962: 37-38), arguing that interactions needed to be categorized, counted, sequenced, and compared on the basis of ratios to identify individuals who tended to “originate” or “terminate” action.[19]

4. Thinking, Theorizing, and Communicating Structural Research through Visualization

While mathematics may have unified the scattered strands of structural analysis in the 1970s, the same cannot be said about its interwar precursors. Each program proposed unique theories of social structure, employing quantitative tools and forms of mathematics ranging from counts, combinatorial algorithms, logic, to topology. What united all three programs, however, was a practice of expressing structural research visually that impacted how each thought about, theorized, and communicated ideas about social structure. While sociograms, field diagrams, and positional charts drew from different theories, they shared a common role in structural research heretofore neglected in historical accounts of SNA. To examine this role, I ask three questions. First, how did visualization enable new ways of thinking about social structure? Second, how did visualization impact how scholars theorized structural research? And lastly, how did visualization facilitate the communication of ideas about social structure?

[19] The two went so far as to ask their colleague Willard Quine, a mathematician in the Harvard Society of Fellow, to help formalize their approach into a set of equations based on mathematical logic. However, these equations use an obscure notation that is neither explained in the text nor standard in set theory. Their approach was loosely adapted by Whyte (1941) in his study of corner boys in an Italian slum. Otherwise, it appears to have been abandoned. Arensberg shifted research focus, while Chapple sought to commercialize a device that assessed personality by timing and measuring conversational interviews.

4.1. Thinking through Visual Features

First, all three programs used visualization to think about and explore social structure. This approach required readers to actively decode features of visualizations in order to interpret an explanation that was marginally referenced in the text. Moreno's *Who Shall Survive*, Lewin's *Principles of Topological Psychology*, and Warner's *The Status System of a Modern Community* contained a substantial number of diagrams. Moreno's monograph allotted 86 pages to diagrams. Lewin's contained 48 figures. Only a few of these visualizations were explicitly referenced and explained in the text. Warner's contained only 10 diagrams, but its entire analysis was organized around a complex positional chart (see Figure 6). Book reviewers of Warner's monograph expressed annoyance at having to "follo[w] the text and the maze-like diagrams closely" to understand its argument (Brooks 1943: 114; see also Opler 1942).

In this way, visualizations offloaded the task of explanation onto the reader through what Gibson (1986) conceptualizes as *affordances*. Affordances are properties of an object that provide observers opportunities for perception and action. Objects that afford action do not cause action any more than they act as "blank slates" for users to inscribe meaning, and it is through their "access and use that they can be understood to enable forms of activity" (Acord and DeNora 2008: 228). The affordances of a network visualization consist of its visual features: from double-pointed arrows, dotted lines, continuous regions, to circles, among others used by the three precursors.

With no standard principles for visualizing social structure to draw on, Moreno, Lewin, and Warner used visual features for different purposes and to express different ideas. For example, circles denoted individuals for Moreno, a region of behavior for Lewin, and positional situations for Warner, while pointed arrows denoted flows of feeling for Moreno, the direction of a force for Lewin, and interaction for Warner. However, a reader of their works could expect to use these features to articulate the social structure depicted by a given visualization. All three programs placed the burden of explaining a figure on the reader, who was left to decode and interpret the meaning of each figure with the available contextual clues. Social structure did not require explicit description. It could be visually reasoned into existence.

Neither Moreno, Lewin, nor Warner appeared to provide a rationale for treating the meaning of a visualization as self-evident. However, the way they presented social structure in their publications did deviate from how they thought about it in their research. Moreno and Lewin found sociograms and field diagrams useful for enabling thinking and exploration in the process of conducting research.

Moreno compared the work of a sociometrist to that of an astronomer or a microscopist. Whereas the astronomer had the geography of the universe before him, the sociometrist was in the "paradoxical situation" of constructing his map before he could explore it (Moreno 1937: 212). Charting through the sociogram was therefore not merely a method of presentation, but a way to "mak[e] possible the exploration of sociometric facts". A sociogram made the patterns of the social universe visible, shifting the focus from the problem of the individual to the individual's relation and adjustment to the group. For Moreno, sociograms were particularly useful as a method for placing and studying smaller structures from the "primary" sociogram under a "microscope". Through examination, one could isolate "secondary" or "derivative" sociograms, characterize their functional significance within a larger psychological network, and derive several sociometric facts. Moreno termed the task of characterizing functional significances "dynamic sociometry" and the task of deriving sociometric facts "descriptive sociometry".

Lewin was so visually minded that he "couldn't think without chalk."[20] "This was part of his charm, why he excited people so much. When he began to think or talk, he had to have a pencil in his hand and a paper before him and he immediately converted any psychological problem into a spacial [sic] problem."[21] Every theoretical discussion brought forth a topological diagram.[22] For some, diagrammatic thinking offered a process of clarifying interrelationships and expressing a problem in a new light.[23]

Lewin's passion for diagrams over words – a passion that he expressed through the chalkboard, snow,[24] and even with his hands off the wheel while driving[25] – stimulated others to form hypotheses on the basis of their own diagrams. Indeed, as Norman R.F. Maier recalls, Lewin's associates found field diagrams practical not for their mathematical orientation, but for their use in theoretical and conceptual development:

> *I often felt that field theory was the product of communications by means of drawings and that it just so happened that each of the disciples seemed to think in terms of drawings. There was no evidence of mathematics at this stage, and topology came into the picture quite a bit later. Outgroup members had negative reactions to these drawings, which were regarded as vague and*

---

[20] Kurt Lewin with Robert and Pauline (Pat) Sears", 10 January 1967, Box M947 Folder 45, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[21] Character evaluation of Kurt Lewin by Donald MacKinnon, 9 May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[22] Character evaluation of Kurt Lewin by Dorwin P. Cartwright, 8 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[23] Character evaluation of Kurt Lewin by Donald MacKinnon, 8 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[24] Statement made by Alexander "Alex" Bavelas, 31 May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, University of Akron, Akron, Ohio.

[25] Statement made by Margaret Mead, 8 May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, University of Akron, Akron, Ohio.

> *unscientific. However, it was the way this group generated ideas and I'm quite sure that if Lewin had been a mathematician, field theory would not have been developed. However, the drawings convinced me that this group was trying to communicate concepts that were entirely new, and they suggested the need to explore forces that went beyond psychological processes, as encompassed by the schools of Functional Psychology and Behaviorism then in vogue.*[26]

All three programs constructed network visualizations using a variety of visual features – red or black lines indicated feelings of like or dislike in a sociogram, positive and negative signs denoted demands on behavior in a field diagram, double-pointed arrows indicated interactions in a positional chart. These visual features constituted the affordances through which each thought about and explored social structure.

4.2. Theorizing by Visualizing the Concrete

Second, all three programs created visualizations that were theoretical and generative of conceptual distinctions, yet also practical and illustrative of "concrete" empirical situations. Diagrammatic approaches, of course, were not new to the social sciences. However, what was distinct about the approach taken by Sociometry, Group Dynamics, and Positional Analysis was that it simultaneously visualized both abstract concepts and situations drawn from contemporary social life. A sociogram identified sociometric "stars" and "isolates", but also the attractions and repulsions between girls at Hudson. A field diagram identified "forces" within a given social "space," but also the situation of a particular experiment. A positional chart identified a set of behavioral "situations," but also predicted the behavior of a given individual in a given situation in Yankee City.

---

[26] Statement made by Norman R.F. Maier, 8 May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, University of Akron, Akron, Ohio.

Of the three scholars, Lewin made the most effort to explain his view on the relationship between visualization, empirical analysis, and theorization. He reflected on this view in a letter, which was published as the preface to *Principles of Topological Psychology*, to his former colleague Wolfgang Köhler. Reminiscing over his time as a doctoral student, Lewin told Köhler that the figures he had drawn on the blackboard were not mere illustrations but representations of real concepts. With the intuition that psychology needed to take seriously the concepts of space and time, Lewin had turned to the young mathematical discipline of topology to help make psychology a science of real concepts. Topology visualized a conceptual space that bridged the gap between psychology and mathematics while remaining in contact with the experimental work of psychological research. Field diagrams offered, through successive expressive drawings, a way to theorize and gradually approximate the structure of a given experimental situation.

Visualizations, and the conceptual vocabularies used to describe them, offered what Lewin argued were necessary to advance the study of individuals in their environments. Lewin recognized that using spatial concepts such as directions, distances, and regions to represent psychological phenomena would invite criticism (51-52). Some in his profession preferred to use statistics to describe the influence of the environment on the individual. However, Lewin considered this method of representation incomplete. For Lewin, novelists such as Dostoevsky could capture what "statistical characterizations have notably lacked, namely, a picture that shows in a definite way how the different facts in an individual's environment are related to each other and to the individual himself" (13). If psychology sought to create as lifelike a picture of a situation as possible, it needed to develop a new means of scientific representation.[27]

[27] Lewin argued that the topological form of representation differed from the more general usage of diagrams in psychology. Others such as Bühler, Boring, Raschevsky, and Thurstone had used graphic illustrations or geometrical approaches to represent concepts in psychology (Lewin 1936). For Lewin, however, these illustrated relations

For Lewin, the mathematics of topology offered a "language" (Lewin 1935: vi) and corresponding visual scheme that could simultaneously theorize and represent real empirical relationships and real concepts. While neither Moreno nor Warner were as engaged in the philosophy of science, both used visualizations to theorize and represent social structure on the basis of the concrete.

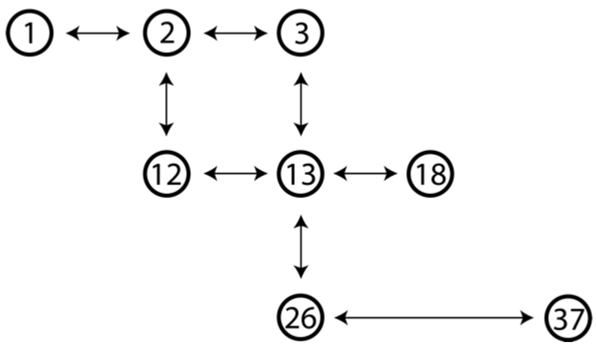

Figure 6. Mrs. Breckenridge held a "political tea" involving upper-upper, lower-upper, and upper-middle class individuals, represented as circles 3, 13, and 26 in the context of tea. But these individuals shared relations in other contexts (e.g., 2 and 12). Warner used these relations to explain the behaviors he observed across Yankee City, including at social tea (Warner and Lunt 1942: 39).

For Warner, positional charts offered a way to explain behaviors across any specific situation in Yankee City, such as interactions during Mrs. Breckenridge's social tea. As illustrated by **Figure 6**, Mrs. Frederica Alton, Mrs. Starr, and Mrs. French occupied different classes and therefore different structural positions (circles 3, 13, and 26, respectively) in interaction at social tea. However, unlike Mrs. French, Mrs. Frederica Alton and Mrs. Starr also shared membership in the House and Home Club (circles 2 and 12, respectively). This put Mrs. Frederica Alton and Mrs. Starr in more positions of direct interaction (circles 2 and 12 and 3 and 13, respectively), which as Warner explains results in their feeling of being "nearer" and "having something to talk about" during tea (Warner and Lunt 1942: 38-39).

between abstract concepts rather than concrete situations. Furthermore, topological representations needed to make clear the relation between behavior and environment using symbols (e.g., point of application of force as the head of an arrow; strength of a force is related to length of an arrow; strength of a barrier is indicated by thickness of a line) and topological relationships (e.g., whether a curve is closed or not closed) that were consistent, univocal, and unambiguous as the mathematical concepts they were based upon.

For Moreno, sociograms offered a way to identify "characteristic" social structures observed across numerous situations: from "red stars" identifying individuals who are particularly attractive, "black stars" identifying those largely rejected, "black chains" denoting mutual rejection across multiple individuals, to "simple isolates" identifying individuals who neither receive nor send feelings to others in her group (Moreno 1934: 104-106). Like Warner, Moreno used sociograms to explain the behavior of any specific individual in Hudson. Girls at Hudson could capture "the center of the stage like stars" if they attracted or repulsed many of the choices of the other girls, the former visually represented as red stars and the latter as black stars (Moreno 1934: 25). For example, black star May ("LF") was both isolated and rejected in her work group and home group, and her enjoyment of work and work performance suffered as a result (110).

Visualizations, and the language used to explain them, offered each precursor a bridge between the theoretical and the concrete at a time where the connection between social theory and empirical analysis was not taken-for-granted. Warner never used the term "theory" to describe his positional approach. Moreno (1934: 80) emphasized that Sociometry was "not a theoretical scheme but the product of empirical induction". Lewin (1936: 4) argued that in order for a science to advance, "it is necessary to have a theory, but a theory that is empirical and not speculative." Visualizations provided a way to simultaneously represent theories of social structure and concrete empirical situations, rather than abstract schemes that bore no relevance to contemporary social life. In this way, visualizations were purposed as integral to the development of an empirical science.

4.3. Communicating Ideas Across Social Divides

Lastly, visualizations provided an emblem of structural research that captured the imagination of the public and enabled communication across linguistic, disciplinary, and professional divides. Here, what mattered were not the methodological particularities of constructing a sociogram, field diagram, or positional chart so much as the idea that social structure could be visually expressed. Drawing, doodling, charting, or mapping became a way to solve problems or create new ones, but by no means were social scientists the only ones who could participate. Journalists, teachers, muckrakers, and literary critics, among others, used visualizations to engage with and critique the science of social structure.

Sociometry made its grand debut in 1933 at the 127th Annual Meeting of the Medical Society of the State of New York. Moreno installed a huge map of the New York State Training School for Girls near the grand ballroom of the Waldorf-Astoria. The map contained over 7,000 lines depicting the likes and dislikes of the population of the reformatory school. Moreno's overture captured the attention and headlines of the New York press: "Emotions Mapped By New Geography" in the *New York Times*; "Minds Mapped Geographically By New Science" and "Psychological Geography Explained At Luncheon Given By Julia Jaffray" in the *New York Herald Tribune*.

The press paid particular attention to Moreno's sociogram. "Psychological geography," as identified by the press, provided a technique for planned social organization grounded on visual evidence. As reported by the *Times*, a "mere glance at the chart show[ed] the strange human currents that flow in all directions." These currents generated what the *Herald Tribune* considered "a network that resemble[d] a spider web" that could "illustrate tendencies that may in time come to be regarded as laws of life."

Moreno used the publicity to describe his vision for the scale of what was to ultimately become known as Sociometry. However, instead of drawing on Sociometry's vast terminology to describe the products of its research, Moreno used visual and spatial metaphors:

> *"If we ever get to the point of charting a whole city or a whole nation, we would have an* ***intricate maze*** *of psychological reactions which would present a* ***picture of a vast solar system of intangible structures****, powerfully influencing conduct,* ***as gravitation does bodies in space****. Such an invisible structure underlies society and has its influence in determining the conduct of society as a whole. […] Until we have at least determined the nature of these fundamental structures which form the* ***networks****, we are working* ***blindly*** *in a hit-or-miss effort to solve problems which are caused by group attraction, repulsion and indifference."*[28]

Lewin's field diagrams did not command as much (if any) attention from the press as his work on autocracy, ethnoracial conflict, and discrimination (Marrow 1969). Like Moreno, Lewin used visualizations to engage different audiences. However, Lewin used topological drawings for more practical than promotional purposes: to communicate ideas across epistemic, linguistic, and professional divides.

Colleagues such as Robert R. Sears remarked that Lewin's diagrams were useful not for their scientific merit, but for their "social effects": topological diagrams provided a "rallying point for people who belonged to the group" and enabled individuals to come together to think as a group.[29] Lewin controlled a corner of the blackboard, but others were encouraged to use the remainder to display competing ideas.[30] One needn't be in the central core of scientific

---

[28] "Emotions Mapped By New Geography," *The New York Times*, April 3, 1933, ProQuest Historical Newspapers: The New York Times (100714405).

[29] Character evaluation of Kurt Lewin by Robert R. Sears, 19 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[30] Character evaluation of Kurt Lewin by Dorwin P. Cartwright, 8 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

psychology in order to engage with topological principles.[31] But one needn't be an American or German scientist either, as topological psychology took root in Tokyo with the formation of the discussion group called the *Lewin-Klasse*.[32] Furthermore, one needn't have a command of the English language: Lewin's accented English and writing could be difficult to understand,[33] but his expressive use of gestures and drawings "more than made up for his language problems."[34] And one needn't be a scientist, as Lewin presented topological principles to professionals, such as school teachers, who had relatively little mathematical or psychological expertise.[35] In this way, Lewin was characteristically "German" for his concern with ideas and theory, yet "so very American" for his manner of communication: free from concerns about rank, status, or other barriers of formality (Tolman 1948: 2).

However, visualizations also facilitated or generated criticism. Lewin's approach faced criticisms for its emphasis on diagrams. Alvin Zander, a colleague who had worked with Lewin during his days at Iowa, considered Lewin's topology an ingenious but "wobbly mathematical

---

[31] Statement made by Doris Twitchell Allen ["Comments Regarding Kurt Lewin and his Topological-Dynamic Psychology"], 10 March 1967, Box M947 Folder 24, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[32] Inspired by Lewin's lectures in Berlin, a group of scholars formed the discussion group. The group generated intense discussions over topological psychology. But it also generated skepticism. As Marrow (1969: 67) describes, Professor Koreshige Masuda expressed doubts over the merits of the method of representation. Lewin produced a topological diagram in order to address Masuda's concerns.

[33] Character evaluation of Kurt Lewin by John R.P. French, Jr., 9 May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[34] Character evaluation of Kurt Lewin by Robert R. Sears, 19 May 1967, Box M944, Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[35] Statement made by Doris Twitchell Allen ["Comments Regarding Kurt Lewin and his Topological-Dynamic Psychology"], 10 March 1967, Box M947 Folder 24, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

system" that conveyed intuitive meanings but created the impression that his work consisted primarily of "clever diagrams".[36] Perhaps less charitable, psychologist William McDougall dismissed Lewin's topological psychology as just one more "diagrammatic effort" among many.[37]

These criticisms came from outside the academy, too, from conservative muckrakers like Jo Hindmand and writers like John P. Marquand. Group Dynamics and Sociometry, or "[s]ocial engineering for 1984" as warned by Hindman, represented a conspiracy to promote communism and left-wing ideology in American life. For Hindman, "social engineers" like Lewin and Moreno created Orwellian tools to classify individuals who held conservative ideals as mentally ill.[38] One such tool was the sociogram. Despite its "high-sounding" title, the sociogram was "merely a chart resembling a maze of pool-table shots" that diagrammed trivial facts such as whether "Helen chooses Frances" or whether "Betty is Mary's first choice" (Hindman 1958: 2). However, by placing influential individuals in strategic positions, sociograms could be used to channel behavior, create "sociometrized 'agents'", and mold attitudes of entire communities. For Hindman, the sociogram was a tool for weaponizing left-wing ideals based on nothing more than academic jargon.

Perhaps the most dramatic criticism can be found in American literature. Marquand, an American novelist raised in the town Warner studied, used Warner's likeness and research as a

---

[36] Character evaluation of Kurt Lewin by Alvin Zander, May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[37] Character evaluation of Kurt Lewin by Jerome Frank, May 1967, Box M944 Folder 1, Kurt Lewin Papers, The University of Akron, The Drs. Nicholas and Dorothy Cummings Center for the History of Psychology, Akron, Ohio.

[38] According to Hindman, individuals who opposed racial equality, public housing, foreign aid, salvational religion, organized labor, or the Tennessee Valley Authority under this "sociometric dictatorship" were classified as mentally ill.

source of satire. Like Hindman, Marquand saw visualizations as a vehicle for critique that illustrated the hubris of social science. Marquand's *Point of No Return*, published 10 years after Warner's *Yankee City* series began, explored themes of class, identity, and work in the wake of the Depression. The fictional novel chronicled the coming-of-age of Charles Gray, an ambitious Manhattan banker who left his small, tradition-bound hometown in (fictional) Clyde, Massachusetts to build a life and career. When Charles was a child, an anthropologist named Malcolm Bryant had studied the people of Clyde and published his findings in a monograph titled *Yankee Persepolis*. A chance encounter with Malcolm led Charles to question his past. Malcolm and his team of anthropologists had meticulously rendered the world of Clyde into visualizations that were alluring yet alien:

> *"The Clyde of Malcolm Bryant was a complex of instinctive forces and behavior. Its inhabitants moved into a pattern like bees in a hive, or like the Spartans under King Lycurgus. There was the individual's unknowing surrender to the group, the unthinking desire for order. He could see the Grays on Spruce Street and the Lovells on Johnson Street through Malcolm Bryant's eyes, and it was hard to believe that he ever could have lived in this arbitrary frame, illustrated by curves and diagrams, and now he was living in another. He could almost see the Stuyvesant Bank and that evening at Oak Knoll in a new revealing light—almost, but not entirely"* (Marquand 1949, 147–48).

Charles, recognizing his family in *Yankee Persepolis* as the "lower-upper" class Henry Smiths, struggled to reconcile his ambitions with Malcolm's research. Yankee Persepolis put Clyde under the microscope, presenting the class mobility of its inhabitants as a matter of marriage, connections, and exclusivity rather than intelligence, reliability, and hard work. "Charles had never thought of himself as convertible into diagrams and geometric curves and a mass of static, regimented fact" (Marquand 1949: 308). Yet, living in Clyde was like walking through spiderwebs, its inhabitants tied by invisible strings (248). Malcolm's portrayal of Clyde, while lacking in trimming or charity, struck a nerve. *Yankee Persepolis* imagined individuals as figures on a chart whose futures were predetermined, and Charles could not help but reevaluate his own past in Malcolm's terms.

Malcolm Bryant, and his treatment of individuals as diagrammatic categories, formed the basis of Marquand's satiric critique of social science and ivory tower academics. Malcolm's diagrams commanded authority by creating complicated abstractions. Charles and the people of Clyde, however, were familiar with the streets, traditions, and subtleties that revealed Yankee Persepolis to be a clumsy translation of the real thing. The complexity of Malcolm's diagrams of social structure belied a simple truth: Malcolm was shielded from the strife of living and "displayed the unskillful ignorance of most dwellers in academic ivory towers" (282). Charts, constructed by pampered and preposterous social scientists who did not understand or want to be like other people, were folly. As Jessica Lovell, Charles' unrequited upper-upper lover commanded, "Darling, don't let anyone ever put us on a chart" (342).

While Marquand carried out his critique using a fictional New England town, his message was not without an audience. In a review of *Point of No Return* for *Harper's Magazine*, literary critic Granville Hicks commented that Marquand not only had fun with the sociologists, but also "beat[] them at their own game" (Hicks 1950: 105). The social structure of Newburyport, "too complex and too subtly defined to be reduced to a diagram," had a reality that only Marquand could capture.

Visualizations enabled communication across various kinds of social divides, facilitating the spread of the "diagrammatic effort" to social structure across space and time. While this sometimes resulted in the misrecognition of these efforts as one and the same, it provided others the opportunity to mobilize their own ideas for representing social structure. The visual approach to social structure spread across linguistic, professional, public, and academic boundaries and had careers across blackboards, newspapers, and novels.

5. Discussion and Conclusion

Network visualizations aided in the creation of a new conceptual space for social structure. This finding affirms a wealth of scholarship that highlights the role of visualization in knowledge production (see Coopmans et al. 2014). By enabling new modes of thinking through affordances, network visualizations, like protein crystallographic structures (Myers 2008) and computer animations of mathematics (Steingart 2014), transformed abstract ideas into perceptible and experiential phenomena that could be engaged with and visually investigated. By expressing theories that moved between observation, metaphor, and imagery, network visualizations expanded the vocabulary for representing social structure, just as preserved specimens did for ecology (Griesemer and Wimsatt 1989), simulations did for artificial life (Helmreich 1998), and cross-sections of cadavers did for the body (Waldby 2000). And by providing an image of the relational approach to social structure, network visualizations, like Feynman diagrams in theoretical physics (Kaiser 2005) and Laffer curves in supply-side economics (Giraud 2014), facilitated communication across various audiences.

Measurement can serve as a powerful tool for simplifying, directing attention, and establishing a shared language. But it often arises through a politicized and contentious process (Porter 1995; Espeland and Stevens 1998; 2008; Espeland and Sauder 2016; Igo 2009). Histories of SNA that gauge its development solely in relation to the formalization of measures may miss this fact. What results is an impression that the network paradigm emerged from isolated moments of ingenuity unbounded by a shared historical milieu. While it is beyond the scope of the current paper to explain why visual approaches to structure emerged at this moment in Interwar America, I can speculate.

The first explanation aligns with an enduring criticism lobbed from both outside and within the social sciences (MacIver 1931; Brinton 1939; Machotka 1949), and that is that these early efforts embraced visualization to emulate their peers in the natural sciences. Indeed, Warner (1941) and Moreno (1937) likened theirs to the maps drawn by cartographers and astronomers. Lewin argued that diagrammatic concepts represented real concepts that were no less valid a form of representation than those applied in physics. This choice was likely strategic. According to Cravens (1978), social science during the first half of the twentieth century faced a broader academic context that sought to replace it with biological science. Drawing analogies to the visual practices of their peers in the natural sciences was a way to demonstrate that the social sciences followed the same analytical and explanatory procedures. But it was also a way to assert the importance of examining social "facts" alongside facts derived from biology, chemistry, and physics.[39]

Second, all three precursors comprised the "assorted leftovers" of the other social sciences (Camic 2007). Occupying an interstitial (Halliwell 2013) or underinstitutionalized space (Abbott 2001b) at the periphery of the more central social sciences provided these precursors latitude to address with visualization an urgent concern: advancing concrete empirical research. With several notable exceptions, including studies by W.E.B. DuBois and Jane Addams (Morris 2015), empirical research in American sociology began around 1920 in fits and starts (Platt

---

[39] Camic (1989: 51) finds that sociologists made similar efforts to align themselves with the natural sciences. For example, while Talcott Parsons asserted a distinction between biological and normative or cultural factors, Parsons asserted that normative factors were still subject to the same analytical and explanatory procedures as biology, chemistry and physics.

1996: 2). Rather than draw from the empirical practices of their disciplinary backgrounds, Moreno (1937), Lewin (1945), and Warner (1941) advocated among sociologists for the integration of the social sciences. Each was thus confronted with setting a charter for empirical research.

Unbound by disciplinary convention, Moreno, Lewin, and Warner had the freedom to create unconventional means for representing concrete empirical research. They used visualization to do so, believing it could be applied at great scale. Moreno imagined that Sociometry could eventually visualize patterns of interrelationships at the scale of cities and countries (Moreno 1934: 432-434). Warner argued that positional charts could be used to identify and navigate thousands of community relations much like a mariner used a map to navigate the sea (Warner 1941: 796). Even Lewin, who was hesitant to theorize behavior beyond a particular person in a particular condition, argued that behavior needed to be explained through a great number of facts that assumed no limit (Lewin 1936: 243).

Lastly, and perhaps most provocatively, visualization offered the promise of prediction and social control in a moment when the social sciences gained a new public role. As Ross (1991) argues, the trauma of the World War and the influx of European scholars with weak ties to America's past raised skepticism over the belief that America was on a steadfast course toward moral progress. American social scientists of the nineteenth century sought fixed laws of history and nature influenced by a vision of continuous and progressive historical development. In contrast, social scientists of this new generation saw America as in a state of perpetual transition. This period was, according to W.I. Thomas (1917: 196), an "entirely new world unique, without parallel in history." The only remedy was a science based on replicable and exact measurements that could precisely predict behavior (Ross 1993: 109-110) and advise on how to accomplish public policy (Bannister 1987).

Practically, such work was supported by philanthropic foundations and the various agencies that sprung up in the era of the Great Depression and the New Deal. Moreno (1934) anticipated using his study of Hudson as a model for populating communities in homesteads created by the National Recovery Act to house the jobless (555). Lewin studied the forces influencing food habits and nutrition for the National Research Council before he established the RCGD. Warner's studies of Newburyport were funded by various New Deal administrations over the course of five years. Visualization for each provided a way to construct a map or "constellation" (Lewin 1938) of relationships that could predict behavior for a given concrete situation. Lewin argued that a field diagram with all the relevant facts represented could predict the behavior of a particular man. Sociograms for Moreno identified the positions of individuals in a larger social structure. In doing so, sociograms answered "concrete questions" about attitudes or behaviors by revealing the "position the individual X has in Kansas City" or "what position the family unit B has in Forest Hills" (Moreno 1934: 340). And positional charts could systematize entire communities and enable one to better understand the attitudes of any individual in any given event in their life (Warner 1941: 796).

Whatever the reason for their emergence, visualizations of structure at this moment illustrated vastly different theories of social structure. Contemporary network scholars have begun to take note by identifying, outlining, and historicizing fissures in the theoretical foundations of contemporary social network theory (Mohr 2005; Pachucki and Breiger 2010; Mische 2011; Erikson 2013; 2017). This work calls attention to the benefits of articulating the theoretical foundations of structural analysis: from finding affinities between substantively and methodologically divergent theories (J. L. Martin 2003), distinguishing between different understandings of culture (Mische 2011), to identifying theoretical tensions that point to areas for theoretical engagement and empirical research (Erikson 2017). In the spirit of this research, early network visualizations offer a way to examine vibrant theories of social structure that in some ways anticipate contemporary scholarship. For example, field diagrams represented the dynamism between multiple kinds of facts and between groups and individuals, suggesting the existence of multimodal if not multidimensional networks (Contractor, Monge, and Leonardi 2011) and hypergraphs (Lungeanu et al. 2018). Sociograms offered momentary pictures of relations that changed over time in response to changing cultural "conserves" or stereotypes, suggesting an interdependency between culture and structure (Lizardo 2006). And positional charts were comprised of behavioral situations or positions that could be occupied by any number of individuals, suggesting a prototypical blockmodel (H. C. White, Boorman, and Breiger 1976), albeit one that was treated as a concrete representation rather than a hypothesis that could be tested.

Sociograms, field diagrams, and positional charts represented attempts to create new conceptual machineries, ones that offered visual affordances for thinking about and exploring social structure, tied the theorization of social structure to empirical research, and enabled communication across different audiences. It is perhaps the preponderance of these representational forms that made social network analysis seem like an "eclectic bag of techniques" (White, Boorman, and Breiger 1976: 732) where similar metaphorical concepts like "connectedness" and "connectivity" could be methodologically incompatible (J. A. Barnes 1969). Mathematics may have certainly provided a means to integrate contradictory structural concepts, as numerous practitioners have argued (Leinhardt 1977; Wasserman and Faust 1994; Freeman 2004)

Yet, to regard visualization as auxiliary to mathematics overlooks two important lessons learned from the history of SNA. First, it ignores the sheer variety of incompatible mathematical approaches used to study social structure: from classificatory counts, topology and geometry, to complex combinatorial algorithms. Second, it ignores that visualization impacted how each thought about, theorized, and communicated ideas about social structure. In a milieu that was dominated by statistics and the emergence of the variables paradigm of explanation, the relational approach to social structure was presented with a problem: presenting society in its complexity in a moment when social scientific concepts were far from-taken-for-granted. Early network visualizations provided a way to engage with and experience an emergent science that minimized social divides and created a network of representations, metaphorical and mathematical, that formed the basis of a new conceptual approach to structure.

ARTICLE 2

Mertonian Intellectual Canons and Geertzian Cognitive Frames: Theories and Indicators of Interdisciplinarity in the Context of Contemporary Higher Education Scholarship

1. Introduction

Interdisciplinary scholarship is touted as essential to accelerating scientific discovery (National Science Foundation n.d.), addressing questions of increasing complexity and societal urgency (National Academy of Science 2005), and unlocking tomorrow's innovations (National Science and Technology Council 2018). Yet, to date, there is little consensus over how to define and assess interdisciplinarity (Klein 1996; 2006; Lattuca 2001; Mansilla 2006; Huutoniemi et al. 2010; Jacobs 2013; O'Rourke et al. 2014), leaving ample opportunity to address calls to specify its core theoretical foundations and corresponding methodological basis for measurement (Huutoniemi et al. 2010; Mansilla, Lamont, and Sato 2016). I address this problem by beginning with a fundamental question: how do we define the interdisciplinarity of scholarship?

To address this question, I argue that the way scholars theorize interdisciplinarity can be divided into two conceptually complementary but methodologically divergent approaches. The first, which I call the *Mertonian* approach, views science as a system of institutions (Merton 1968b; 1988). Here, interdisciplinarity arises through the *intermixing of disciplinary actors*, and is traditionally analyzed primarily through the use of quantitative article bibliometrics. The second, which I call the *Geertzian* approach, views science as increasingly blurred genres (Geertz 1983). Here, interdisciplinarity arises through the *intermixing of ideas across disciplinary actors*, but is traditionally analyzed primarily through the use of qualitative assessments such as review panels, interviews, or the assessments of disciplinary experts.

I use each approach to develop "partial" indicators of interdisciplinarity (B. R. Martin and Irvine 1983; B. R. Martin 1996; Bergmann et al. 2005; Rafols et al. 2012). Rather than search for a singular metric, studies of interdisciplinarity recognize that interdisciplinarity is a multidimensional concept that is best measured using multiple partial indicators. I offer two partial indicators: Mertonian intellectual canon and Geertzian cognitive frames. The former assesses interdisciplinarity through the integration of canonically cited disciplinary actors. The later assesses interdisciplinarity through the integration of the cognitive content of research across disciplinary actors. Each indicator offers complementary yet distinct insights for how we define and assess interdisciplinarity. I demonstrate this distinction in the context of studies on higher education.

I leverage higher education as both a revelatory and critical case (Yin 1994). Higher education presents an extreme or unusual case in that its scholars and practitioners regard it as a highly interdisciplinary enterprise. It thus provides a revelatory means to test the "sensitivity" of my analysis and demonstrate the differences of each approach. Any significant deviation from a Mertonian intermixing of actors or Geertzian intermixing of ideas in this case should be difficult to detect without an instrument sensitive enough to find it. However, it also provides a case to critically address growing concerns that its methodological, theoretical, and topical diversity has resulted in the creation of disciplinary silos (Kimball and Friedensen 2019; Renn 2020). I address these concerns in Mertonian and Geertzian terms to systematically reevaluate the interdisciplinarity of higher education scholarship.

Using a corpus of data derived from the top three scholarly journals in higher education research, I operationalize the Mertonian approach using co-citation network analysis and the Geertzian approach using a linguistic topic model. For the former, I examine bibliographies in my journal corpus to characterize the intermixing of scholars. For the latter, I examine the content of the articles to characterize the intermixing of ideas. In both analyses, I focus on the disciplinary background of the scholar who is either cited or who authored the article.

In my Mertonian analysis, I find that authors trained in Psychology, Economics, and Sociology, when compared to authors trained in Higher Education, are both less central and co-cited alongside authors who are less central to the network, have a lower tendency to connect two authors who are not co-cited in the same articles, and are relatively farther on average from all of the other authors in the network. Additionally, unlike those trained in Sociology and Higher Education, authors trained in Economics and Psychology tend to significantly cluster together in the co-citation network.

In my Geertzian analysis, I find that articles written by authors who share the same disciplinary training tend to be relatively less dissimilar than those who do not. This is particularly true for authors trained in Economics, Psychology, Educational Administration, and Business. However, articles written by authors trained in Economics and Business tend to be relatively more dissimilar to articles written by authors who do not share the same disciplinary training. These findings are robust to different specifications of the topic model.

As a critical case, my findings provide systematic evidence in support of the disciplinarity of higher education scholarship (Eisenmann 2004; Renn 2020), but with a few complications. When considering the scholars that make up higher education's Mertonian intellectual canon, trained economists and psychologists tend to be invoked in silos. Trained higher education scholars, in contrast, are both more central to this canon and thoroughly invoked throughout it. When considering the Geertzian cognitive frames used in its scholarship, trained economists and business scholars produce work that is topically distinct from the work of their peers. However, this is not true for trained psychologists. Thus, despite persistent concerns that its scholars operate in disciplinary silos (Eisenmann 2004: 8; Renn 2020: 919), studies of higher education exhibit some degree of interdisciplinary integration with reference to the works of trained psychologists.

As a revelatory case, my findings demonstrate that the Mertonian and Geertzian approaches offer complementary insights and indicators that can be used to more consciously define, assess, and facilitate interdisciplinary scholarship. With regard to higher education scholarship, trained economists and business scholars may benefit from adopting the cognitive frames used by their peers, while scholars more generally may benefit from centering the canonical works of psychologists and economists. I discuss how each approach may be used to promote interdisciplinarity more generally through the use of journal initiatives and curricular interventions.

2. Interdisciplinarity: Theories and Measurement

Interdisciplinarity is hailed by universities, scientific funding agencies, policy makers, and scholars as crucial to producing both practical research and innovative breakthroughs (Jacobs and Frickel 2009). The term itself has a history that begins in the twentieth century, and has been used to describe anything from cutting-edge scientific discoveries to philosophical works in ancient Greece (Klein 1990). Despite its ubiquity and persistence, however, interdisciplinarity remains a slippery concept. Numerous scholars offer a variety of frameworks, typologies, and indicators for assessing and measuring interdisciplinarity. As a result, there is no standard consensus over how to define and assess it (Klein 1996; 2006; Lattuca 2001; Mansilla 2006; Huutoniemi et al. 2010; Jacobs 2013; O’Rourke et al. 2014).

In response to calls for a more integrated sociological approach to interdisciplinarity (Mansilla, Lamont, and Sato 2016: 572) and its operationalization into empirically testable measures (Huutoniemi et al. 2010: 80), I propose that there are rich grounds for elaborating the theoretical foundations of interdisciplinarity. I begin with the question of how we define the interdisciplinarity of scholarship. I argue that the way scholars traditionally answer this question ultimately originates from what I call the *Mertonian* and *Geertzian* approaches to interdisciplinarity. The former proposes that interdisciplinarity arises from the intermixing of actors, while the later from the intermixing of ideas. Despite methodological differences, each approach offers complementary "indicators" of interdisciplinarity. I use these indicators to reformulate the question of how we define the interdisciplinarity of scholarship into a set of propositions.

2.1. The Mertonian Approach

Robert Merton inspired a legacy of research on the sociology of science, one that focused on treating science as a social system with institutionalized norms, stratified resources, and reputational rewards. One of his major methodological contributions was the idea that scientific institutions could be observed and measured through the allocation of rewards, citations, and other markers of scientific activity (Merton 1968b). His studies focused on scientists and the normative structures of science rather than on scientific knowledge. It was not necessarily the content of science that interested Merton so much as its social and cultural character (Calhoun 2010: 5).

One stream of Merton's research focused specifically on how the system of publication both reflected and refracted the social nature of science. Here, publications provided not only a way to offer a "scientific contribution" to a community, but also a means to signal ownership over ideas (Merton 1957). Citations were essential to this process (Merton 1988). Citations served an instrumental function by directing readers to sources of knowledge. But they also served an important symbolic institutional function: citations provided peers with recognition and demarcated intellectual traditions (621). By fulfilling a communal obligation to honor the intellectual contributions of others (Merton 1942; Zuckerman and Merton 1971) citations identified intellectual peers and in doing so created links between the works of scientists and links between ideas (Merton in Garfield 1979: vi-vii).

Merton's approach to science, including an analytical focus on the attributes of individual scientists and a methodological emphasis on the social ties between them, serves as the foundation for what I call the Mertonian approach to interdisciplinarity. In the Mertonian approach, interdisciplinarity arises through the *intermixing of disciplinary actors*, and is analyzed primarily through the use of quantitative article bibliometrics.

Merton himself was never explicitly concerned with the concept of disciplines, let alone clarifying their relationship to intellectual traditions or canons. However, Merton's ideas directly inspired the development of quantitative studies of citation and had an influential impact outside of sociology on the field of information science and scientometrics (Garfield 1998; 2004a; 2004b). These research programs operationalized the interdisciplinarity of intellectual canons, in formal terms, through the method of co-citation network analysis.[40]

Co-citation networks represent social networks where authors share a social tie if they are cited in the same article. They provide two strategies for assessing interdisciplinarity. The first network strategy characterizes interdisciplinarity using the formal structural properties of

---

[40] Co-authorship, or the joint authorship of a scientific publication by two or more authors, is also seen as a natural corollary of co-citation.

individuals (or groups of individuals) in the network, often in the form of *network centrality* (Freeman 1978). Measures of centrality provide a way to identify individual authors or journals that have the most ties to others in the network (Cottrill, Rogers, and Mills 1989), those who are “closer” to all the others in the network (Ni, Sugimoto, and Jiang 2011), or those who act as “brokers” across the network (Leydesdorff and Rafols 2011; Leydesdorff, Wagner, and Bornmann 2017). In doing so, they also identify the structural position of disciplines (via authors by disciplinary specialization or journals by disciplinary categorization), thereby offering a way to assess the interdisciplinarity of a given set of publications.

The second network strategy characterizes interdisciplinarity using the formal structural properties of the network itself, often in the form of *network clustering*. Measures of clustering provide a way to identify groups of densely co-cited authors or journals. Whether calculated using multidimensional scaling (H. D. White and McCain 1998; Morillo, Bordons, and Gómez 2003), k-means clustering (Yan, Ding, and Jacob 2012), or modularity (Yan and Ding 2012), these densely connected groups and their content are used to assess the interdisciplinary structure of a given set of publications. According to this approach, clusters containing a wider variety of disciplinary actors generally demonstrate a greater degree of interdisciplinarity than those that do not (Rafols and Meyer 2010).

2.2. The Geertzian Approach

Like Merton, Clifford Geertz believed it was necessary to view the sciences as fundamentally social activities in a social world. Unlike Merton, Geertz took a more critical stance on how to study thought and outlined what he considered were the crucial elements needed to understand the formation of disciplines.[41] Geertz argued that disciplines should be understood broadly as "cultural frames" that form attitudes and direct the conduct of intellectuals (Geertz 1983: 14). Cultural frames, or what I call cognitive frames to underscore Geertz' focus on the study of thought, constitute "the way we think" (5) and are rooted in communal symbolic systems.

Geertz' criticism of the sociology of knowledge was that it oversimplified the foundations of the arts and sciences by "matching varieties of consciousness to types of social organization" (153). For Geertz, knowledge was instead "a matter of trafficking" of symbolic forms available to a community. Certain "genres" of intellectual work cut across intellectual "borders-and-territories" (7-21). This work blurred distinctions otherwise upheld by preexisting notions of intellectual taxonomies. But it also called attention to how knowledge had a "local" character: it was specific to an author's "intellectual village" – his/her/their societies, university departments, and cliques – where ties were political, moral, and personal rather than purely intellectual (157). As a result, the study of knowledge for Geertz necessitated ethnographic methods that emphasized the particularity or subjectivity of knowledge.

In the Geertzian approach, interdisciplinarity arises through the *intermixing of ideas* across disciplinary actors. It focuses not on the disciplinarity of individual actors, but on how scholars think and how scholars define and put interdisciplinarity into practice (Klein 1990). Under this approach, interdisciplinarity ideally represents an integrative synthesis of existing knowledge, of cognitive frames across disciplinary actors (Holley 2009; Klein 2006; Nikitina 2005; Jacobs and Frickel 2009; Huutoniemi et al. 2010). Thus, the rise of the Geertzian approach

---

[41] Geertz referred here to Thomas Kuhn's "disciplinary matrix", or elements such as values, ideas, or formalizations that were shared by scholars of a particular discipline.

can in some ways be understood as a response to its Mertonian counterpart. A common critique of the latter is that it black boxes the content of interdisciplinary knowledge by relying on disciplinary categories and other institutionally defined boundaries. By relying on journal subject categorizations or author affiliations, Mertonian approaches use measures of disciplines that are non-ambiguous but nonetheless “coarse” (Huutoniemi et al. 2010) and do not get at the cognitive content of interdisciplinary work itself.

However, the Geertzian emphasis on the subjectivity of interdisciplinary knowledge makes defining interdisciplinarity and analyzing the intermixing of cognitive frames difficult. Geertzian studies find that interdisciplinarity “on-the-ground” is often complicated by competing and local assumptions about what constitutes good or successful interdisciplinary scholarship (Lamont, Mallard, and Guetzkow 2006; Mansilla and Duraising 2007; Lamont and Huutoniemi 2011). As a result, in order to assess cognitive integration, Geertzian studies tend to be contextually grounded and methodologically based on evaluative review panels (Lamont 2009), case studies (Huutoniemi et al. 2010; Mansilla, Lamont, and Sato 2016), or the assessments of experts (Collins 2007). Defining the context or conditions for the integration of ideas becomes as important as assessing the disciplinary integration of cognitive frames itself.

2.3. Complementary “Partial Indicators”: Intellectual Canons and Cognitive Frames

Mertonian and Geertzian studies of interdisciplinarity carry on largely independently: the former are predominantly found in the field of the information sciences, the latter are found in science and technology studies and the sociology of knowledge. At the same time, both have abandoned the search for a singular metric to assess interdisciplinarity, embracing instead a “multiple” or “converging partial indicators” approach (B. R. Martin and Irvine 1983; B. R. Martin 1996; Bergmann et al. 2005; Rafols et al. 2012). Given that no single measure can model what is a multidimensional concept, the idea is to use multiple indicators to provide a more robust operationalization of interdisciplinarity.

In the spirit of partial indicators, I propose that each approach offers complementary indicators of interdisciplinarity in the form of Mertonian *intellectual canons* and Geertzian *cognitive frames* (see **Table 1**). I use these indicators to develop a set of propositions to address the question of how we define the interdisciplinarity of scholarship.

	Interdisciplinarity	**Common Modes of Analysis**	**Borders and Territories**	**Partial Indicator**
Mertonian	Intermixing of disciplinary actors.	Quantitative co-citation or co-authorship network analysis.	Scholar's disciplinary training or affiliation, or journal disciplinary classification.	Intellectual traditions or canons.
Geertzian	Intermixing of knowledge across disciplinary actors.	Qualitative reviews, interviews, or ethnographic observation.	Scholar's disciplinary background or (non-institutional) specialty or field of knowledge.	Cognitive frames.

Table 1. Complementarities of the Mertonian and Geertzian approaches to interdisciplinarity.

By focusing on the intermixing of disciplinary actors *qua* citations, the Mertonian approach does not engage with the cognitive frames used by those actors. However, it does capture one form of symbolic "traffic": intellectual traditions or canons identified through the interweaving of scholarly work. Merton (1988) brought attention to the connection between citations and intellectual canons with Newton's aphorism that his accomplishments "stood on the shoulders of giants" (621). Citational studies operationalize this insight by identifying the most cited and central scholars (and the systematic relationships between them) as they are repeatedly invoked in the published literature. The scholars who make up an intellectual canon represent a network of "giants" or highly cited scholars numerous others consult to motivate or make sense of their research. The structural features of scholars in this network and of the network itself provide indicators for assessing the interdisciplinarity of an intellectual canon.

If interdisciplinarity arises through the intermixing of disciplinary actors, and if network centrality and clustering offer two means of measuring it, then we can use the Mertonian approach to define the interdisciplinarity of scholarship as two propositions:

> *P1: Interdisciplinary scholarship is characterized by an intermixing in an intellectual canon where the most central scholars are not significantly predicted by disciplinary background.*
>
> *P2: Interdisciplinary scholarship is characterized by an intermixing in an intellectual canon where clusters of scholars are not significantly predicted by disciplinary composition.*

Nevertheless, if the goal of interdisciplinary research is to produce interdisciplinary knowledge, then knowledge itself should be used as the signpost for assessing research. The Geertzian approach makes a more conscious effort to understand the synthesis of interdisciplinary knowledge with regards to both its context and cognitive content. However, to ascertain the intermixing of cognitive frames, the Geertzian approach relies on time-consuming methods that require close readings of text or the judgment of disciplinary experts.

To circumvent this constraint, I take advantage of advances in computational linguistics to "scale up" the Geertzian analysis of frames. A computational approach to knowledge may appear to represent a departure from Geertz's vision for an interpretive and ethnographic science. Yet, as numerous scholars attest (Mohr and Rawlings 2012; DiMaggio, Nag, and Blei 2013; Lee and Martin 2015; Breiger, Wagner-Pacifici, and Mohr 2018), there is no reason to assume that formal methods for cultural analysis intrinsically fail as tools for comparing how people think. The computational approach I adopt here is simply an advanced form of counting for comparison: counting relationships between symbolic forms (i.e., words) across texts, and comparing authors on the basis of measures derived from these counts. This is no different from a qualitative close reading of text, where the goal is to code documents to identify systematic differences between authors (Mohr, Wagner-Pacifici, and Breiger 2015). Like other Geertzian studies, I am interested in these codes (i.e., in the cognitive content of scholarship) insofar as they enable me to identify systematic differences between scholars on the basis of their disciplinary background. But I make no claims regarding the interpretive meaning of these codes, and I do not adopt computational tools to interpret the meaning of higher education scholarship.

If interdisciplinarity arises through the intermixing of ideas across disciplinary actors, and if judgments of cognitive integration offer a means of measuring it, then we can use the Geertzian approach to define the interdisciplinarity of scholarship as the following proposition:

> *P3: Interdisciplinary scholarship is characterized by an intermixing of cognitive frames across actors that are not significantly distinguishable by disciplinary training.*

3. Case, Data, and Methodology

3.1. Case

I operationalize my propositions into hypotheses and demonstrate how each approach offers complementary yet distinctive insights using the case of studies on higher education. In the spirit of the Mertonian approach, I conduct an author co-citation network analysis in order to examine the formation of disciplinary clusters and characterize the citational foundations of higher education scholarship. In the spirit of the Geertzian approach, I scale up by analyzing the integration of cognitive frames in higher education scholarship using topic modelling.

I leverage studies of higher education as both a revelatory and critical case. Higher education provides an opportunity to reveal the Mertonian and Geertzian approaches to interdisciplinarity, since scholars and practitioners regard it as a highly interdisciplinary enterprise. Scholars agree that research on higher education constitutes “a diverse field” (Budd

1990), is "multidisciplinary" (Corwin and Nagi 1972; Silverman 1984; 1985; 1987), is "not monolithic" (Bayer 1983), and is "interdisciplinary" (Bayer 1983; Budd 1990; Kezar 2000; Mars and Rios-Aguilar 2010). For this reason, one should not find academic "silos" and strict disciplinary boundaries (Brint 2005). If the intellectual canon and cognitive integration of higher education scholarship were defined by disciplinary boundaries, a model of interdisciplinarity would need to be sensitive enough to reveal them.

However, higher education also provides a case to critically address concerns that its tolerance for "low consensus" has resulted in the resurgence of disciplinary segregation. Scholars of higher education often celebrate the interdisciplinarity of both its ideas and ranks (Bayer 1983; Kezar 2000). However, a growing concern is that its broad definition of what constitutes meaningful research proceeds at the expense of scholarly consensus (Kimball and Friedensen 2019: 1570). According to this argument, scholars turn to disciplinary methods, frameworks, and epistemologies in the absence of consensus for guidance, leading to a resurgence of disciplinary thinking. Kristen Renn (2020: 919) draws on this point precisely in her presidential address to the *Association for the Study of Higher Education*, cautioning that if the association continued to operate in disciplinary silos, it ran the risk of losing influence over the direction of postsecondary education. I evaluate these concerns in Mertonian and Geertzian terms using a corpus of research where the outcome of these anxieties over interdisciplinarity are made manifest.

3.2. Data

The data I compile originates from three academic journals: *The Journal of Higher Education* [JHE], *Research in Higher Education* [RHE], and *Review of Higher Education* [RevHE]. These journals represent three "core" journals in the higher education research literature (Bayer 1983; Hunter and Kuh 1987; Silverman 1985; 1987; Milam 1991; Hutchinson and Lovell 2004; Hart 2006; Donaldson and Townsend 2007; Tight 2007; Mars and Rios-Aguilar 2010). Scholars of higher education read and cite these journals at an above average rate and consider them to be the three most prestigious journals in the field of higher education scholarship (Bray and Major 2011). Thus, while my data lack monographs and is in no way representative of the entire spectrum of research published on higher education, it nonetheless represents a substantial if not consequential context for characterizing the interdisciplinarity of higher education scholarship.

The bibliographic data I use for my Mertonian analysis consists of 4,260 bibliographies published from 2004 to 2013. I use the Social Sciences Citations Index (SSCI) to obtain bibliographic data, which yields 3,703 bibliographies from JHE, 371 from RHE, and 186 from RevHE. After correcting and disambiguating the citation data (see section 1.1 in Appendix), I identify the intellectual canon of higher education scholarship by selecting highly cited scholars who meet two criteria: they must be cited in at least 15 different articles and must be co-cited in an article with at least 1 other author in the sample. I exclude organizations (e.g., the US Census, NCES) from my sample. The total number of authors included in the final sample of cited authors totals 300. References to these authors represent 35.9% (15,805) of all the citations (44,079) made over the ten-year period.

The article data I use for my Geertzian analysis consists of 1,401 articles published from 2000 to 2016. Articles exclude author comments, letters, and book reviews. I focus only on the first author of each article. The total number of unique first authors included in the final sample of article authors totals 811. I use the text of each article, which excludes bibliographies, appendices, and other content removed after standard text processing (see section 1.2 in Appendix), to identify cognitive frames.

I collect author biographical information, including disciplinary training, using a mix of personal websites, curriculum vitae, department websites, archived websites, dissertation abstracts, and published books (see section 1.3 in Appendix). To classify an author's training, I use the 2010 release of the Classification of Instructional Program, a taxonomic scheme of academic disciplines developed by the US Department of Education's National Center for Education Statistics. The taxonomy codes academic disciplines according to a 2-, 4-, and 6-digit code. Each code represents a progressively granular distinction in classification. I recode an author's training into its 4-digit classification (e.g., Sociology, Economics, Psychology), which I use to represent a scholar's disciplinary field.

3.3. Methodology

I use two methods to operationalize the Mertonian and Geertzian approaches: a bibliographic co-citation network analysis and an article topic model (**see Table 2**). I use these methods to derive three measures, which I use to reformulate my propositions into hypotheses about the interdisciplinarity of higher education scholarship.

<table>
<tr><th></th><th>Indicator</th><th>Operationalization</th><th>Measurement</th></tr>
<tr><td rowspan="2">Mertonian</td><td rowspan="2">Intellectual Canon</td><td rowspan="2">Co-Citation Network</td><td>Disciplinary Centrality by Centrality Measures (EC, BC, CC)</td></tr>
<tr><td>Disciplinary Clustering by Louvain Community</td></tr>
<tr><td>Geertzian</td><td>Cognitive Frames</td><td>LDA Topics</td><td>Disciplinary Topical Divergence by Jensen-Shannon Divergence</td></tr>
</table>

Table 2. Indicator, operationalization, and measurement of interdisciplinarity, by approach.

3.3.1. Mertonian Approach: Co-Citation Network Centrality and Clustering

The Mertonian approach makes extensive use of bibliographic co-citation networks, which I use here to operationalize an intellectual canon. Specifically, I define the set of scholars that comprise an intellectual canon by selecting scholars who are highly cited across multiple publications. I define relationships between scholars in an intellectual canon on the basis of co-citation, or whether scholars are jointly cited in the same article bibliography. Co-citation networks comprise the set of relationships between a set of authors based on co-citation. The greater the number of times an author is co-cited with another author, the greater the "weight" of the tie between the pair. Using these definitions, I define an intellectual canon as a co-citation network comprised of scholars who are highly cited across multiple publications, where the relationship between each pair of scholars is weighted by the number of times each pair is co-cited. I pursue two strategies to assess the interdisciplinarity of an intellectual canon: one based on author centrality, and another based on author clustering.

Centrality provides a means to identify "stars" or prominent individuals in a social network (Moreno 1934; Wasserman and Faust 1994). While there are numerous ways to specify and measure centrality, all measures attempt to capture the relative inequality in the distribution of centrality for a given network. An interdisciplinary intellectual canon not only features scholars trained in more than one discipline, but also centrality scores that are not significantly associated with disciplinary training. I use three classical measures of centrality, including eigenvector centrality, betweenness centrality, and closeness centrality, to characterize the centrality of authors in higher education's intellectual canon.

Eigenvector centrality [EC] (Bonacich 1987; 1991) measures the centrality of an author relative to the centrality of neighboring authors. The EC of an author is equal to the sum of its ties to other authors, weighted by the number of ties incident on those authors. A higher EC indicates that a cited author is co-cited with other authors who are also highly co-cited - hence, the author is more "popular."

Betweenness centrality [BC] (Freeman 1978) measures the extent to which a particular author lies "between" various other authors in the network. The concept of BC relies on the idea of "local dependency", where an author may play an important intermediary role as a "broker" connecting all the other authors in the network. BC is calculated by finding all of geodesics between any two authors and counting the number of shortest paths each author falls on. A higher BC indicates that a cited author has a greater tendency to connect two authors who are not co-cited in the same articles.

Finally, closeness centrality [CC] (Freeman 1978; Wasserman and Faust 1994; Opsahl, Agneessens, and Skvoretz 2010) is expressed in terms of the distances among the various authors. CC is calculated by taking the average *geodesic*, the distance of the shortest path between two authors, between an author and all other authors in the network. A lower CC indicates that a cited author is, on average, relatively closer to all of the other authors in the network.

In contrast to centrality, clustering provides a means of identifying densely connected groups of individuals. Whereas centrality is calculated as an attribute of individuals in the network, clustering is a structural attribute of the network itself. An interdisciplinary intellectual canon features clusters that are not significantly distinguishable by disciplinary composition. I use the Louvain algorithm (Blondel et al. 2008) to identify clusters or communities of authors by modularity.

A community represents a partition of a network whose members have a higher probability of being connected to each other than to members of another community (Fortunato and Castellano 2012). Co-citational communities represent groups of authors who have a higher probability of being cited together. Modularity is a scalar value between -1 and 1 that compares the density of ties within a community to the density of ties between communities. Modularity can be taken to represent the relative density of a community. The Louvain algorithm constructs communities solely on the basis of ties between authors, weighted for the number of times each pair of authors is co-cited.[42]

To calculate centrality scores and communities, I construct a weighted co-citation network. Each tie between each pair of authors is weighted by the number of times the pair is co-cited in the same article bibliography. Authors who are frequently co-cited share a tie with a greater weight than authors who are not. I use this weighted network to generate centrality measures and assign each author to a Louvain community.

To determine whether centrality or community assignment are significantly associated with disciplinary training, I generate two sets of regression models. First, I use ordinary least squares [OLS] regression to determine whether author centrality is significantly predicted by the author's disciplinary training. Next, I use multinomial logistic [ML] regression to determine whether an author's assigned community is significantly predicted by the author's disciplinary training. For both, I construct two sets of models using two different disciplinary fields as the base category: one using Higher Education and another using Sociology. I select these disciplines because they contain the highest number of authors in the intellectual canon (66 and 60, respectively). Additionally, given the salience of race (Bellas and Toutkoushian 1999), career

[42] There are two phases in the Louvain algorithm. In the first phase, individual authors are taken to represent individual communities. These communities are grouped and regrouped with neighboring communities (authors) to maximize modularity. Communities grouped together that achieve no positive gain in modularity are kept separate. This process is reiterated sequentially for all communities until no positive gain in modularity is achieved, thus completing the first phase. In the second phase, the communities formed in the first phase are taken to represent individual nodes. Ties between communities are weighted by the sum of the weighted ties between the component nodes connecting each corresponding community.

stage (Thursby, Thursby, and Gupta-Mukherjee 2007), gender (Cronin and Sugimoto 2015), and doctoral program prestige (Williamson and Cable 2003; Duffy et al. 2011) in explaining productivity and citation count, I include covariates for race, gender, year the author's highest degree was obtained, and several Carnegie Classification measures of doctorate-granting institutions in the full model for both models. Finally, I visualize the co-citation network using the force-directed Fruchterman and Reingold (1991) algorithm.[43]

With the Mertonian approach thus operationalized, then we can reformulate propositions 1 and 2 into the following set of hypotheses:

> *H1: The interdisciplinarity of higher education scholarship is characterized by a bibliometric co-citation network where the eigenvector, betweenness, and closeness centralities of scholars are not significantly predicted by disciplinary background.*

> *H2: The interdisciplinarity of higher education scholarship is characterized by a bibliometric co-citation network where Louvain communities of scholars are not significantly predicted by disciplinary composition.*

3.3.2. Geertzian Approach: Topical Divergence

The Geertzian approach emphasizes the integration of cognitive frames, which I operationalize here using a linguistic topic model. Linguistic topic models represent a class of probabilistic machine learning algorithms for characterizing the content of large and otherwise unstructured bodies of text (Blei 2012; Grimmer and Stewart 2013; Mohr and Bogdanov 2013; Bail 2014). Topic models identify ranked sets of words called "topics" that tend to co-occur together across textual documents. Topic models, if properly validated, represent a replicable and

[43] The Fruchterman-Reingold algorithm models actors and ties in a social network as a physical system of rings and springs. The algorithm arranges rings in two-dimensional space in a way that minimizes the energy of the system and reduces strain on the springs.

relatively unbiased approach to characterize large corpora with results that are consistent with codes developed by trained human coders (Chang et al. 2009; Mimno et al. 2011).

In the social sciences, topic models are commonly used to characterize the semantic content of large textual corpora (Griffiths and Steyvers 2004; Grimmer 2010; DiMaggio, Nag, and Blei 2013). In sociology, topic models are commonly used to formally represent cognitive frames that social actors use to think or make sense of a phenomenon defined by a given set of documents (Mohr and Bogdanov 2013; Fligstein, Stuart Brundage, and Schultz 2017). These frames enable comparisons between actors on the basis of cognitive or cultural distance (Giorgi and Weber 2015; Corritore, Goldberg, and Srivastava 2020). Applied to the study of interdisciplinarity, linguistic topic models provide a way to "scale up" a Geertzian analysis of intellectual integration by making comparisons both systematic and scalable across a large corpus of research.

I define a set of cognitive frames as a set of topics across a corpus of documents. First, I use latent Dirichlet allocation [LDA] (Blei, Ng, and Jordan 2003) to generate topics for my corpus of higher education articles and a topic distribution for each article. Next, I generate pair-wise Jensen-Shannon divergence [JSD] measures (Lin 1991) between each article to determine whether mean topic divergence significantly differs by author disciplinary training.

LDA identifies distinct topics across a corpus by observing words or terms that tend to co-occur frequently within a document, reducing each document into a finite probability distribution. LDA represents each document as a probability distribution over topics, giving the percentages across all topics that the model estimates comprise the document. Each topic is assumed to be a probability distribution over terms. To generate per-document topic and per-topic term distributions, the algorithm allocates a term within a document to a topic, and updates the assignment based on the prevalence of the term across topics and the prevalence of the topic within the document. While the initial assignments are random, terms become more common in topics where they are already common while topics become more common in documents where they are already common.

After using LDA to render each article into a probability distribution over a set number of topics, I generate pairwise JSD measures between articles to measure topical similarity between articles. JSD provides a symmetric and finite measure of dissimilarity between two probability distributions, and has been used in natural language processing to deal with sparse, power-law distributions of words (Klingenstein, Hitchcock, and DeDeo 2014; Goldberg et al. 2016; Srivastava et al. 2017). It can be expressed as the sum of two Kullback–Leibler divergences (KLD):

$$JSD(P \parallel Q) = \frac{1}{2}KLD(P \parallel M) + \frac{1}{2}KLD(Q \parallel M)$$

Where $M = \frac{1}{2}(P + Q)$ and $KLD(P \parallel M)$ is the Kullback-Leibler divergence of M from P:

$$KLD(P \parallel M) = \sum_{i \in I} P\,(i) log_2 \frac{P(i)}{M(i)}$$

Intuitively, KLD measures the amount of information lost when $M(i)$ is used to approximate $P(i)$. If these distributions are identical, $log_2(P(i)/M(i))$ equals 0. As these distributions diverge, or as the topic probability distributions between two documents becomes dissimilar, the average dissimilarity as measured by the JSD increases. Documents that are more similar are likely to have similar topic distributions and therefore a relatively lower JSD. This approach follows from previous efforts to use topic models to measure document similarity (Rosen-Zvi et al. 2004; Grimmer 2010; Giorgi and Weber 2015).

The number of JSD measures between 1,401 articles totals 980,700. Based on the disciplinary training of an article's first author, I generate pair-wise mean JSD between degree concentrations. Next, I use a Welch's t-test to check if the mean JSD between two concentrations is significantly different compared to the average JSD for the population excluding the two concentrations. I use a heat map to visualize mean JSD between disciplinary fields.

With the Geertzian approach thus operationalized, we can reformulate proposition 3 into the following hypothesis:

> *H3: The interdisciplinarity of higher education scholarship is characterized by an intermixing of LDA topics across actors that does not significantly diverge, on average, by disciplinary training.*

4. Results

4.1. Interdisciplinarity as the Intermixing of Actors

4.1.1. Disciplinary Network Centrality

Table 3A summarizes results from the OLS regression models for each measure of centrality using authors trained in Higher Education as the base category for comparison. Model I estimates centrality by degree. Model II estimates centrality controlling for an author's gender, race, year the author's highest degree was obtained, and several Carnegie Classification measures describing the institution where the author's highest degree was obtained. Model III, the full model, estimates centrality combining the covariates used in models I and II. Significant coefficients of P-values equal to or less than alpha (α=0.001 or 0.01 or 0.05) are denoted by asterisks.

Table 3A. Ordinary least squares regression using scholars trained in Higher Education as reference category.

	Eigenvector Centrality			Betweenness Centrality			Closeness Centrality		
	Model I	Model II	Model III	Model I	Model II	Model III	Model I	Model II	Model III
Unknown (N=6)	-0.0478			-23.35			0.0521		
	-0.0679			-24.41			-0.0665		
Communication (N=1)	0.22		0.202	79.93		73.46	-0.216		-0.196
	-0.161		-0.161	-57.68		-58.96	-0.157		-0.158
Education (General) (N=19)	-0.000593		0.0138	2.543		7.777	0.00084		-0.0122
	-0.0415		-0.0459	-14.91		-16.75	-0.0406		-0.0449
Educational Admin (Other) (N=15)	-0.0337		-0.0263	-6.943		-3.927	0.0337		0.0273
	-0.0456		-0.0515	-16.38		-18.79	-0.0446		-0.0504
English and Liberal Arts (N=2)	-0.239*		-0.427**	-56.89		-109.4	0.225*		0.410*
	-0.114		-0.164	-41.09		-60.04	-0.112		-0.161
Mathematics (N=5)	-0.146*		-0.164	-50.95		-62.39	0.148*		0.175
	-0.0739		-0.0955	-26.56		-34.89	-0.0723		-0.0935
Interdisciplinary Sciences (N=2)	-0.155		-0.0757	-40.86		-23.88	0.144		0.0636
	-0.114		-0.169	-41.09		-61.62	-0.112		-0.165
Religious Studies (N=1)	-0.205			-55.8			0.179		
	-0.161			-57.68			-0.157		
Psychology (N=38)	-0.0979**		-0.144***	-26.21*		-44.84**	0.0934**		0.143***
	-0.0325		-0.0391	-11.66		-14.28	-0.0317		-0.0383
Public Administration (N=20)	0.0256		0.00975	1.335		-2.819	-0.0187		-0.00236
	-0.0407		-0.0428	-14.61		-15.63	-0.0398		-0.0419
Social Sciences (Other) (N=19)	-0.0907		-0.111	-27.25		-37.89	0.0883		0.11
	-0.0566		-0.0667	-20.34		-24.37	-0.0554		-0.0653
Economics (N=39)	-0.0425		-0.0786*	-20.06		-32.44*	0.047		0.0830*
	-0.0322		-0.0366	-11.56		-13.37	-0.0315		-0.0358
Sociology (N=60)	-0.0489		-0.0935**	-19.66		-36.58**	0.0516		0.0975**
	-0.0284		-0.0341	-10.21		-12.47	-0.0278		-0.0334
Health Professions (N=2)	0.0945		0.0307	13.67		15.39	-0.0856		-0.0374
	-0.114		-0.163	-41.09		-59.57	-0.112		-0.16
Business and Management (N=5)	-0.00554		-0.0618	-17.28		-38.76	0.0168		0.0735
	-0.0739		-0.0764	-26.56		-27.9	-0.0723		-0.0747
History (N=7)	-0.0538		-0.123	-20.68		-46.22	0.0549		0.125
	-0.0633		-0.0661	-22.76		-24.13	-0.062		-0.0647
JD (N=3)	-0.14		-0.237*	-35.99		-69.17	0.132		0.230*
	-0.0941		-0.0994	-33.8		-36.32	-0.092		-0.0973
Female (N=89)		-0.0557*	-0.0577*		-17.14*	-19.37*		0.0513*	0.0538*
		-0.0238	-0.0239		-8.627	-8.717		-0.0234	-0.0234
Asian (N=17)		-0.047	-0.0338		-21.33	-18.5		0.0519	0.0407
		-0.0427	-0.0432		-15.45	-15.79		-0.0418	-0.0423
Black (N=13)		-0.0282	-0.0172		-15.47	-13.02		0.0341	0.025
		-0.0477	-0.0473		-17.26	-17.26		-0.0467	-0.0463
Latino (N=16)		0.0451	0.0258		14.39	5.606		-0.0415	-0.0211
		-0.0444	-0.0438		-16.07	-16.01		-0.0435	-0.0429
Highest Degree Year		0.000637	-0.00126		0.009	-0.567*		-0.000492	0.00136
		-0.000673	-0.000774		-0.244	-0.283		-0.000659	-0.000757
Research Activity Level		0.0505	0.0413		5.178	2.309		-0.0417	-0.0333
		-0.0476	-0.0484		-17.24	-17.68		-0.0467	-0.0474
Student Population		-8.3E-07	-8.3E-07		-4.1E-04	-4.9E-04		8.3E-07	8.3E-07
		-1.4E-06	-1.4E-06		-0.0005	-5.2E-04		-1.4E-06	-1.4E-06
Private School		-0.00236	0.0139		-11.85	-5.284		0.0078	-0.00953
		-0.0331	-0.034		-11.97	-12.4		-0.0324	-0.0332
High Correspondence		-0.0463	-0.0822		-23.29	-38.88		0.0555	0.0929
		-0.135	-0.132		-48.7	-48.26		-0.132	-0.129
Not a Large 4 Year University		-0.0679	-0.0494		-16.98	-10.94		0.0624	0.0437
		-0.0558	-0.0555		-20.17	-20.27		-0.0546	-0.0543
Prof. Degrees Offered In Addition to PhD		0.00944	0.0121		-8.693	-11.18		-0.00164	-0.00522
		-0.0849	-0.091		-30.71	-33.25		-0.0831	-0.0891
Medical/Veterinarian School Present		-0.0072	0.0116		-0.415	4.577		0.00603	-0.0125
		-0.0292	-0.0303		-10.57	-11.07		-0.0286	-0.0297
Constant	0.638***	-0.754	3.077*	82.41***	62.53	1229.1*	1.420***	2.498	-1.232
	-0.0196	-1.347	-1.549	-7.047	-487.4	-565.8	-0.0192	-1.32	-1.516
Observations 300	300	300	300	300	300	300	300	300	300
R-squared	0.09	0.049	0.157	0.061	0.043	0.136	0.085	0.046	0.157

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Table 3B. Ordinary least squares regression using scholars trained in Sociology as reference category.

	Eigenvector Centrality			Betweenness Centrality			Closeness Centrality		
	Model I	Model II	Model III	Model I	Model II	Model III	Model I	Model II	Model III
Unknown (N=6)	0.00112			-3.692			0.000446		
	-0.0682			-24.51			-0.0667		
Communication (N=1)	0.269		0.295	99.59		110	-0.268		-0.294
	-0.161		-0.162	-57.73		-59.13	-0.157		-0.158
Education (General) (N=19)	0.0483		0.107*	22.2		44.36*	-0.0508		-0.110*
	-0.0419		-0.0476	-15.07		-17.37	-0.041		-0.0465
Educational Admin. (Higher Ed.) (N=66)	0.0489		0.0935**	19.66		36.58**	-0.0516		-0.0975**
	-0.0284		-0.0341	-10.21		-12.47	-0.0278		-0.0334
Educational Admin (Other) (N=15)	0.0153		0.0672	12.71		32.65	-0.0179		-0.0703
	-0.046		-0.0524	-16.53		-19.14	-0.045		-0.0513
English and Liberal Arts (N=2)	-0.19		-0.334*	-37.24		-72.86	0.174		0.312*
	-0.115		-0.162	-41.15		-59.04	-0.112		-0.158
Mathematics (N=5)	-0.097		-0.0709	-31.29		-25.81	0.0962		0.0773
	-0.0742		-0.0943	-26.65		-34.45	-0.0726		-0.0923
Interdisciplinary Sciences (N=2)	-0.106		0.0178	-21.2		12.7	0.0919		-0.034
	-0.115		-0.168	-41.15		-61.37	-0.112		-0.164
Religious Studies (N=1)	-0.156			-36.14			0.127		
	-0.161			-57.73			-0.157		
Psychology (N=38)	-0.049		-0.0501	-6.556		-8.256	0.0418		0.0452
	-0.033		-0.0362	-11.87		-13.23	-0.0323		-0.0354
Public Administration (N=20)	0.0745		0.103*	20.99		33.76*	-0.0703		-0.0999*
	-0.0411		-0.0431	-14.78		-15.76	-0.0402		-0.0422
Social Sciences (Other) (N=19)	-0.0417		-0.0177	-7.594		-1.306	0.0367		0.0126
	-0.057		-0.0651	-20.46		-23.78	-0.0557		-0.0637
Economics (N=39)	0.00644		0.0149	-0.407		4.145	-0.00466		-0.0145
	-0.0328		-0.0356	-11.78		-12.99	-0.0321		-0.0348
Health Professions (N=2)	0.143		0.124	33.33		51.97	-0.137		-0.135
	-0.115		-0.161	-41.15		-58.84	-0.112		-0.158
Business and Management (N=5)	0.0434		0.0317	2.38		-2.174	-0.0349		-0.024
	-0.0742		-0.0755	-26.65		-27.57	-0.0726		-0.0739
History (N=7)	-0.00485		-0.0294	-1.018		-9.634	0.00323		0.0274
	-0.0636		-0.0639	-22.87		-23.33	-0.0623		-0.0625
JD (N=3)	-0.0911		-0.144	-16.33		-32.59	0.0802		0.132
	-0.0943		-0.0957	-33.87		-34.96	-0.0922		-0.0937
Female (N=89)		-0.0557*	-0.0577*		-17.14*	-19.37*		0.0513*	0.0538*
		-0.0238	-0.0239		-8.627	-8.717		-0.0234	-0.0234
Asian (N=17)		-0.047	-0.0338		-21.33	-18.5		0.0519	0.0407
		-0.0427	-0.0432		-15.45	-15.79		-0.0418	-0.0423
Black (N=13)		-0.0282	-0.0172		-15.47	-13.02		0.0341	0.025
		-0.0477	-0.0473		-17.26	-17.26		-0.0467	-0.0463
Latino (N=16)		0.0451	0.0258		14.39	5.606		-0.0415	-0.0211
		-0.0444	-0.0438		-16.07	-16.01		-0.0435	-0.0429
Highest Degree Year		0.000637	-0.00126		0.009	-0.567*		-0.000492	0.00136
		-0.000673	-0.000774		-0.244	-0.283		-0.000659	-0.000757
Research Activity Level		0.0505	0.0413		5.178	2.309		-0.0417	-0.0333
		-0.0476	-0.0484		-17.24	-17.68		-0.0467	-0.0474
Student Population		-8.3E-07	-8.3E-07		-4.1E-04	-4.9E-04		8.3E-07	8.74E-07
		-1.4E-06	-1.4E-06		-0.0005	-5.2E-04		-1.4E-06	-1.4E-06
Private School		-0.00236	0.0139		-11.85	-5.284		0.0078	-0.00953
		-0.0331	-0.034		-11.97	-12.4		-0.0324	-0.0332
High Correspondence		-0.0463	-0.0822		-23.29	-38.88		0.0555	0.0929
		-0.135	-0.132		-48.7	-48.26		-0.132	-0.129
Not a Large 4 Year University		-0.0679	-0.0494		-16.98	-10.94		0.0624	0.0437
		-0.0558	-0.0555		-20.17	-20.27		-0.0546	-0.0543
Prof. Degrees Offered In Addition to PhD		0.00944	0.0121		-8.693	-11.18		-0.00164	-0.00522
		-0.0849	-0.091		-30.71	-33.25		-0.0831	-0.0891
Medical/Veterinarian School Present		-0.0072	0.0116		-0.415	4.577		0.00603	-0.0125
		-0.0292	-0.0303		-10.57	-11.07		-0.0286	-0.0297
Constant	0.589***	-0.754	2.984	62.75***	62.53	1192.5*	1.472***	2.498	-1.135
	-0.0206	-1.347	-1.541	-7.391	-487.4	-562.6	-0.0201	-1.32	-1.508
Observations	300	300	300		300		300	300	300
R-squared	0.09	0.049	0.157		0.043		0.085	0.046	0.157

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Compared to authors trained in Higher Education, authors trained in Psychology, Economics, and Sociology have significantly lower EC and BC, and a significantly higher CC, in the full model. For authors trained in Psychology, the coefficients for EC and BC decrease by 0.144 and 44.84, respectively, and for CC increases by 0.143. For authors trained in Economics, the coefficients for EC and BC decrease by 0.0786 and 32.44, respectively, and for CC increases by 0.083. And for authors trained in Sociology, the coefficients for EC and BC decrease by 0.0935 and 36.58, respectively, and for CC increases by 0.0975.

Thus, authors trained in Psychology, Economics, and Sociology, as compared to authors trained in Higher Education, are (1) less central and co-cited alongside authors who are less central to the network, (2) have a lower tendency to connect two authors who are not co-cited in the same articles, and (3) on average, relatively farther from all of the other authors in the network. Hence, in the intellectual canon of higher education research, trained psychologists, economists, and sociologists are significantly less central across multiple measures of centrality than their peers trained in Higher Education.

These findings remain when using Sociology as the base category. **Table 3B**, organized like Table 3A, summarizes results from the OLS regression models for each measure of centrality using authors trained in Sociology as the base category. Compared to authors trained in Sociology, authors trained in Higher education have significantly higher EC (0.0935) and BC (36.58), and a significantly lower CC (0.0975). Additionally, once covariates from the second model are added into the full model, authors trained in Education and Public Administration obtain significantly higher EC and BC and lower CC compared to authors trained in the degree concentration of Sociology. For authors trained in Education, the coefficients for EC and BC increase by 0.107 and 44.36, respectively, and for CC decreases by 0.110. For authors trained in

Public Administration, the coefficients for EC and BC increase by 0.103 and 33.76, respectively, and for CC decreases by 0.0999.

Thus, authors trained in Education and Public Administration, as compared to authors trained in Sociology, are (1) more central and co-cited alongside authors who are more central to the network, (2) have a greater tendency to connect two authors who are not co-cited in the same articles, and (3) on average, relatively closer to the other authors in the network. Hence, in the intellectual canon of higher education research, trained education and administrative scholars are significantly more central across multiple measures of centrality than their peers trained in Sociology.

Additionally, regardless of base category, women have a significantly lower EC and BC and significantly higher CC in both the partial and full models. "Younger" scholars also incur a loss in centrality, as a one-year increase in the year a degree was earned leads to a small but significant decrease in BC in the full models. Hence, in the intellectual canon of higher education research, women are significantly less central than their male peers; both women and younger scholars have significantly lower tendency to connect two authors across articles than their male and older peers, respectively.

Thus, we can reject **H1**. *Contrary to what I predict in H1, the centrality of scholars in the intellectual canon of higher education scholarship is significantly predicted by disciplinary background.*

Disciplinary differences in centrality become evident in the visualized network (**see Figure 1**). Authors trained in Economics and Psychology appear to cluster together on the periphery of the co-citation network, particularly in comparison to authors trained in Sociology and Higher Education. Such visible clustering occurs to a lesser extent for authors trained in

Sociology and Higher Education. This indicates that authors trained in Economics and Psychology have relatively more co-citations with authors from their respective disciplines. To examine if clustering is significantly distinguishable by disciplinary composition, I turn to an analysis of the co-citation network's communities.

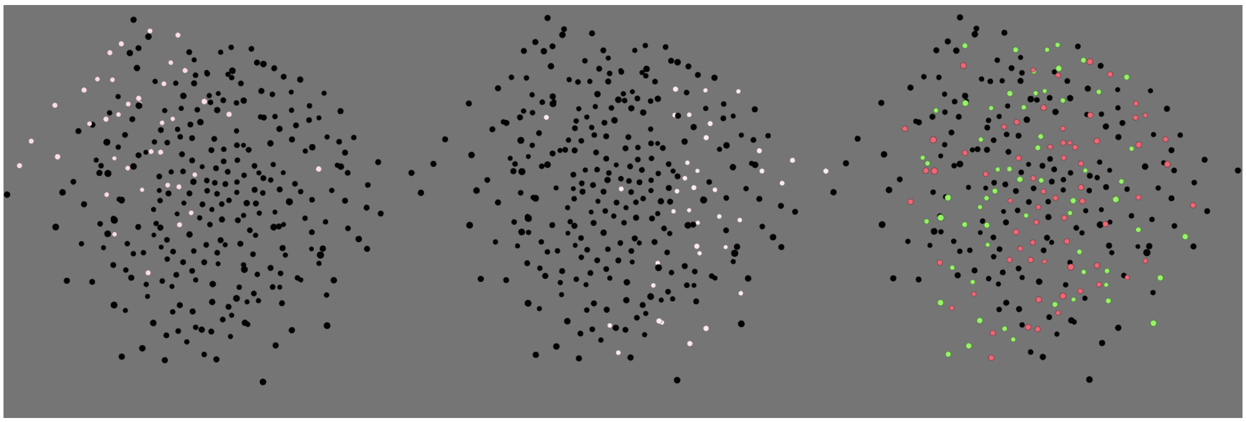

Figure 1. *The co-citation network of the intellectual canon. From left to right: authors trained in Psychology (white nodes), authors trained in Economics (white nodes), and authors trained in Sociology (green nodes) and Higher Education (red nodes).*

4.1.2. Disciplinary Network Community

The Louvain community detection algorithm identifies three distinct communities. **Table 4** tallies the number of scholars assigned to each community, separated by disciplinary training. A majority of authors trained in Psychology are situated in Community B, while a majority trained in Economics are situated in Community C.

Table 4. Louvain community assignment by degree field.

Highest Degree Field	**Community**		
	A	**B**	**C**
Unknown (N=6)	2	2	2
Communication (N=1)	0	1	0
Education (General) (N=19)	6	8	5
Educational Admin. (Higher Ed.) (N=66)	20	27	19
Educational Admin (Other) (N=15)	4	**9**	2
English and Liberal Arts (N=2)	1	1	0
Mathematics (N=5)	1	1	3
Interdisciplinary Sciences (N=2)	1	1	0
Religious Studies (N=1)	1	0	0
Psychology (N=38)	8	**28**	2
Public Admin. & Soc. Service (N=20)	6	2	12
Social Sciences (Other) (N=19)	3	3	3
Economics (N=39)	4	1	**34**
Sociology (N=60)	24	11	25
Health Professions (N=2)	1	0	1
Business and Management (N=5)	2	1	2
History (N=7)	**5**	0	2
JD (N=3)	3	0	0
Total	92	96	112

Table 5A-1 and **Table 5A-2** summarize the results from the ML regression models for Louvain community assignment using authors trained in Higher Education and communities C and B, respectively, as base categories. **Table 5B-1** and **Table 5B-2** summarize results using authors trained in Sociology and communities C and B, respectively, as base categories. All ML models include the full range of covariates included in the OLS regression models, but only display covariates for gender, race, and degree for simplicity. Significant coefficients of P-values equal to or less than alpha (α=0.001 or 0.01 or 0.05) are denoted by asterisks. The primary distinction between these two sets of models is which degree (Higher Education or Sociology) is used as the base category, and I describe results from the four tables in reference to these base categories.

Table 5A-1. Multinomial logistic regression using scholars trained in Higher Education and Community B as the base categories.

Compared to Community A		**Compared to Community C**	
Female (N=89)	1.005**	Female (N=89)	0.542
	-0.381		-0.404
Asian (N=17)	-0.785	Asian (N=17)	-0.167
	-0.697		-0.677
Black (N=13)	-1.499	Black (N=13)	-1.079
	-0.869		-0.797
Latino (N=16)	-0.909	Latino (N=16)	-0.442
	-0.739		-0.688
Unknown (N=6)	1.132	Unknown (N=6)	1.061
	-1.278		-1.277
Communication (N=1)	-16.24	Communication (N=1)	-16.11
	-4179.9		-3788.4
Education (General) (N=19)	-0.117	Education (General) (N=19)	-0.241
	-0.641		-0.656
Edu. Admin (Other) (N=15)	-0.884	Edu. Admin (Other) (N=15)	-1.385
	-0.706		-0.855
English and Liberal Arts (N=2)	-0.0637	English and Liberal Arts (N=2)	-14.68
	-1.497		-1642.5
Mathematics (N=5)	0.242	Mathematics (N=5)	1.38
	-1.465		-1.208
Interdisciplinary Sciences (N=2)	0.831	Interdisciplinary Sciences (N=2)	-14.33
	-1.517		-1629.7
Religious Studies (N=1)	17.16	Religious Studies (N=1)	0.532
	-4274.2		-5810.7
Psychology (N=38)	-1.070*	Psychology (N=38)	-2.397**
	-0.518		-0.799
Public Admin. & Soc. Service (N=20)	1.245	Public Admin. & Soc. Service (N=20)	2.019*
	-0.885		-0.83
Social Sciences (Other) (N=19)	0.609	Social Sciences (Other) (N=19)	0.51
	-0.906		-0.9
Economics (N=39)	1.727	Economics (N=39)	3.870***
	-1.165		-1.065
Sociology (N=60)	1.198*	Sociology (N=60)	1.198*
	-0.496		-0.49
Health Professions (N=2)	14.84	Health Professions (N=2)	15.01
	-1671		-1671
Business and Management (N=5)	1.132	Business and Management (N=5)	1.061
	-1.278		-1.277
History (N=7)	16.04	History (N=7)	15.05
	-1092.9		-1092.9
JD (N=3)	17.16	JD (N=3)	0.532
	-2467.7		-3354.8
Constant	-0.439	Constant	-0.368
	-0.364		-0.363
Observations	300		
Pseudo R-squared	0.212		

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Table 5A-2. Multinomial logistic regression using scholars trained in Higher Education and Community C as the base categories.

Compared to Community A		**Compared to Community B**	
Female (N=89)	0.463	Female (N=89)	-0.542
	-0.365		-0.404
Asian (N=17)	-0.618	Asian (N=17)	0.167
	-0.72		-0.677
Black (N=13)	-0.42	Black (N=13)	1.079
	-0.946		-0.797
Latino (N=16)	-0.468	Latino (N=16)	0.442
	-0.783		-0.688
Unknown (N=6)	0.0711	Unknown (N=6)	-1.061
	-1.07		-1.277
Communication (N=1)	-0.126	Communication (N=1)	16.11
	-5641.3		-3788.4
Education (General) (N=19)	0.124	Education (General) (N=19)	0.241
	-0.694		-0.656
Edu. Admin (Other) (N=15)	0.501	Edu. Admin (Other) (N=15)	1.385
	-0.933		-0.855
English and Liberal Arts (N=2)	14.62	English and Liberal Arts (N=2)	14.68
	-1642.5		-1642.5
Mathematics (N=5)	-1.138	Mathematics (N=5)	-1.38
	-1.21		-1.208
Interdisciplinary Sciences (N=2)	15.16	Interdisciplinary Sciences (N=2)	14.33
	-1629.7		-1629.7
Religious Studies (N=1)	16.63	Religious Studies (N=1)	-0.532
	-3936.5		-5810.7
Psychology (N=38)	1.326	Psychology (N=38)	2.397**
	-0.858		-0.799
Public Admin. & Soc. Service (N=20)	-0.775	Public Admin. & Soc. Service (N=20)	-2.019*
	-0.603		-0.83
Social Sciences (Other) (N=19)	0.0985	Social Sciences (Other) (N=19)	-0.51
	-0.9		-0.9
Economics (N=39)	-2.143***	Economics (N=39)	-3.870***
	-0.628		-1.065
Sociology (N=60)	0.0000226	Sociology (N=60)	-1.198*
	-0.45		-0.49
Health Professions (N=2)	-0.161	Health Professions (N=2)	-15.01
	-1.464		-1671
Business and Management (N=5)	0.0711	Business and Management (N=5)	-1.061
	-1.07		-1.277
History (N=7)	0.987	History (N=7)	-15.05
	-0.919		-1092.9
JD (N=3)	16.63	JD (N=3)	-0.532
	-2272.7		-3354.8
Constant	-0.0711	Constant	0.368
	-0.381		-0.363
Observations	300		
Pseudo R-squared	0.212		

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Table 5B-1. Multinomial logistic regression using scholars trained in Sociology and Community B as the base categories.

Compared to Community A		Compared to Community C	
Female (N=89)	1.005**	Female (N=89)	0.542
	-0.381		-0.404
Asian (N=17)	-0.785	Asian (N=17)	-0.167
	-0.697		-0.677
Black (N=13)	-1.499	Black (N=13)	-1.079
	-0.869		-0.797
Latino (N=16)	-0.909	Latino (N=16)	-0.442
	-0.739		-0.688
Unknown (N=6)	-0.066	Unknown (N=6)	-0.137
	-1.281		-1.28
Communication (N=1)	-17.44	Communication (N=1)	-17.31
	-4179.9		-3788.4
Education (General) (N=19)	-1.315	Education (General) (N=19)	-1.439*
	-0.686		-0.698
Edu. Admin. (Higher Ed.) (N=66)	-1.198*	Edu. Admin. (Higher Ed.) (N=66)	-1.198*
	-0.496		-0.49
Edu. Admin (Other) (N=15)	-2.082**	Edu. Admin (Other) (N=15)	-2.583**
	-0.756		-0.893
English and Liberal Arts (N=2)	-1.262	English and Liberal Arts (N=2)	-15.88
	-1.514		-1642.5
Mathematics (N=5)	-0.956	Mathematics (N=5)	0.182
	-1.474		-1.215
Interdisciplinary Sciences (N=2)	-0.367	Interdisciplinary Sciences (N=2)	-15.53
	-1.523		-1629.7
Religious Studies (N=1)	15.96	Religious Studies (N=1)	-0.666
	-4274.2		-5810.7
Psychology (N=38)	-2.268***	Psychology (N=38)	-3.595***
	-0.56		-0.824
Public Admin. & Soc. Service (N=20)	0.0467	Public Admin. & Soc. Service (N=20)	0.822
	-0.908		-0.851
Social Sciences (Other) (N=19)	-0.589	Social Sciences (Other) (N=19)	-0.688
	-0.914		-0.908
Economics (N=39)	0.529	Economics (N=39)	2.672*
	-1.18		-1.08
Health Professions (N=2)	13.65	Health Professions (N=2)	13.81
	-1671		-1671
Business and Management (N=5)	-0.066	Business and Management (N=5)	-0.137
	-1.281		-1.28
History (N=7)	14.84	History (N=7)	13.86
	-1092.9		-1092.9
JD (N=3)	15.96	JD (N=3)	-0.666
	-2467.7		-3354.8
Constant	0.759*	Constant	0.830*
	-0.377		-0.373
Observations	300		
Pseudo R-squared	0.212		

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Table 5B-2. Multinomial logistic regression using scholars trained in Sociology and Community C as the base categories.

Compared to Community A		Compared to Community B	
Female (N=89)	0.463	Female (N=89)	-0.542
	-0.365		-0.404
Asian (N=17)	-0.618	Asian (N=17)	0.167
	-0.72		-0.677
Black (N=13)	-0.42	Black (N=13)	1.079
	-0.946		-0.797
Latino (N=16)	-0.468	Latino (N=16)	0.442
	-0.783		-0.688
Unknown (N=6)	0.071	Unknown (N=6)	0.137
	-1.043		-1.28
Communication (N=1)	-0.126	Communication (N=1)	17.31
	-5641.3		-3788.4
Education (General) (N=19)	0.124	Education (General) (N=19)	1.439*
	-0.693		-0.698
Edu. Admin. (Higher Ed.) (N=66)	-0.0000226	Edu. Admin. (Higher Ed.) (N=66)	1.198*
	-0.45		-0.49
Edu. Admin (Other) (N=15)	0.501	Edu. Admin (Other) (N=15)	2.583**
	-0.937		-0.893
English and Liberal Arts (N=2)	14.62	English and Liberal Arts (N=2)	15.88
	-1642.5		-1642.5
Mathematics (N=5)	-1.138	Mathematics (N=5)	-0.182
	-1.195		-1.215
Interdisciplinary Sciences (N=2)	15.16	Interdisciplinary Sciences (N=2)	15.53
	-1629.7		-1629.7
Religious Studies (N=1)	16.63	Religious Studies (N=1)	0.666
	-3936.5		-5810.7
Psychology (N=38)	1.326	Psychology (N=38)	3.595***
	-0.846		-0.824
Public Admin. and Soc. Service (N=20)	-0.775	Public Admin. and Soc. Service (N=20)	-0.822
	-0.589		-0.851
Social Sciences (Other) (N=19)	0.0984	Social Sciences (Other) (N=19)	0.688
	-0.87		-0.908
Economics (N=39)	-2.143***	Economics (N=39)	-2.672*
	-0.605		-1.08
Health Professions (N=2)	-0.161	Health Professions (N=2)	-13.81
	-1.458		-1671
Business and Management (N=5)	0.071	Business and Management (N=5)	0.137
	-1.043		-1.28
History (N=7)	0.987	History (N=7)	-13.86
	-0.888		-1092.9
JD (N=3)	16.63	JD (N=3)	0.666
	-2272.7		-3354.8
Constant	-0.071	Constant	-0.830*
	-0.297		-0.373
Observations	300		
Pseudo R-squared	0.212		

Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

First, the results suggest that these assignments are significantly associated with disciplinary training. First, scholars trained in Psychology have a greater relative risk of belonging to Community B. Compared to those trained in Higher Education, for scholars trained in Psychology, the relative risk of belonging to B over C and B over A increases by a factor of 2.397 and 1.070, respectively. Holding Sociology as the base category, the relative risk of belonging to B over C and B over A increases by a factor of 2.143 and 1.198, respectively. Hence, in the intellectual canon of higher education research, trained psychologists appear to significantly cluster in Community B relative to peers trained in Higher Education and Sociology.

Second, scholars trained in Economics have a greater relative risk of belonging to Community C. Compared to those trained in Higher Education, for scholars trained in Economics, the relative risk of belonging to C over B and C over A increases by a factor of 3.870 and 2.143, respectively. Holding Sociology as the base category, the relative risk of belonging to C over A and C over B increases by a factor of 2.143 and 2.672, respectively. Hence, in the intellectual canon of higher education research, trained economists appear to significantly cluster in Community C relative to peers trained in Higher Education and Sociology.

Finally, compared to scholars trained in Sociology, scholars trained in Educational Administration, Higher Education, and Education have a greater relative risk of belonging to Community B. For scholars trained in Educational Administration, the relative risk of belonging to B over A and B over C increases by a factor of 2.082 and 2.583, respectively. For scholars trained in Higher Education the relative risk of belonging to B over C and B over A increases by a factor of 1.198. For scholars trained in Education the relative risk of belonging to B over C increases by a factor of 1.439. Hence, in the intellectual canon of higher education research, scholars trained in Educational Administration, Higher Education, and Education appear to significantly cluster in Community B relative to peers trained in Sociology.

Thus, we can reject **H2**. *Contrary to what I predict in H2, the clustering of scholars in the intellectual canon of higher education scholarship is significantly predicted by disciplinary background.*

4.2. Interdisciplinarity as the Intermixing of Ideas

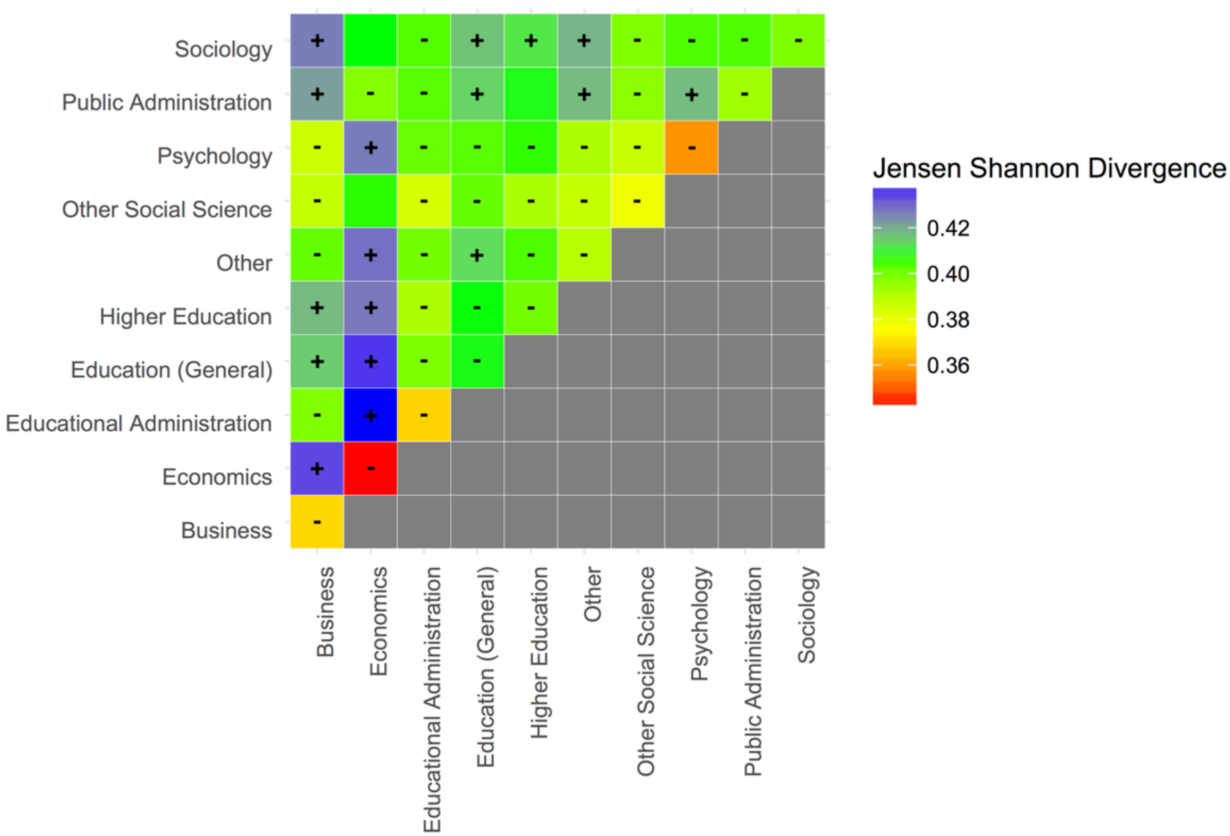

Figure 2*. Heatmap comparing average JSD between articles by first author discipline.*

Figure 2 represents a heatmap visualizing the mean JSD between degree concentrations for a 20-topic topic model. Each shaded cell represents mean JSD between the degrees identified by the row and column degree labels. Warmer colors such as red and yellow represent relatively smaller JSD, or lower average dissimilarity. Cooler colors such as green and blue represent relatively larger JSD, or greater average dissimilarity. Positive signs indicate a significantly higher average divergence, and negative signs a significantly lower average divergence, when compared to the population average using Welch's t-test (P-value less than α=0.05). No sign indicates no significant difference. These comparisons are symmetric along the diagonal, so only one half of the heatmap is displayed for clarity.

The composition of LDA topics used by scholars trained in Economics, and to a lesser extent Business, have inter-average JSD measures that tend to be significantly higher than the population average. Thus, the composition of LDA topics used by these scholars tend to be, on average, relatively more dissimilar across different disciplines.

Additionally, intra-average JSD measures across all scholars tend to be significantly lower than the population average. Thus, the composition of LDA topics used by scholars tend to be, on average, relatively more similar within the same discipline. This effect is most pronounced for scholars trained in Economics, Psychology, Educational Administration, and Business. These findings are robust and remain in models with a higher number of LDA topics.

Thus, we can reject **H3**. *Contrary to what I predict in H3, the use of cognitive frames in higher education scholarship significantly diverges by disciplinary background.*

5. Discussion and Conclusion

From a Mertonian perspective, contemporary higher education scholarship is far from a truly interdisciplinary enterprise. Its intellectual canon features the work of Higher Education scholars most centrally. Yet it sequesters the contributions of trained economists and psychologists into disciplinary silos. Specifically, scholars trained in Higher Education are more central than their peers trained in Psychology, Economics, and Sociology, while scholars trained in Public Administration are more central than their peers trained in Sociology. Additionally, scholars trained in Economics and Psychology are significantly grouped into distinct canonical clusters.

A Geertzian perspective both reinforces and complicates this conclusion. Specifically, scholars trained in Economics and Business use cognitive frames that are relatively dissimilar to those used by peers outside their respective disciplines. Everyone, on average, uses cognitive frames that are relatively similar to those used by peers from the same discipline. This effect is most pronounced for scholars trained in Economics, Psychology, Educational Administration, and Business. However, scholars trained in Psychology, Educational Administration and social sciences other than Economics or Sociology use an assortment of frames that are, on average, *relatively less dissimilar* to those used by peers across disciplinary borders. How scholars trained in Psychology use cognitive frames does not reflect the disciplinary clustering of canonical psychologists.

Taken together, the Mertonian and Geertzian approaches to interdisciplinarity provide evidence for critically reevaluating interdisciplinarity of higher education scholarship. Its intellectual canon centers the work of scholars trained in Higher Education, lending systematic evidence in support of the belief that Higher Education has become a discipline in its own right (Terenzini 1996; Kimball and Friedensen 2019). At the same time, the clustering of economists and psychologists in this canon reinforces claims that disciplinary thinking persists (Eisenmann 2004; Renn 2020). Indeed, when examining the intermixing of knowledge in higher education scholarship, scholars trained in Economics and Business use cognitive frames that significantly diverge from those used by peers outside their disciplines. However, this is not true for all other scholars, including those trained in Psychology. Thus, while higher education scholarship exhibits disciplinary bias in how it uses its intellectual canon, and while some scholars use cognitive frames specific to their disciplinary peers, studies of higher education exhibit some degree of interdisciplinary integration. For those seeking to promote interdisciplinary scholarship, however, scholars trained in Economics and Business may benefit from adopting the cognitive frames used by their peers; scholars more generally may benefit from centering the canonical works of psychologists and economists.

Higher education scholarship as a revelatory case demonstrates that two divergent approaches to interdisciplinarity can provide complementary yet distinctive insights, even in situations where interdisciplinarity is taken-for-granted. Scholars and practitioners may use the Mertonian and Geertzian approaches to more consciously define, assess, and facilitate interdisciplinary scholarship.

First, both approaches offer a foundation for organizing studies of interdisciplinarity on the basis of how interdisciplinarity is conceptually defined: as the intermixing of disciplinary actors or the intermixing of ideas across disciplinary actors. These definitions do not invalidate the work of developing fine-grained conceptual distinctions between different categories of interdisciplinary work (e.g., Huutoniemi et al. 2010; Klein 2017). Nor do they replace the work of identifying conditions that foster successful interdisciplinary projects (e.g., Lamont, Mallard, and Guetzkow 2006; Mansilla, Lamont, and Sato 2016). However, they provide a way to delineate between different traditions of scholarship on interdisciplinarity, such as the approach assumed by the information sciences and the approach assumed by STS and sociology. The latter's Mertonian emphasis on actors does not substitute for the former's Geertzian emphasis on ideas, and there remains ample opportunity unexplored here for conceptual crosspollination.

Second, both approaches offer complementary indicators to assess the interdisciplinarity of scholarship. The Mertonian approach assesses the interdisciplinarity of the intellectual canon upon which it is built; the Geertzian approach assesses the interdisciplinarity of the cognitive frames that make up the content of its knowledge. While Mertonian and Geertzian studies often assess interdisciplinarity at different levels of analysis, these approaches are not incompatible. Rather than characterize interdisciplinarity on a global level across thousands of scholarly journals, a study leveraging the Mertonian approach can go local by identifying the intellectual canon of a collection of scholarly works that is meaningful to a given community. Conversely, a study leveraging the Geertzian approach can analyze the use of cognitive frames across this collection systematically and for purposes of comparison. In the present study, I compile a collection of data from three journals that are meaningful because of their status and widespread use and among scholars who study higher education (Bray and Major 2011). By shifting communities (e.g., scholars versus practitioners) or corpora (e.g., top journals versus standard curricular textbooks), however, one may embed the study of interdisciplinarity in different scholarly contexts for different audiences.

Finally, both approaches offer measures based on an operationalization that is practical and readily interpretable: the Mertonian approach analyses cited authors, while the Geertzian approach analyses the topical content of published works. Practitioners seeking to promote interdisciplinary scholarship may potentially facilitate interventions by adapting these units of analysis as a guide. I speculate on what such interventions would look like in the context of two scholarly areas: academic journals and interdisciplinary curriculum.

Academic journals may encourage authors to review relevant works others from their discipline have historically neglected to cite. This move is particularly appealing given the recent adoption of journal citation diversity statements (Zurn, Bassett, and Rust 2020), wherein authors are encouraged to describe potential sources of bias in the sources they cite. Additionally, journals may propose issues that address gaps in the literature created by the disciplinary segregation of cognitive frames, using LDA topics as a guide.

Conversely, interdisciplinary programs may encourage students to combine cross-disciplinary canonical works that are otherwise independently clustered. Likewise, they may develop curricula that bring studies grounded on the use of divergent cognitive frames into conversation. These interventions are apt, given evidence that the primary action educators take to facilitate interdisciplinary research is curriculum development (National Academy of Sciences 2005: 66). They may even serve as the basis for creating new programs and majors in the arts, humanities, and social sciences (Brint et al. 2009). Interdisciplinary program development has become an engine for establishing new training programs, hiring new faculty (University of Michigan 2010), promoting the global competitiveness of American education (U.S. Department of Education 2016), and shaping the future of education and research. Theoretically driven partial indicators of interdisciplinarity and corresponding metrics grounded in empirical research offer a means to reach agreement over what interdisciplinarity means and how we might assess it.

One limitation of my study is its reliance on first authors to identify the author of an article. While this would be a problem for publications where authors are listed alphabetically, the journals included in this study list authors based on contribution. Another limitation is that its bibliographic and article corpus overlap but do not fully coincide. Relatedly, authors must be cited in at least 15 different articles alongside at least 1 other author in the bibliographic intellectual canon to be included. Both of these decisions were motivated by pragmatic reasons.

Manually correcting and disambiguating bibliographic data and collecting biographical data are time-intensive tasks that will be addressed in the future with the creation of cross-linked article-scholar databases (Cronin and Sugimoto 2015). However, it is unlikely that extending the bibliographic corpus to perfectly overlap with the article corpus will change the composition of the intellectual canon. The mean, median, and modal year each scholar in the canon received his/her/their highest degree is 1979, 1979.5, and 1996, respectively. This suggests that extending the range limits of the bibliographic corpus by 3 years will not lead to a drastic change in the canon, short of an anomalous mass citation of a new author.

Additionally, my study relies on the use of non-ambiguous disciplinary categories. I take direction from my case: higher education scholars and practitioners use disciplinary categories (e.g., Sociology, Economics, Psychology) to make sense of intellectual divisions in the research literature (Kezar 2000: 451), while researchers who study the interdisciplinarity of higher education scholarship use disciplinary categories and standard taxonomies (Biglan 1973; Silverman 1987; Laird et al. 2008; Holley 2009; Brint et al. 2009; Knight et al. 2013). Thus, my framework may be less relevant to the analysis of intellectual "fields" (e.g., health policy, artificial intelligence, social theory) or domains of knowledge that preclude disciplinary classification (Huutoniemi et al. 2010). However, despite desires to shift the study of interdisciplinarity away from disciplines toward shared questions or problems that address a domain of knowledge, disciplines and disciplinary categories are unlikely to lose scholarly relevance. Disciplines endure because they maintain authority over the academic labor market, house a large share of undergraduate majors, and are established across multiple universities (Abbott 2001: 208-210). Disciplines give academics a lineage, a common set of research practices, and a general reason for intellectual existence. It is difficult to discuss interdisciplinarity without disciplines not because of a lack of imagination, but because disciplines remain relevant to how universities, funding agencies, policy makers, and scholars understand and organize scholarly work (Jacobs 2013).

Finally, the Mertonian and Geertzian approaches by no means describe the entire theoretical foundation upon which studies of interdisciplinarity stand. An exhaustive review of how studies of interdisciplinarity define the concept is beyond the scope of my study. Extant reviews suggest interdisciplinarity is largely defined as the integration of disciplines (Lattuca 2001: 78; Klein 2017: 23). Yet, this begs the question: the integration *of what*? The two traditions of analysis outlined here offer studies of interdisciplinarity greater precision by defining interdisciplinarity in terms of the intermixing of disciplinary actors or the intermixing of ideas across disciplinary actors. They may not capture the intermixing of disciplinary knowledge and practices that are difficult to formalize, codify, and make explicit. However, they offer a foundation for coordinating, operationalizing, and comparing two ways to assess the interdisciplinarity of scholarship.

ARTICLE 3

A Visual Approach to Interpreting the Career of Metaphor

1. Introduction

Metaphors are pervasive in everyday life as they are in sociological theory. More than a way to express a rhetorical flourish, metaphors structure our perceptions and embody values that we live by (Lakoff and Johnson 1980). Metaphors arise when a concept from one conceptual domain, or set of interrelated concepts, is viewed in terms of the properties of another. Metaphors, and the domains of knowledge they mobilize, impact how we think, act, make sense of experience, and create social theory. Whether we are putting *intersectionality* into practice (Crenshaw 1989), at home on a *second shift* (Hochschild and Machung 1989), or a member of the *creative class* (Florida 2002) seeking to address questions with broader cultural *resonance* (Snow et al. 1986), social scientific metaphors form the currency of theorizing and can live public lives beyond the ivory tower if we are so lucky (Hallett, Stapleton, and Sauder 2019).

Despite all this work, tracing the core dynamics of metaphors over time remains a persistent challenge. Metaphors may ground our perception and sense of the world, but their meanings may change as they are used to describe new experiences or understand the world in a new light. To address this problem, I propose a systematic analysis of metaphor anchored around four core questions: *What do metaphors describe? How do metaphors change over time? What do metaphors do? And how do conventional metaphors emerge?*

To answer my questions, I take inspiration from studies of metaphor, ideas, and careers to offer a formal model in the tradition of Mohr and Rawlings (2012) of the *career of metaphor***.** Specifically, I draw on cognitive linguistics and sociological theories of public ideas and professional careers to develop four core representational constructs that constitute the career of metaphor: its *jurisdiction* (Abbott 1988), *temporality* (Blumer 1971; Hallett, Stapleton, and Sauder 2019), *ecology* (Abbott 2005), and *conventionality* (Gentner and Bowdle 2001; Bowdle and Gentner 2005). I use each core construct to develop a proposition for each question.

I address my questions and develop my propositions in the context of the network metaphor using the Google Books Ngram corpus as my source of data. I leverage the network metaphor as both a revelatory and critical case (Yin 1994). A revelatory case provides an opportunity to explore a previously inaccessible phenomenon, while a critical case provides an opportunity to test and reexamine an established idea in a new light. As a metaphor, the network provides a revelatory case for examining what metaphors do and describe and how they change and conventionalize. The network metaphor has had a long and ubiquitous career, occupying what Jagoda (2016) calls an imaginary that informs our thinking and experience of the contemporary social world. I use the career of such a persistent and prolific metaphor to evaluate my methodology. As an historical object, the network metaphor provides a way to critically reappraise our understanding of the network against an established canon of historically oriented work (Mattelart 1999; Boltanski and Chiapello 2005; Castells 2010; Jagoda 2016). I integrate the Ngram corpus with computational techniques that leverage co-occurrence to operationalize each core construct into a heuristic with measurable and visual forms, which I use to derive my four propositions into four hypotheses.

As a revelatory case, my findings provide a demonstration of and lend validation to my model. I show that metaphors describe not isolated concepts, but multiple distinct domains that can be operationalized as Louvain communities within a co-occurrence network of terms. Yet, metaphors can demonstrate both incremental and notable changes within this network, corresponding to annual changes in how they are used. If what a metaphor does is understanding and experiencing one thing in terms of another, I show that metaphors stand in for an evolving set of symbols that can be operationalized as its nearest neighbors in neural embedding space. And metaphors conventionalize in the long run by creating a new cognitive category of meaning, involving a shift in linguistic expression from comparison form in simile ("*like a* network") to categorization form in metaphor ("*is a* network").

As a critical case, my findings corroborate historical arguments about the concept of the network, but also raise questions about the dynamism of networks that cannot be fully addressed with a history limited to the contemporary period. My analysis of the entire Ngram corpus lends validation to the argument that the network metaphor has achieved the status of a broad category for thinking about contemporary life, including relationships, infrastructures, and flows. However, it also demonstrates that the network metaphor had a lively history prior to the twentieth century. This includes significant changes in how it was used in the first half of the nineteenth century, a career standing in for anatomical structures of the body in the mid-nineteenth century, and a predominant expression in simile form prior to the start of the twentieth century.

The *career of metaphor* provides a theoretical model with a computational operationalization, offering an actionable methodology that is portable to settings where metaphors can be used as a lens to systematically analyze meaning. Furthermore, it provides experimental studies of metaphor a methodology for constructing sets of metaphors that can vary by conventionality and aptness of use. Finally, by addressing what metaphors describe and do and how they change and conventionalize, my core constructs engage in the poetic approach to text analysis that John Mohr argued to be the promise of computational hermeneutics (Mohr and

Rawlings 2012; Mohr et al. 2013; Wagner-Pacifici, Mohr, and Breiger 2015; Breiger, Wagner-Pacifici, and Mohr 2018).

2. The Dynamics of Metaphor

Metaphor comes from the Greek work *metaphorá,* meaning "to transfer." By aligning two conceptual domains, metaphors invite us to see and evaluate one domain of experience in terms of another (Black 1962; Hesse 1966). In doing so, we generate new knowledge, insight, and meanings irreducible to those of the parent domains. An oeuvre of empirical work across the social sciences attests to the importance of metaphors in influencing how we think, act, make sense of experience, and create social theory. Metaphors anchor our understanding of the social world (Kane 1997; Ignatow 2003; Kharchenkova 2018), can enable and constrain organizational change and innovation (Etzion and Ferraro 2010; McDonnell and Tepper 2014), and can significantly impact decision-making in social policy (Thibodeau and Boroditsky 2015). While metaphors can put blinders on how we think and theorize (Keller 1995; Mohr 2005), they can also provide a model for generating theory (Griswold 1987) and have a profound effect on how our ideas are received (Hallett, Stapleton, and Sauder 2019).

A persistent challenge in sociological studies of metaphor is accounting for the dynamism of its subject. Metaphors evolve over time (Colyvas 2007), evoking associations that arise through practical use (Kane 1997) that are far less coherent than typically assumed (Massengill 2008). Philosopher Mary Hesse (1988), arguing against the presupposition in the analytic philosophy of language that its descriptive tools were literal, stable, and univocal, makes this point precisely. For Hesse, all language is metaphorical and is constituted by a changing and holistic network of meanings (3). While a metaphor can evoke a whole network of associated metaphors, it can also shift in meaning in undesired or unexpected directions over time or when applied beyond familiar contexts.

An example of Hesse's insight can be readily observed in the history of the production metaphor in the context of contemporary biotechnology (Colyvas 2007). Universities embraced metaphors of production in the 1970s to hail the advent of academic patenting, but with mixed results. On one hand, scientists became pioneering "genetic *engineers*" (150) and bacteria became "genetic *factories*" (148) that created important therapeutic "*products*" (150) (proteins). On the other hand, commercialization inspired new anxieties: from concerns among scientists that industry partnerships created "*hazards*" that contaminated academic science (156-157), to fears among environmental activists that genetic engineering resulted in "genetic *pollution*" (Schurman 2004: 254). The production metaphor in biotechnology invoked a network of associations (factories, pollution, engineering, hazards) that evoked unexpected meanings (promise, danger) when it was applied to new contexts (academia, activism).

For Hesse (1988), a solution to the destabilizing dynamism that metaphor introduces into philosophical analysis is to ascribe truth-value to metaphoric statements within a given "social network of conventions" (14). Although a metaphor and its associations are dynamic, its meaning can be located in its use within a given cultural vernacular. Lakoff and Johnson (1980) echo this view, arguing more broadly that if there if there is an absolute truth to a definition of a concept, it is relative to the conceptual system of a culture (193). However, Lakoff and Johnson are primarily concerned with theorizing the experiential basis of metaphor—how it structures how we perceive, think and act in the world – while Hesse offers her claims as a prolegomena for developing a more adequate theory of metaphor.

I take this invitation as a starting point for theorizing metaphor as both a stable and dynamic cultural form by asking four core questions. What do metaphors describe? How do metaphors change over time? What do metaphors do? And how do conventional metaphors emerge? To answer my questions, I offer a formal model of the *career of metaphor*.

3. The Career of Metaphor: Formal Functions and Core Constructs

3.1 Formal Models

A formal model as outlined by Mohr and Rawlings (2012) reduces a collection of data into a set of structure-preserving features using formal pattern analysis procedures (71). In doing so, it performs four functions. A formal model *represents*, providing theoretical constructs that condense social complexity into a measurable simplicity. It does so on the basis of a *heuristic*, which operationalizes and anchors our thoughts into an understanding that gathers bits of information into an aggregate formation. In aggregating information, it has the *power* to "extend our thoughts into material space" (73) to achieve greater impact through what I define as forms of measurement and visualization. Finally, it has a *sociality* in that it derives from work and data produced by scholarly communities invested in the craft of computational research.

Representation	Heuristic	Measurement	Visualization	Sociality
Jurisdiction	Semantic Network	Co-Occurrence Network, Modularity	Force-Directed Graph	Research on semantic networks and graph drawing.
Temporality	Annual Relative Change in Use	Pairwise Annual Distances	Heatmap	Research leveraging distance metrics.
Ecology	Similar Word Embeddings	K-Nearest Neighbors in Neural Embedding Space	2-Dimensional T-SNE Embedding	Research on neural networks and dimensionality reduction techniques.
Conventionality	Simile versus Metaphor	Relative Use of Form	Stacked Area Chart	Humanistic approaches to text analysis.

Table 1. A formal model for the career of metaphor.

I propose a formal model of the career of metaphor (**Table 1**) that performs these four functions using a collection of data comprised of over 8 million published books in English. Like other models constructed on the basis of a large, general corpus of published works, my model and data offer a way to characterize the "supra-individual" (DiMaggio 1997) or "public" (Lizardo 2017) dynamics of metaphor by aggregating individual declarative expressions (i.e., linguistically articulated) of personal culture. I make this point to emphasize that the career of metaphor like other models built on "big data" does not necessarily offer a neutral presentation of reality (Wagner-Pacifici, Mohr, and Breiger 2015) that exists in the minds of all individuals (J. L. Martin 2010). A model constructed on the basis of published books and periodicals in English is by no means representative of the cultural vernacular of the general public or of cultural phenomena that elude linguistic articulation. Following Kozlowski, Taddy, and Evans' (2019) analysis of the same corpus, my model examines the dynamics of metaphors in the vernacular of the U.S. literary public, a limited but by no means inconsequential population.

Drawing inspiration from cognitive linguistics and sociological theories of public ideas and professional careers, I develop four core representational constructs that constitute the career of metaphor, and I use each construct to develop a proposition for each core question. A metaphor's *jurisdiction* addresses the question as to what metaphors describe, its *temporality* the question as to how metaphors change, its *ecology* the question as to what metaphors do, and its *conventionality* the question as to how conventional metaphors emerge.

3.2. Jurisdiction

Careers have jurisdictions describing the activities that fall under their claimed areas of work (Abbott 1988: 59). These sets of activities are defined through a fundamentally interrelational process of competition. Furthermore, the organization of work within a jurisdiction has an internal structure (79) that reflects the differentiation of work. Cognitive linguistics offers insight into this idea through the concept of domains. In cognitive theory, a domain refers to an experiential gestalt, a structured whole that labels and gives organization to experience (Lakoff and Johnson 1980: 177). In cognitive experiments, a domain refers to a set of interrelated objects and attributes evoked in the mind of an individual (Gentner 1983:156). In both, the unit of an analysis is an individual's mental schemata.

A jurisdiction has an internal structure that consists of what I conceptualize as multiple domains. Activities that share similar patterns of occurrence give rise to a domain, but also relationships between domains. Each domain labels and gives organization to work within the jurisdiction. For example, within a profession one may find groups of activities organized around the domains of lobbying, educational training, or practitioner control.

Metaphors are constantly put to work by individuals who use them to describe and make sense of experience. This work, inclusive of the symbols and relationships between them, constitutes what I define as a metaphor's jurisdiction. This jurisdiction can be organized by sets of interrelated activities, or domains, that can be treated as structured wholes.

To address the question as to what metaphors describe, I use a metaphor's jurisdiction to propose the following proposition:

> *P1: If a metaphor describes not isolated concepts but entire domains of experience structured through use (Lakoff and Johnson 1980: 117), a metaphor's jurisdiction consists of multiple distinct and interrelated domains. Comprised of sets of interrelated symbols, domains describe how a metaphor is used to make sense of experience.*

3.3. Temporality

Careers have a periodic temporality, an "ebb and flow" (Hallett, Stapleton, and Sauder 2019: 546), that reflects change in how they are put to work. How society comes to define a social problem (Blumer 1971) or how public mediators use sociological ideas (Hallett, Stapleton, and Sauder 2019) is a process that unfolds over time.

A career's ebb and flow correspond to changes in how its subject is put to work. Hallett, Stapleton, and Sauder (2019) conceptualize the ebb and flow of public ideas in terms of a shifting binary between two analytical abstractions: whether an idea is the subject of the news or whether it is used to make sense of the news. Here, the use of an idea changes with the passage of time.

I refine this idea by suggesting that change is relative: careers have ebbs *in relation* to their flows or have peaks because they have plateaus. I treat ebb and flow, or *temporality*, as a construct that captures relative change over an entire career. A metaphor's temporality captures change in how it is put to work in its jurisdiction, relative to another point in time. How it is put to work depends on the kind (and degree) of activities that comprise its jurisdiction at a given point in time.

To address the question as to how metaphors change over time, I use a metaphor's temporality to propose the following proposition:

> *P2: If a metaphor can evolve to become polysemous* (Bowdle and Gentner 2005) *and the meaning of a symbol changes through use* (Mohr 1998)*, a metaphor's temporality identifies relative changes in its jurisdiction (i.e., how it is used to make sense of experience) over time.*

3.4. Ecology

Careers have ecologies that are linked through competition (Abbott 2005). An individual ecology comprises a complex interactional structure filled with subgroups that compete for and do the same work (Abbott 2005: 247). Ecologies are not static structures and can evolve over time.

For the purpose of this paper, a metaphor's ecology comprises the set of symbols that "compete" or stand in for the same work. These symbols perform similar duties in language and can include synonyms, metonyms, and synecdoches, but also antonyms (e.g., hot and cold both work to describe personalities, weather, or states of activity) and other symbols that work with similar sets of symbols. Symbols of an ecology share similar syntactic environments, analogous to nodes of a network that share similar social environments or structural equivalence. However, a metaphor's ecology can evolve over time, and with it the symbols that most closely compete with it. For example, the ecology of the word *gay* in the 1950s consisted of words such as healthy, bright, witty, or frolicsome (Kulkarni et al. 2015; Hamilton, Leskovec, and Jurafsky 2016). By the 1990s, its ecology had evolved, such that it more closely competed with words like lesbian, gays, transgender, and homosexual.

To address the question as to what metaphors do, I use a metaphor's ecology to propose the following proposition:

> *P3: If the essence of a metaphor is understanding and experiencing one thing in terms of another* (Lakoff and Johnson 1980: 5)*, a metaphor's ecology comprises an evolving set of symbols that compete for work by performing similar duties (as in meaning) in language.*

3.5. Conventionality

The concept of metaphor conventionality, as developed in the field of cognitive linguistics (Gentner and Bowdle 2001), refers to the extent to which the use of a metaphor comes to yield the same basic interpretation regardless of the context in which it is used. This analytic distinction is important because it implies a cognitive shift in how a metaphor is understood. As a novel metaphor conventionalizes through instruction or repeated use, it shifts from evoking cognitive processes of comparison to processes of categorization (Bowdle and Gentner 2005).

Conventionality so defined raises an analytic puzzle: how does a novel metaphor come to evoke a seemingly fixed category in the minds of a *multiple* individuals? This question is best addressed by the sociological solution to the problem of emergence. Here, seemingly fixed objects like careers emerge and congeal in a process that plays out over time. In the short run, a career relies on the active work of individuals, who must constantly defend its jurisdiction in relation to other competing careers. In the long run, a career becomes an established and enduring social structure in its own right (Abbott 2005: 245; Padgett and Powell 2012: 2). Conventionalized careers evoke an established category of work.

I conceptualize a metaphor's conventionality by integrating these two ideas. In the short run, a (novel) metaphor *evokes a comparison* between base and target domains that yields an abstract relational schema. In the long run, this abstract relational schema comes to stand in as a category elicited by the base. Here, the (conventional) metaphor *evokes a categorization* of the target as a member of the base.

To address the question as to how conventional metaphors emerge, I use a metaphor's conventionality to propose the following proposition:

> *P4: If a conventional metaphor creates a new category of meaning through repeated use* (Bowdle and Gentner 2005) *and social structures like new categories emerge over the long run, then a metaphor's conventionality emerges over time through repeated use.*

4. Case, Corpus, and Methodology

4.1. Case

I address and develop my propositions using the case of the network metaphor. I select the case of the network metaphor with two goals in mind. I use the network metaphor as revelatory case for evaluating the career of metaphor, as it represents a persistent and prolific metaphor with a dynamic history that spans several centuries. However, in the spirit of treating computational text analysis as a complement to a close reading rather than a substitute (Mohr et al. 2013; Breiger, Wagner-Pacifici, and Mohr 2018), I use the career of the network metaphor as a critical case for reappraising our understanding of the network.

"Network" originates from the sixteenth century as an amalgamation of the words "net" and "weorc" (Jagoda 2016). Its literal definition refers to a material object in which treads or wires were interlaced into an intersecting arrangement, such as fabric (9). The network of the mid-eighteenth century, as exemplified in Diderot and Alembert's *Encyclopaedia*, still revolved exclusively around the concept of thread (Mattelart 1999: 170). However, as Mattelart (1999) argues, the "image" of the network was present much earlier: in the seventeenth century, the Italian physician Marcello Malphigi described an anatomical tangle of lines he noticed on the epiderm as a "reticular body", while French military engineers described underground military fortifications as a complex system of "arteries". Nonetheless, by the nineteenth century, the term came to denote technological systems: communication systems such telecommunication lines and media, and transportation infrastructures such routes and railways.

By the twentieth century, the network came to refer to a concept that could describe anything from the brain to the economy to geopolitics to the earth. According to Boltanski and Chiapello (2005), the network and its logic of connection became a normative model for organizing the city. Inspired by management literature, the "projective" city replaced centralized hierarchies of governance with projects: projects that brought a variety of people together to work in teams, encouraged people to become networkers, and equated progress to a never-ending succession of interconnected projects. The rise of network science, the Internet, neoliberalism, and the postindustrial economy in the 1990s, however, fortified the status of the network as fundamental to life in the twenty-first century (Jagoda 2016: 11). Network metaphors for connectivity, complexity, and interdependence entered into mass culture across novels, television shows, and digital media. If the network was not simply a way to describe the activities of contemporary societies, it became a natural feature of the world (Boltanski and Chiapello 2005: 150) and, "in essence, the fabric of life" (Lima 2011: 69).

From our extant histories and appraisals, the network has had a dynamic career comprising moments of stability and change over the course of several centuries: from denoting an intersecting arrangement of fabric in the sixteenth century, to living ecologies and biological structures in the seventeenth century, to technological systems in the nineteenth century, to entire social and technical worlds in the twentieth century. I make use of a large corpus of publications to inductively characterize and explore the career of the network metaphor, and to compare and contrast it to our received understandings about the concept.

4.2. Corpus

The data I use to model the career of the network metaphor draws from the Google Books Ngram corpus (Michel et al. 2011). The latest iteration of the corpus is comprised of n-grams, or segments of words 1 to 5 terms in length, from over 8 million books in English primarily spanning the period 1800 to 2000. I draw on the complete, 5-gram English corpus released in 2012. A majority of the books in the corpus are provided by university libraries, ultimately at the decision of authors, editors, and publishers. Each book represents one and only one copy of the book. Only n-grams that occur in at least 40 books are included in the corpus. As a result, the Ngram corpus should not be treated as an unbiased sample upon which one can draw definitive inferences about cultural popularity or linguistic evolution (Pechenick, Danforth, and Dodds 2015). Its overrepresentation of scientific works, particularly since the 1980s, presents challenges to studies of contemporary shifts in language and culture.

With these considerations in mind, however, the n-grams corpus provides an unparalleled resource for examining diachronic change. It offers linguistics and the cultural sciences a valuable tool for characterizing semantic laws (Hamilton, Leskovec, and Jurafsky 2016) and cultural meaning (Kozlowski, Taddy, and Evans 2019). The language of networks, in particular, cannot be understood independent of the culture of the U.S. literary public: from the network and information sciences (Castells 2010; Jagoda 2016) to the social sciences more broadly (Boltanski and Chiapello 2005). Since contemporary appraisals primarily focus on changes in the latter-half of the twentieth century, the Ngram corpus provides more than an adequate basis for a revelatory illustration and critical comparison.

4.3. Methodology

I operationalize my core constructs by integrating the Ngram corpus with computational techniques that leverage co-occurrence, translating each heuristic into its measurable and visual forms (see Table 1). I use each measurement as a basis for developing my propositions into hypotheses, which I test by visualizing each core construct using the case of the network metaphor.

4.3.1. Jurisdiction: Semantic Network

An individual uses a metaphor as they/he/she sees fit, identifying relationships between some symbols at the expense of others. Words, or terms, are symbols that are related to one another through their joint use, or co-occurrence, in a linguistic expression. Terms that co-occur with a metaphor comprise the activities of its *jurisdiction* in the mind of the individual. Within the jurisdiction, terms that share similar patterns of co-occurrence share a similar domain. A supra-individual (DiMaggio 1997) or public (Lizardo 2017) career emerges as more individuals put the metaphor to work in systematically similar ways.

Net of all individual uses of a metaphor, I treat co-occurring terms as nodes and shared patterns of co-occurrence as ties in a *semantic network* that represents a metaphor's supra-individual jurisdiction. Terms that systematically share similar patterns of use, co-occurring with similar interrelated sets of terms, share a domain of work. This operationalization follows from the relational axiom that symbolic forms gain meaning in relationship to other forms through use by social actors (Somers 1995; Mohr and Duquenne 1997; Brieger 2000; Lee and Martin 2018; Fuhse et al. 2020).

Domains have interpretive value insofar as they are able to organize a metaphor's jurisdiction into structured wholes. An emphasis on interpretability imposes a limit on the number of terms (and their interrelationships) one can consider. I focus only on frequently co-occurring terms and observe only those ties of a given degree of similarity that maximizes both the number of ties and the number of terms per domain.

I measure term relationships within a metaphor's semantic network by constructing a weighted co-occurrence network, and I identify and measure the number of domains in the semantic network by the number of Louvain communities (Blondel et al. 2008). To generate a co-occurrence network, I first isolate a subset of 5-grams containing the term network. Each 5-gram in this subset represents a linguistic expression, used by any number of authors, that puts the metaphor to work. Second, I isolate the top 1,000 terms V over the subset of 5-grams. I select V after discarding punctuation and stop words. This subset of terms comprises a set of activities that frequently occur under the metaphor's jurisdiction. Third, I then generate a co-occurrence matrix whereby terms i and j (i, j) in V are considered joint if they co-occur in the same n-gram. I measure co-occurrence frequency $f_{i,j}$ of (i, j) across n-grams, based on the number of books that contain each n-gram, summed across years. Fourth, I generate a proximity score $w_{i,j}$ for

(i,j) in V, yielding a proximity matrix $W_{i,j}$. I calculate $w_{i,j}$ using the cosine similarity of (i,j) based on each term's co-occurrence frequencies across V. Thus, each term has ties to all the other terms in the metaphor's jurisdiction, weighted by $w_{i,j}$.

Finally, given that virtually none of the term pairs in V have a tie weight of zero, I follow Rule, Cointet, and Bearman (2015) and sparsify $W_{i,j}$ using a threshold that maximizes the number of distinct domains and the number of connected terms. This threshold takes the form of $\log(\mathrm{n}) * \mathrm{modularity}$ (Hoffman et al. 2018), where n represents the number of connected terms and modularity represents the quality of the network partitions or communities computed on the basis of the Louvain algorithm (Blondel et al. 2008). I identify 8 Louvain communities from the largest connected component that I take to represent 8 different domains. The advantage a network approach to meaning (over bag-of-words approaches like topic models) is that it offers a way visualize and interpret the internal structure of domains and their positions relative to one another (Lee and Martin 2015). I visualize the co-occurrence network using the ForceAtlas2 algorithm (Jacomy et al. 2014) where I color nodes by domain, and I identify relationships between domains on the basis of their positions relative to one another.

With measures of a metaphor's jurisdiction so defined, I address the question as to what metaphors describe by reformulating my first proposition (P1) into the following hypothesis:

> *H1: A metaphor describes multiple distinct Louvain communities of interrelated terms. Comprised of sets of terms related by similar patterns of use measured by cosine similarity, communities can be interpreted to describe how a metaphor has been used over a corpus of publications to make sense of experience.*

4.3.2. Temporality: Annual Relative Change in Use

The temporality of a metaphor's career depends on relative changes in how it is put to work. I take the set of *terms* comprising a metaphor's supra-individual jurisdiction to represent the set of ways it can be put to work at any given point in time. I operationalize temporality as the relative change in the set of term frequencies over time.

Following Hallett, Stapleton, and Sauder (2019), I observe the temporality of a career by *year*. Net of all individual uses of a metaphor, years in which a metaphor works in vastly different ways demonstrate a greater relative change than years in which the work of the metaphor converges. Following Rule, Cointet, and Bearman (2015), I identify years marking relatively notable change by comparing use before and after each year.

I measure annual relative changes in use of a metaphor by calculating a matrix comprised of pairwise annual distances. To calculate pairwise annual distances, I first isolate annual term frequencies for the set of terms V. I use the subset of 5-grams containing the term network and count term frequency by number of books. I treat each year as a vector of terms V weighted by frequency. Second, I calculate the relative change between each year for over two centuries of the n-grams corpus. Specifically, I calculate pairwise cosine distances between annual vectors from 1800 to 2008, yielding a temporality matrix. Finally, I identify relatively notable changes in use by partitioning the temporality matrix following the method outlined by Rule, Cointet, and Bearman (2015). I visualize the temporality matrix as a heatmap, where the temporality of the metaphor's career can be seen in the colored cells above and below the main diagonal.

With measures of a metaphor's temporality so defined, I address the question as to how metaphors change over time by reformulating my second proposition (P2) into the following hypothesis:

> *H2: A metaphor's meaning changes incrementally, annually. This change corresponds to the relative change in the frequencies of terms that frequently co-occur with the metaphor, measured by pairwise annual cosine distances.*

4.3.3. Ecology: Similar Word Embeddings

A metaphor co-occurs with terms that comprise its jurisdiction. But the terms that comprise its jurisdiction may co-occur alongside terms *other than* the metaphor. These terms constitute the set of symbols in the metaphor's ecology: terms that may not necessarily co-occur together, but nonetheless share similar lexical contexts or *similar distributions in embedding space* across many linguistic expressions. The evolution of a metaphor's ecology corresponds to changes in the terms that are closest to it in embedding space, over time.

I measure similarity in word embeddings and identify terms in a metaphor's ecology by computing the k-nearest neighbors by cosine distance relative to the metaphor's neural embedding space. I follow Hamilton, Leskovec, and Jurafsky (2016) and use neural embeddings that correspond to sequential decades of the Google Books corpus. To construct my embeddings I use skip-gram with negative sampling [SGNS], a variant of word2vec (Mikolov et al. 2013) that has been widely used to characterize both language and culture (Hamilton, Leskovec, and Jurafsky 2016; Kozlowski, Taddy, and Evans 2019). SGNS learns embeddings on the basis of optimizing the prediction of a target term's context terms within a given fixed-length window (skip-gram) and ensuring that its predicted probability for a random sample of "negative" terms that never co-occur with the target term is small (negative sampling).

The goal of SGNS is to learn a dense, low-dimensional embedding vector of numerical weights for each term in the corpus. This vector represents the term's location in embedding space, contingent on the data used to train the model. Twenty models trained on 20 sequential decades of the corpus will learn 20 different embeddings for each term. Differences between sequential embeddings for a given term follow from changes in its co-occurrence with other terms over time. Terms that occur in similar contexts will share similar distributions in embedding space. As a result, I use embeddings to identify a metaphor's ecology, and I use sequential embeddings to characterize how its ecology evolves over time.

I follow Hamilton, Leskovec, and Jurafsky (2016) and use pre-trained and pre-aligned embeddings trained on decade-long time-periods over the entire span of the corpus. I extract the learned weights from these embeddings and use them to characterize the changing embedding space of the network over sequential decades.

To visualize the metaphor's changing ecology and location in embedding space, I reduce the dimensionality of the space using the t-distributed neighbor embedding [t-SNE] visualization algorithm (Maaten and Hinton 2008). Specifically, I visualize semantic change conditioned on the term network. First, I compute the cosine distance between its embeddings and identify its nearest neighbors across consecutive time-periods. Next, I compute the t-SNE embedding of these words, while optimizing a new t-SNE embedding for each time period to visualize shifts in the embedding space of the network. Given changes in semantic meaning, the position of the term network should shift around a two-dimensional background of associated terms.

With measures of a metaphor's ecology so defined, I address the question as to what metaphors do by reformulating my third proposition (P3) into the following hypothesis:

> *H3: A metaphor can stand in for other terms, occupying similar lexical contexts that correspond to quantitatively similar distributions in embedding space and can change over time.*

4.3.4. Conventionality: Simile vs Metaphor

Assuming that linguistic form reflects cognitive function, I operationalize conventionality as a shift from a metaphor's linguistic expression in simile to its expression in metaphor. While the simile form of metaphor ("like a") evokes a comparison, its metaphor form ("is a") evokes categorization. An increasingly conventional metaphor should witness an increasing preference for the latter over the former (Gentner and Bowdle 2001; Bowdle and Gentner 2005).

I measure the conventionality of a metaphor by counting and comparing the annual number of times “like a network” and “is a network” appear in books in 5-grams across the corpus. Furthermore, I visualize conventionality by plotting the relative frequency of each form per year using a stacked area chart.

With measures of a metaphor’s conventionality so defined, I address the question as to how conventional metaphors emerge by reformulating my fourth proposition (P4) into the following hypothesis:

> *H4: A metaphor’s conventionality emerges over time, involving a shift in its linguistic expression from its comparison form in simile (“like a”) to its categorization form in metaphor (“is a”).*

5. Results

5.1. What does the network metaphor describe?

As hypothesized by **H1**, the network metaphor describes not an isolated concept, but several distinct domains operationalized here as Louvain communities. **Figure 1** visualizes the supra-individual jurisdiction of the network metaphor as a semantic network. Nodes represent symbol colored on the basis of Louvain community or domain, while ties represent relationships between symbols that co-occur with other symbols in similar ways. After filtering symbols with no ties to the largest connected component of the network, the aggregated matrix of co-occurring terms across the entire Google Books corpus consists of a network of 864 nodes, 4281 ties, and 8 domains. Each domain has an internal structure consisting of a central set of symbols and sets of relationships with other domains. I interpret what each domain describes on the basis of its central symbols, and I interpret relationships between domains on the basis of their relative position in the network's jurisdiction.

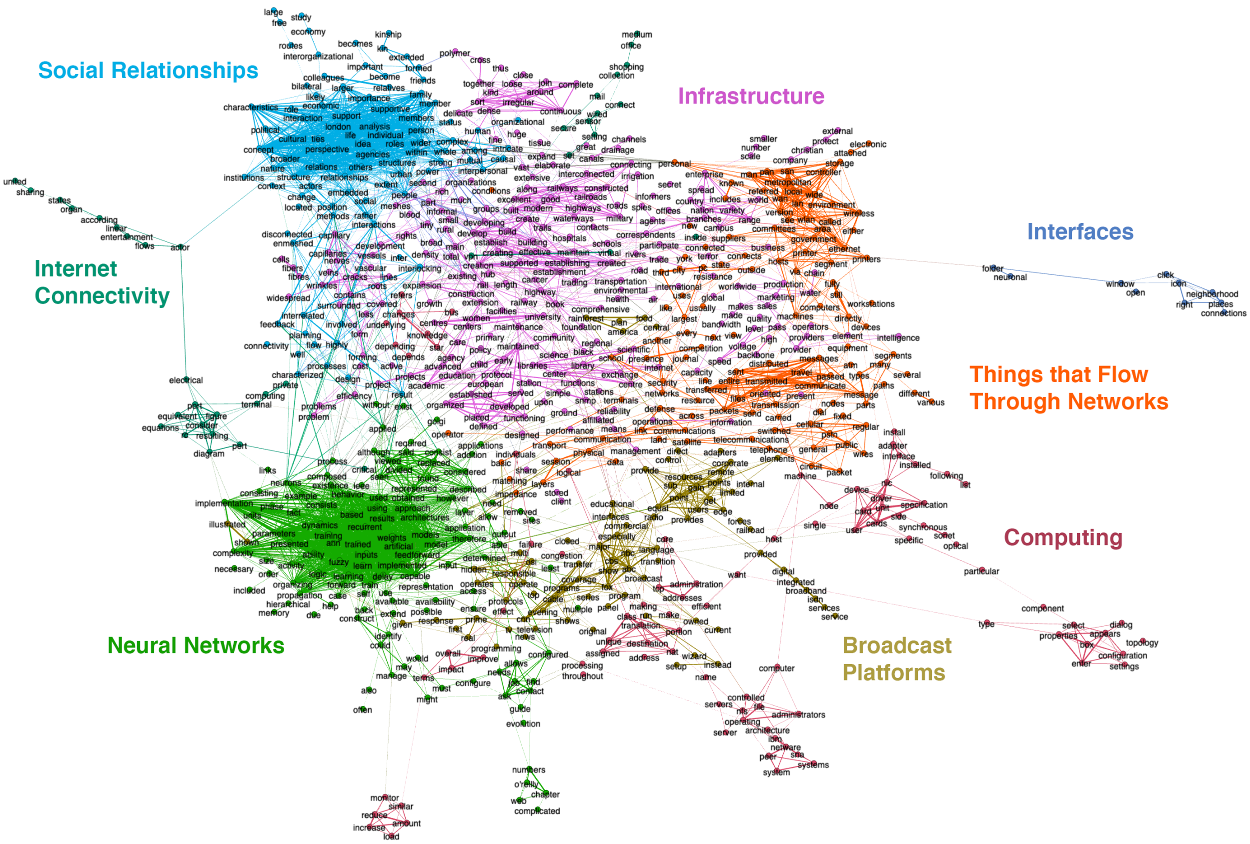

Figure 1. The network metaphor's jurisdiction.

The most densely interconnected domain represents artificial *neural networks*. The domain with the largest number of nodes consists of terms denoting forms of *infrastructure*: from environmental (railways, highways, and waterways), organizational (hospitals, centers, and university), social (agents, women, spies), to biological (capillaries, tissue, nerves). Nestled next to this domain is one denoting *social relationships*, signified by symbols such as friends, interaction, relationships, interpersonal, and ties.

Two domains representing *broadcast platforms* and *computing* are nestled next to a large domain representing *objects that move or flow through networks*: from files, data, and packets, to terrorists, knowledge, and messages. A broader domain points to *internet connectivity* (connect, VPN, virtual) while a smaller one contains *interfaces* (click, icon, window).

My findings both lend validation and some specificity to our understanding of the network metaphor. As expected, the network metaphor operates in domains far beyond its original, literal use describing netlike meshes. While half are domain-specific, involving neural networks and various information technologies, the other half are general and relate to anything involving infrastructure and social relations or objects and measures of movement. The generality of the latter corroborates the argument that the network has become a normative concept (Boltanski and Chiapello 2005: 141) that lacks what Jagoda (2016: 5) calls a "descriptive edge": it has become a cliché symbol used to describe anything in its jurisdiction from natural structures or infrastructural technologies like markets, laws, or policies to qualities of interconnection. At the same time, the network metaphor has its descriptive limits. Net of all its linguistic instantiations, I interpret it to have three domain-general conceptual (Lakoff and Johnson 1980) forms: relationships are networks, infrastructures are networks, and movements are networks. How the U.S. literary public thinks about these three broad domains of knowledge is intertwined with the concept of the metaphor.

5.2. How does the network metaphor change over time?

As hypothesized by **H2**, the meaning of the network metaphor, here operationalized by term co-occurrence, demonstrates incremental annual changes. These changes represent relative changes in how the network metaphor has been put to work to make sense of experience. **Figure 2** visualizes the temporality of the network metaphor as a heatmap. Darker purple cells and lighter yellow cells represent relatively similar and different patterns of use between years, respectively. When read vertically (top to bottom) or horizontally (left to right), continuous shades of color indicate moments of stability in patterns of use, while sudden or gradual changes in color indicate change in patterns of use. I identify four notable changes in the network metaphor's career since 1800 that are robust to different sizes of V.

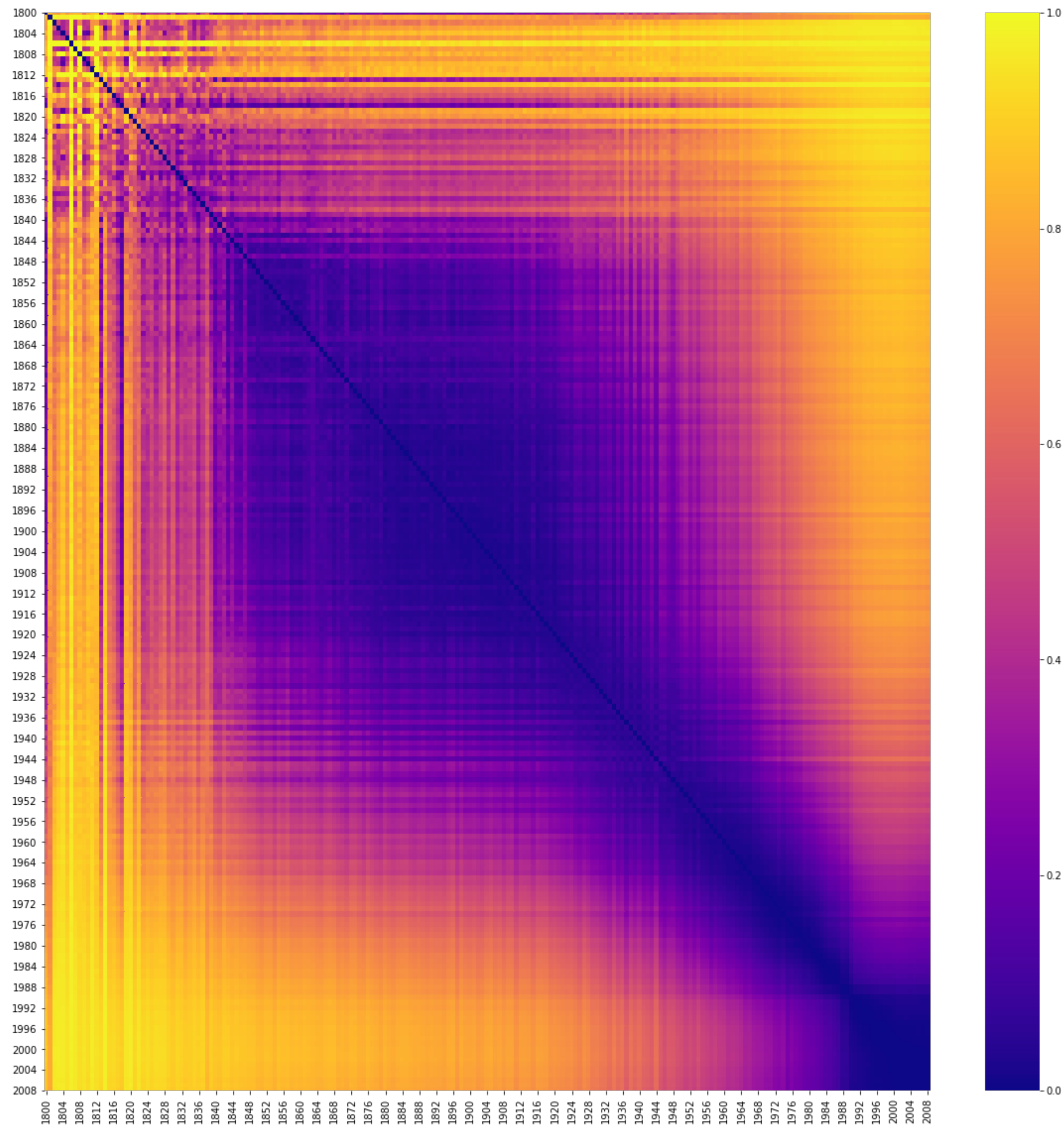

Figure 2. The network metaphor's temporality.

Three of these changes correspond to three moments in the historical narrative of the network metaphor: World War II, the Cold War, and the 1990s. The Second World War witnessed major technological breakthroughs at the core of the Information Technology Revolution (Castells 2010: 39) and the emergence of general systems theory across academia (Jagoda 2016: 11). Cold War cybernetics and the desire to create automated systems of control produced new forms of observation, rationality, and economy enabled by multiple network forms: neural networks, cities, and communication networks, among others (Halpern 2015). And the 1980s and 1990s heralded "networking" as the dominant information technology paradigm in business (Liu 2004) and the popularization of the Internet.

The period of change around 1813 to 1840, however, is novel and less easily interpretable. While its origins date back to the sixteenth century, histories of the network concept focus largely on the period of development following World War II. Indeed, (Castells 2010) argues that the Information Technology Revolution marked a departure from the Industrial Revolution by introducing a networking logic that connected the world through information. Mattelart (1999) provides an exception, but focuses on the emergence of the optical telegraph, railway and other forms of communication in nineteenth century France. However, as the network metaphor's ecology suggests, changes in the network of the nineteenth century might have less to do with communication or information technologies and more to do with its time describing anatomical systems in the body.

5.3. What does the network metaphor do? How has this changed over time?

As hypothesized by **H3**, the network metaphor stands in for an evolving set of competing symbols, here operationalized as its nearest neighbors by cosine distance in embedding space. This set is robust to the use of different distance cutoff and focal time points. **Figure 3** visualizes the network metaphor's evolving ecology as a two-dimensional map. I interpret what the network metaphor does vis-à-vis the symbols it stands in for at various points in its career.

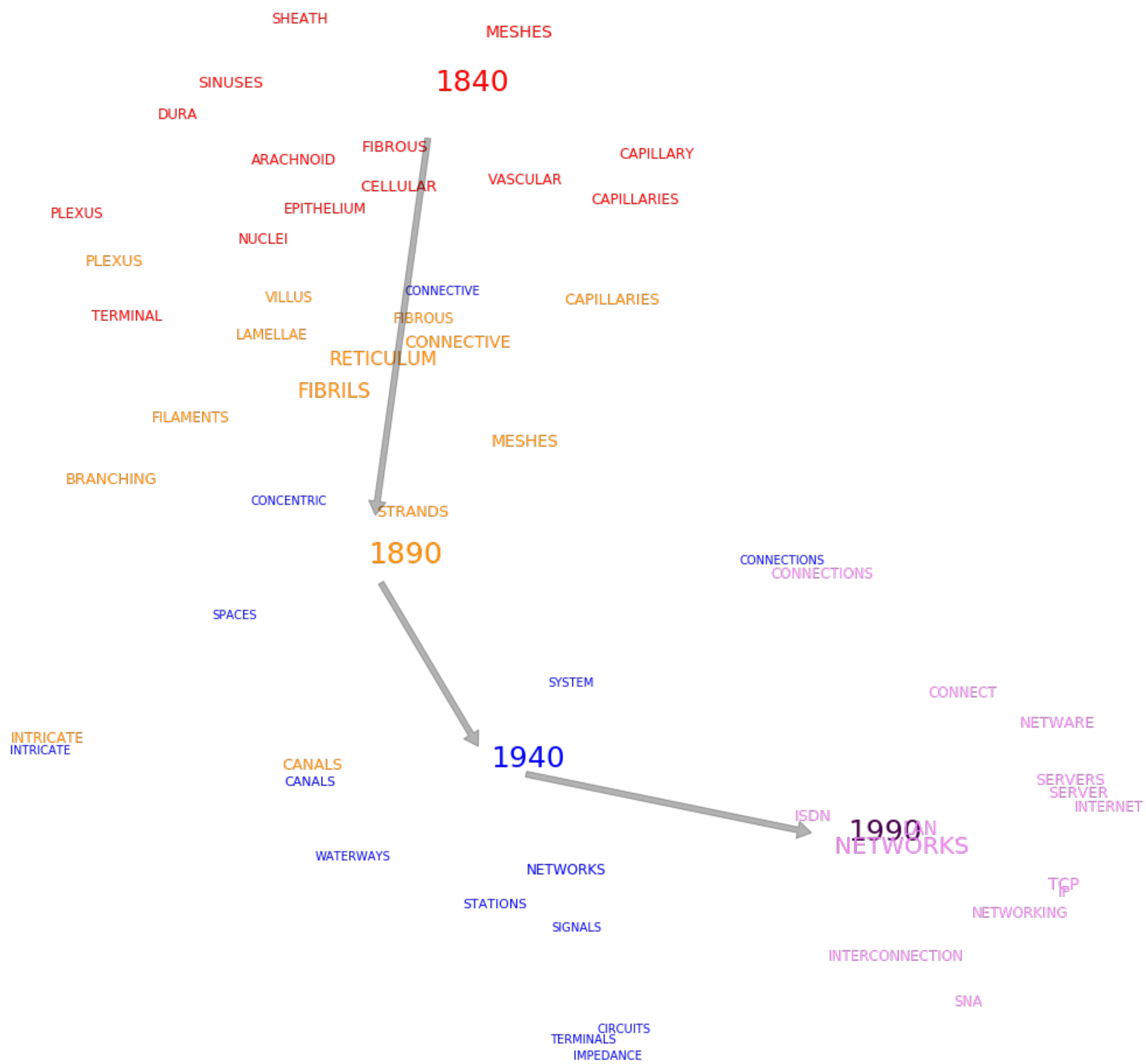

Figure 3. The network metaphor's ecology. Words that are closer to the path of the network metaphor, denoted by the blue line, are closer in embedding space**.**

The early ecology of the network metaphor involves an array of symbols that appear to be specific to a single domain: the body. The network of the mid to late-nineteenth century stands in for various anatomical structures: from membranes such as arachnoids (brain and spinal cord), epithelium (internal and external bodily surfaces), reticulum (stomach), villus (finger-like protrusions in the intestine), and lamellae (bone), to anatomical features that branch and intersect such as plexus (originates from *Latin* as literally a plaited formation), capillaries, and fibrils.

The network metaphor appears to gain a new understanding of what it can do by jumping from nonliving meshes to living bodies. In addition to *interweave* (a figurative sense derived from the network's literal meaning), the network metaphor can also *conduct flows*. Networks not only interweave, intersect, branch, or mesh structures, but also deliver essential liquids such as mucus, nutrients, and blood. It is important to note that while the network metaphor's anatomical emphasis may be an effect of Google Books' bias for scientific and medical texts, these anatomical associations disappear by the end of the nineteenth century. Furthermore, the network continues to conduct flows, albeit of different kinds, well into the end of the twentieth century: from liquids in canals and waterways in the 1940s, to signals in circuits or servers in the 1990s.

The network metaphor takes on a more intangible ecology in the twentieth century. While it extends to particular material infrastructures (of flow) such as canals and waterways, it also stands in for more general symbolic concepts such as spaces, connections, intricate, and system. The network metaphor *emplaces*, *connects*, *makes complex*, and *systematizes*. Such broad and abstract doings demonstrate how the network embodies what scholars describe as a paradox: networks are at once both concrete and abstract, both intimate and distant (Halpern 2015; Jagoda 2016). While the network metaphor's jurisdiction may describe concrete features of social life with which one may be intimately familiar (friends, telephones, roads), its ecology makes an abstraction of these features. For example, the network emplaces highway infrastructures, connects radio broadcasts, makes flows of knowledge complex, and systematizes social relationships based on interaction. As Jagoda (2016: 164) notes, there is an "extimacy" to the network in that it exteriorizes intimate life, complicating the distinction between the internal, individual, and self and the external, general, and other. A road, radio station, idea, or personal interaction may have their own peculiarities, but these features can be subsumed when evaluated in terms of the network metaphor.

Consistent with the career hypothesis (Bowdle and Gentner 2005), which posits that as a metaphor conventionalizes its original literal meaning is lost, the network's ecology is absent of material structures such as meshes, strands, or filaments beyond the mid-twentieth century. By the end of the twentieth century, the network metaphor extends into new technological ecologies, such as the internet (LAN, servers, IP), as well as academic ones with the rise in prominence of social network analysis. Here, the network metaphor comes to systematize and connect not meshes or fabrics, but machines and people.

5.4. How did the conventional network metaphor emerge?

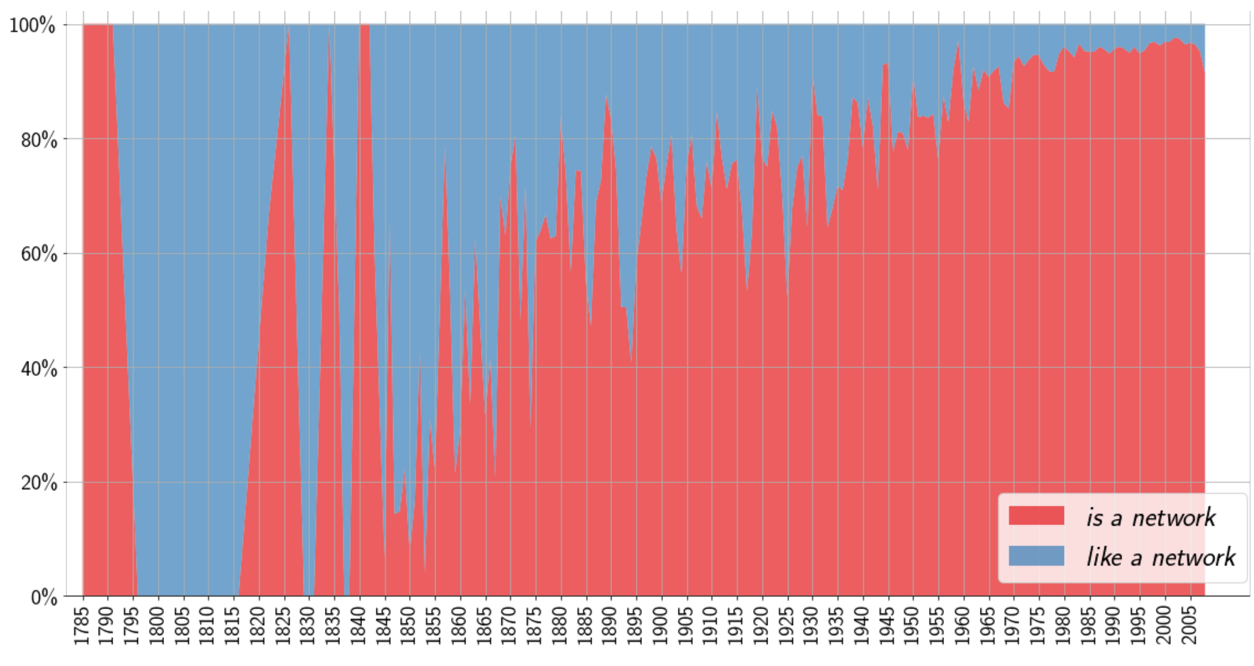

Figure 4. The network metaphor's conventionality, over time.

As hypothesized by H4, the network metaphor demonstrates a gradual but definite shift from novelty to conventionality. **Figure 4** visualizes the conventionality of the network metaphor. In the earliest years recorded in the corpus, the network metaphor vacillates between its expression in simile ("like a network") versus metaphor ("is a network") form. However, by the beginning of the twentieth century, the network metaphor is expressed primarily as a categorization.

6. Discussion and Conclusion

As a critical case, the career of the network metaphor corroborates our understanding that the network describes vastly different social and technical domains, changing notably in moments corresponding to World War II, the Cold War, and the 1990s to become a conventional metaphor for rendering the world in abstract terms. However, it also draws our attention to the dynamics of the network prior to the twentieth century. It highlights a curious time in the network's career, where it was used as a metaphor for anatomical structures that not only interweave but also conduct flows of vital liquids. A more comprehensive account of the network that exhausts all the possibilities enabled by the concept will need to examine its history before the contemporary period, when the network metaphor was still a novelty. Given that metaphors impact how we think and theorize (Keller 1995; Mohr 2005), the benefits of this exercise extends beyond historicization and into how we theorize metaphorically. The relational turn in sociology (Emirbayer and Goodwin 1994) establishes that a network is not simply a static structure, but a constantly changing and dynamic flow (White 2008: 4), channel (Fuhse 2015: 15), or conduit (Lizardo 2006: 779) through which identities, expectations, cultural forms, and other objects move. The contemporary network is alive and dynamic, and it is likely that its time in the body contributed to this figurative meaning.

As a revelatory case, the career of the network metaphor demonstrates how a formal model of metaphor may act upon insights proposed in the philosophy of language to address a fundamental problem in the empirical study of metaphor. The career of metaphor offers an actionable methodology that accounts for the dynamism of metaphor that is portable to settings where metaphors can be used as a lens to systematically analyze meaning. As developed here, I capture the dynamism of a metaphor's jurisdiction, temporality, ecology, and conventionality (relative to the U.S. literary public) by examining its changing patterns of co-occurrence with other symbols across time. Future studies that leverage the duality of culture (Mohr and Duquenne 1997; Brieger 2000) would benefit by examining relationships between actors based on shared metaphorical expressions. Such an approach may bring us methodologically closer to indexing the worldviews (Lakoff and Johnson 1980; Ignatow 2003) implicit in the use of linguistic metaphor.

Furthermore, the career of metaphor provides cognitive and psychological studies a methodology for constructing experimental sets of metaphors. Conventionality is important because it impacts how a metaphor is cognitively processed (Gentner and Bowdle 2001; Bowdle and Gentner 2005). My model offers a parsimonious measure of conventionality as an alternative means to construct sets of conventional metaphors without relying on static lists or artificial simulations of conventionalization. Additionally, my model offers a means of constructing sets of metaphorical expressions that vary on the basis of aptness, or the degree to which the figurative meaning of the metaphorical base describes a relevant feature of the target (Jones and Estes 2006). Here, my model offers two means of formalizing the aptness of a metaphorical expression: in terms of whether it involves target symbols from the metaphor's jurisdiction, or whether the base metaphor is being used in a manner consistent with the symbols in its ecology. For example, metaphorical expressions such as *a network of hospitals*, *political networks*, or *an efficient network* are more apt than *a network of sanitariums*, *voter suppression networks*, or *a* *tired network* because they involve targets derived from the metaphor's jurisdiction. Likewise, *data flows through the network* or *a sparse network of friends* are more apt than *data drifts through the network* or *a flat network of friends* because the network metaphor in the latter expressions does not do what is done by its ecology: conduct flows or emplace objects across space.

Finally, by addressing what metaphors describe and do and how they change and conventionalize, the career of metaphor engages in a more poetic and hermeneutical approach to text analysis. In the spirit of Paul Ricoeur, it sets forth rules required for the interpretation of metaphor on the basis of written documents. As I demonstrate, these rules provide a complement rather than substitute to modes of interpretation that rely on the close reading of text. While formal models of text may know less about syntax, semantics, and other features of language than a human reader, it is precisely because of their denaturalized quality that they are useful. Text provides a key source of semantically rich data, produced in volumes that enable us to examine entire socio-cultural realms but are otherwise analytically intractable on the basis of close reading. By parsing text in search of a theory-driven set of features, formal models of culture like the career of metaphor can help us corroborate, challenge, or refine our ground truths and assumptions. Yet, as John Mohr's oeuvre of work attests, formal models are not mere extensions of our ability to count and categorize. As much as they provide a basis for the measurement of meaning, formal models push us to specify precisely the meaning of our measurements. In doing so, they provide a form of scholarly practice that can push us to coordinate, develop, and refine our theories of meaning.

THEORIZING IN THE AGE OF COMPUTATIONAL SOCIAL SCIENCE

By situating ideas about social structure, interdisciplinarity, and the network metaphor in their respective historical, theoretical, and cultural lineages, my dissertation broadens our understanding of the emergence of SNA, measures of interdisciplinarity, and the meaning of linguistic metaphor. In doing so, my dissertation advances theory through or about formal and computational methods in a way that Robert K. Merton would endorse.

Formal and computational methods open up new forms of analysis by revealing patterns otherwise unknowable: from networks of relationships, disciplinary patterns of citation, to century-long shifts in the use of metaphor. While these methods are persistently critiqued for their inability to generate social theory, some contemporary scholars have argued that computational methods may even change how we theorize social life (Evans and Foster 2019; Edelmann et al. 2020). My dissertation, which takes a Mertonian approach to theorizing, offers an entry into the conversation about the capabilities of formal and computational methods.

Merton was among the most notable and central figures in sociology to argue for an approach to theorizing that treated theory not as parochial collections of ideas, but as a means to create a series of progressively systematic, interconnected, and precise propositions for explaining empirical data. Merton (1968[1949]) made this point in his most cited work, *Social Theory and Social Structure*, but it was echoed by a range of scholars like Howard S. Becker and Talcott Parsons.[44] For Merton and his contemporaries, building a core set of sociological theories was essential if the discipline wanted to find a place among the various social sciences (Parsons 1948) and vitalize sociological theory (Becker 1954).

---

[44] Becker and Parsons credited Merton for this approach to theorizing.

Merton believed that theorizing necessitated the creation of "systematic links to the past" (Merton in Swedberg 2019: 102). Theories offered a resource for new ideas when read in the context of contemporary knowledge (Merton 1968: 37-38).[45] Reanalyzing the series of decisions underlying a sociological theory, such as re-specifying a variable to make it more precise or attending to a neglected level of analysis (i.e., psychological, structural, etc.), offered a way to strengthen and advance sociology's core of insights (Swedberg 2019: 91).[46] Merton's vision may not sound as strong a clarion call today as it did when sociology rejected a focus on either grand theory or methodological empiricism. But Merton's desire to advance sociological theories by maintaining continuity with the past, as well as his more general concern with the practice of theorizing, remain persistent fixtures in discussions about the relationship between theory and method in sociology (Stinchcombe 1968; Weick 2005; Leahey 2008; Timmermans and Tavory 2012; Vaughan 2014; Swedberg 2017).

The wider adoption of formal and computational methods for sociological analysis, by contrast, is a relatively recent development whose impact on social theorizing has only begun to be studied (Koppman and Leahey 2019; see Leahey 2008). While popularized under the neologism "computational social science" (Evans and Foster 2019; Edelmann et al. 2020), the emergence of these techniques dates back much earlier (see Mohr and Rawlings 2012; Evans and Aceves 2016).[47] Uniting contemporary computational scholars with their predecessors is a belief

[45] While Merton considered the *systematics* of social theory (i.e., developing useful theories that reliably explain empirical phenomena with increasing precision) as distinct from the *history* of social theory, Merton did not necessarily hold an ahistorical view of theorizing (see Camic 2010).

[46] Merton called his approach "theorizing as decision-making" (Swedberg 2019). Re-analyzing the decisions made in prior studies offered a way to link past studies to newer ones.

[47] For example, Alfred Kroeber (1919) studied the cyclicality of cultural change by measuring changes in the features of women's evening dresses (e.g., dress length, skirt width, décolletage depth) over time. Stanley Stevens (1946) measured sensory experience by developing the most widely known measurement scale (nominal, ordinal,

that the richness of social life may be captured and systematically reduced to formalized patterns for investigation. From this perspective, the production of ever more abundant and diverse forms of social data outpaces our ability to handle them. Addressing this problem therefore requires an infusion of methods developed outside sociology proper. Much like their predecessors, who sought inspiration from mathematics, experimental psychology, or physics, contemporary scholars turn to computer science and engineering to find and repurpose tools for systematically handling vast and varied sources of data (Golder and Macy 2014; Molina and Garip 2019; Evans and Foster 2019; Edelmann et al. 2020).

Contemporary scholars hail their methods as a boon or testing and advancing sociological theory, yet critics both new and old remain skeptical. At the heart of this skepticism is persistent concern over whether formal techniques can be thoughtfully used to generate sociological theory. Critics across the ages contend there is a risk in adapting formal and computational methods: scholars who refashion formal methods for the purpose of systematic analysis may end up ultimately producing haphazard, unsystematic theories. A more general concern is whether computational social science represents filler for a bottomless "eclectic bag of techniques" (White, Boorman, and Breiger 1976: 732) or a genuine advance in the sociological enterprise.

For Howard S. Becker, sociologists who wielded such tools with full awareness of their uses and limitations merited respect (Barnes, Becker, and Becker 1940: 18). The rest, however, represented fad-obsessed “scientific quacks” with a “yen for gadgets” (Becker 1954: 377-378). Pitirim Sorokin coined the term “quantophrenia” to describe a spreading obsession among sociologists with the use of “sham-mathematical and psuedostatistical” methods (Sorokin 1956:

interval, ratio). Numerous community studies conducted in the wake of World War I and the Great Depression involved the collection and analysis of thousands of interviews and questionnaires.

173). Sorokin argued that quantophrenia introduced unsound logic and unrealistic assumptions into sociological theory. Even Merton, whose approach to theory construction was influenced by his collaborations with the mathematical sociologist Paul Lazarsfeld (Swedberg 2019), was critical of research that focused on methods at the expense of conceptual clarification. For Merton, these studies advanced procedures of inquiry but failed to advance social theory (Merton 1968: 168-169). These criticisms persist today, led most notably by Richard Biernacki on the use of formal techniques for cultural analysis. Biernacki (2012) argues that the coding of documents introduces an unnecessary layer of interpretation: it is much more a ritual for self-fulfilling methods than a rigorous way to study meaning. For Biernacki, formal interpretations of cultural texts are "ludic artifice" that rely on a misleading and reductive use of primary documents (29).[48] Furthermore, visualizations that so often facilitate such interpretations (e.g., network diagrams) are often nothing more than "Rorschach tests" (14).

In light of these debates over the theory-method relationship in formal and computational analysis, my dissertation offers grist for considering how these methods may be used to theorize systematically and may shape how we theorize.

In some respects, computational social science supplements rather than succeeds an orientation to systematic theorizing that emerged some seventy years prior. Formal and computational methods offer an exciting array of methods that could very well challenge existing theories or call out for new ones (Evans and Foster 2019: 11). But the value of these methods, epitomized by Merton's view that method should serve theory and not lead it, may lie in their

[48] Biernacki supports this broad generalization using only one case, Peter Bearman and Katherine Stovel's research on the Nazi identity. While it may be true Bearman and Stovel used abridged adaptations of documents (rather than original primary documents) to draw their conclusions, Biernacki's conclusion about an entire field of analysis on the basis of one case is perhaps less defensible.

integration with theories for the sake of systematically refining sociology's core of insights. I demonstrate such integration in my second and third chapters. My second chapter identifies two rich traditions in the theorization of interdisciplinarity, formulates two corresponding forms of assessment, and adapts co-citation networks and topic models to refine each assessment into testable hypotheses. My third chapter, following a legacy of work on developing formal methods for cultural analysis, adapts semantic networks and neural word embeddings to re-specify sociological concepts about careers and ideas for the purpose of theorizing the dynamics of metaphor.

In both chapters, formal methods provide a means to articulate theory-driven concepts. This Mertonian approach to theorizing appears to be the rule rather than the exception: formal methods have been used, for example, to specify the type and meaning of the relationships we measure (Kirchner and Mohr 2010; Rule, Cointet, and Bearman 2015; Lee and Martin 2015), clarify the scope of our analysis (Lizardo 2006), or explicitly define the mechanisms linking various levels of analysis (Colyvas and Maroulis 2015). What unites the application of formal methods across sociological studies is their usefulness in advancing sociological theory through refinement.

In other respects, however, computational social science impacts how we theorize in ways that are genuinely unprecedented. Large-scale surveys and community studies involving extensive data collection have had a place in sociology since the era marked by World War I and the Great Depression (Igo 2009; Immerwahr 2015). Yet both the kinds of data generated about social life and access to this data have changed. "Born-digital" data, such as emails, personal websites, scientific databases, and Tweets reflect changes in how we live as much as they reflect changes in what sociologists use as evidence (Edelmann et al. 2020). What determines access to this data now are not prohibitive costs or personal connections, but ingenuity (Evans and Foster 2019). Thus, the use of formal and computational methods to drive contemporary theorization mirrors fundamental changes in our social world. But it also reflects changes in terms of who has access to data amenable to formal analysis. As I discuss in my first chapter, early social scientists either envisioned or attempted to capture new types of relational data on much larger scales than ever attempted. The creation of this data, however, required multiyear community projects and small armies of social scientists armed with interview schedules, Dictaphone recordings, and survey punch cards – forms of data that were neither widely circulatable nor widely accessible.

Furthermore, computational social science and other formal methods differ from more mainstream sociological methods in ways that we have only begun to figure out. We take for granted the understanding that the same interview or same act of participant observation may yield different results if conducted by a different investigator. We recognize this even for surveys when we flag resampled data or data collected at different waves under different assumptions or conditions. In contrast, questions about the portability of formal methods across different research contexts are a work in progress. The cultural turn led SNA practitioners to question whether their methods adequately reflected their theories (Emirbayer and Goodwin 1994). These debates (see Mische 2011) led to the careful refinement of network theories alongside network methods (e.g., Lizardo 2006; White 2008) in service of specifying the right tools for the job in network analysis. However, it remains to be seen whether other methods under the umbrella of computational social science (such as online experiments, simulations, or machine learning methods) will undergo their own rites of passage.

In my first chapter I demonstrate the pitfalls of assuming that mathematics represents an unambiguous language that is "portable" and reusable whenever structurally similar problems emerge (Freeman 1984: 127). This assumption ignores the capacity of formal methods to express radically different ideas about the same sociological problems. Indeed, I show how precursors of SNA expressed different theories of social structure using distinctive mathematical methods. It was not simply mathematics, but visualization that facilitated the emergence of a new approach to social structure.

By making this point, my first chapter joins a body of STS scholarship that attests to the role of visualization in enabling new ways of thinking (Myers 2008; Alać 2008; Steingart 2014) and new ways of connecting to others (Giraud 2014; Vertesi 2015). But it also establishes that the impact of formal methods on theorizing cannot be understood solely in terms of how they express ideas using the language of mathematics. *Looking at data*, using visualizations that make highly abstract formal models concrete, introduces a dimension to sociological theorizing that neither words nor charts of numbers can approximate. “To see is to forget the name of the thing that one sees,” an aphorism of the poet Paul Valéry that suggests that images may evoke a self-evidence that can evade explanation. If visualization represents its own modality of thought, then the visibility of ideas that is so often at the heart of computational social science may very well challenge how we theorize and think about our core concepts.

REFERENCES

Abbott, Andrew. 1988. *The System of Professions: An Essay on the Division of Expert Labor*. Chicago: University of Chicago Press.

———. 1997. "Of Time and Space: The Contemporary Relevance of the Chicago School." *Social Forces* 75 (4): 1149–82.

———. 2001a. "The Disciplines and the Future." In *The Future of the City of Intellect: The Changing American University*, edited by Steven G. Brint, 205–30. Palo Alto: Stanford University Press.

———. 2001b. *Chaos of Disciplines*. Chicago: University of Chicago Press.

———. 2005. "Linked Ecologies: States and Universities as Environments for Professions." *Sociological Theory* 23 (3): 245–274.

Acord, Sophia Krzys, and Tia DeNora. 2008. "Culture and the Arts: From Art Worlds to Arts-in-Action." *The ANNALS of the American Academy of Political and Social Science* 619 (1): 223–37.

Adamic, Lada A., and Natalie Glance. 2005. "The Political Blogosphere and the 2004 U.S. Election: Divided They Blog." In *LinkKDD '05: Proceedings of the 3rd International Workshop on Link Discovery*, 36–43. New York: Association for Computing Machinery.

Alać, Morana. 2008. "Working with Brain Scans: Digital Images and Gestural Interaction in FMRI Laboratory." *Social Studies of Science* 38 (4): 483–508.

Andris, Clio, David Lee, Marcus J. Hamilton, Mauro Martino, Christian E. Gunning, and John Armistead Selden. 2015. "The Rise of Partisanship and Super-Cooperators in the U.S. House of Representatives." Edited by Rodrigo Huerta-Quintanilla. *PLOS ONE* 10 (4): e0123507.

Arensberg, Conrad M. 1942. "Industry and the Community." *American Journal of Sociology* 48 (1): 1–12.

Arsenian, John. 1943. "Review of The Status System of a Modern Community." *The Journal of Abnormal and Social Psychology* 38 (3): 398–401.

Bail, Christopher A. 2014. "The Cultural Environment: Measuring Culture with Big Data." *Theory and Society* 43 (3–4): 465–82.

Baldassarri, Delia, and Mario Diani. 2007. "The Integrative Power of Civic Networks." *American Journal of Sociology* 113 (3): 735–80.

Bannister, Robert C. 1987. *Sociology and Scientism: The American Quest for Objectivity, 1880-1940*. Chapel Hill: University of North Carolina Press.

Barnes, Harry Elmer, Howard Becker, and Frances Bennett Becker. 1940. *Contemporary Social Theory*. New York: Appleton-Century Co.

Barnes, J. A. 1969. "Graph Theory and Social Networks: A Technical Comment on Connectedness and Connectivity." *Sociology* 3 (2): 215–32.

Barr, Alred H., Jr. 1936. *Cubism and Abstract Art*. New York: The Museum of Modern Art.

Battista, Giuseppe Di, Peter Eades, Roberto Tamassia, and Ioannis G Tollis. 1994. "Algorithms for Drawing Graphs: An Annotated Bibliography." *Computational Geometry* 4 (5): 235–82.

Bayer, Alan E. 1983. "Multi-Method Strategies for Defining 'Core' Higher Education Journals." *Review of Higher Education* 6 (2): 103–13.

Bearman, Peter S., James Moody, and Katherine Stovel. 2004. "Chains of Affection: The Structure of Adolescent Romantic and Sexual Networks." *American Journal of Sociology* 110 (1): 44–91.

Becker, Howard. 1954. "Vitalizing Sociological Theory." *American Sociological Review* 19 (4):

377–88.

Bellas, Marcia L, and Robert Kevin Toutkoushian. 1999. “Faculty Time Allocations and Research Productivity: Gender, Race and Family Effects.” *The Review of Higher Education* 22 (4): 367–90.

Bergmann, Matthias, Bettina Brohmann, Esther Hoffmann, M. Céline Loibl, Regine Rehaag, Engelbert Schramm, and Jan-Peter Voß. 2005. “Quality Criteria of Transdisciplinary Research: A Guide for the Formative Evaluation of Research Projects.” *Institute for Social-Ecological Research (ISOE).*

Biernacki, Richard. 2012. *Reinventing Evidence in Social Inquiry: Decoding Facts and Variables*. New York: Palgrave Macmillan.

Biglan, Anthony. 1973. “The Characteristics of Subject Matter in Different Academic Areas.” *Journal of Applied Psychology* 57 (3): 195–203.

Black, Max. 1962. *Models and Metaphors: Studies in Language and Philosophy*. Ithaca: Cornell University Press.

Blei, David M. 2012. “Probabilistic Topic Models.” *Communications of the ACM* 55 (4): 77.

Blei, David M., Andrew Y. Ng, and Michael I. Jordan. 2003. “Latent Dirichlet Allocation.” *Journal of Machine Learning Research* 3 (Jan): 993–1022.

Blondel, Vincent D., Jean-Loup Guillaume, Renaud Lambiotte, and Etienne Lefebvre. 2008. “Fast Unfolding of Communities in Large Networks.” *Journal of Statistical Mechanics: Theory and Experiment* 2008 (10): P10008-12.

Blumer, Herbert. 1971. “Social Problems as Collective Behavior.” *Social Problems* 18 (3): 298–306.

Boltanski, Luc, and Eve Chiapello. 2005. *The New Spirit of Capitalism*. London: Verso.

Bonacich, Phillip. 1987. "Power and Centrality: A Family of Measures." *American Journal of Sociology* 92 (5): 1170–82.

———. 1991. "Simultaneous Group and Individual Centralities." *Social Networks* 13 (2): 155–68.

Borgatti, Stephen P., Ajay Mehra, Daniel J. Brass, and Giuseppe Labianca. 2009. "Network Analysis in the Social Sciences." *Science* 323 (5916): 892–95.

Bowdle, Brian F., and Dedre Gentner. 2005. "The Career of Metaphor." *Psychological Review* 112 (1): 193–216.

Bray, Nathaniel J., and Claire H. Major. 2011. "Status of Journals in the Field of Higher Education." *The Journal of Higher Education* 82 (4): 479–503.

Breiger, Ronald L. 1974. "The Duality of Persons and Groups." *Social Forces* 53 (2): 181–90.

Breiger, Ronald L., Robin Wagner-Pacifici, and John W. Mohr. 2018. "Capturing Distinctions While Mining Text Data: Toward Low-Tech Formalization for Text Analysis." *Poetics* 68: 104–19.

Brieger, Ronald L. 2000. "A Tool Kit for Practice Theory." *Poetics* 27 (2–3): 91–115.

Brint, Steven G. 2005. "Creating the Future: 'New Directions' in American Research Universities." *Minerva* 43 (1): 23–50.

Brint, Steven G., Lori Turk-Bicakci, Kristopher Proctor, and Scott Patrick Murphy. 2009. "Expanding the Social Frame of Knowledge: Interdisciplinary, Degree-Granting Fields in American Colleges and Universities, 1975–2000." *The Review of Higher Education* 32 (2): 155–83.

Brinton, Crane. 1939. "What's the Matter with Sociology." *Saturday Review of Literature* 20 (2): 3–4, 14.

Brooks, Lee M. 1943. "Reviewed Work: The Social Life of a Modern Community." *Social Forces* 22 (1): 113–14.

Budd, John M. 1990. "Higher Education Literature: Characteristics of Citation Patterns." *The Journal of Higher Education* 61 (1): 84.

Burgess, Ernest W. 1945. "Sociological Research Methods." *American Journal of Sociology* 50 (6): 474–82.

Burt, Ronald S. 1980. "Models of Network Structure." *Annual Review of Sociology* 6 (1): 79–141.

———. 1995. *Structural Holes: The Social Structure of Competition*. Cambridge: Harvard University Press.

Butts, Carter T. 2008. "Social Network Analysis: A Methodological Introduction." *Asian Journal of Social Psychology* 11 (1): 13–41.

Calhoun, Craig. 2010. *Introduction: On Merton's Legacy and Contemporary Sociology*. Edited by Craig Calhoun. New York: Columbia University Press.

Camic, Charles. 1989. "Structure After 50 Years: The Anatomy of a Charter." *American Journal of Sociology* 95 (1): 38–107.

———. 2007. "On Edge: Sociology during the Great Depression and the New Deal." In *Sociology in America: A History*, edited by Craig Calhoun, 226–80. Chicago: University of Chicago.

———. 2010. "How Robert Merton Sociologizes the History of Ideas." In *Robert K. Merton: Sociology of Science and Sociology as Science*, 273–95. New York: Columbia University Press.

Carley, Kathleen M., and David S. Kaufer. 1993. "Semantic Connectivity: An Approach for

Analyzing Symbols in Semantic Networks." *Communication Theory* 3 (3): 183–213.

Castells, Manuel. 2010. *The Rise of the Network Society*. 2nd ed. West Sussex: Wiley-Blackwell.

Chang, Jonathan, Sean Gerrish, Chong Wang, Jordan L. Boyd-graber, and David M. Blei. 2009. "Reading Tea Leaves: How Humans Interpret Topic Models." In *Advances in Neural Information Processing Systems*, 288–96.

Chapple, Eliot D., and Conrad M. Arensberg. 1940. *Measuring Human Relations: An Introduction to the Study of the Interaction of Individuals*. Provincetown: The Journal Press.

Christakis, Nicholas A., and James H. Fowler. 2007. "The Spread of Obesity in a Large Social Network over 32 Years." *New England Journal of Medicine* 357 (4): 370–79.

Coleman, James S. 1986. "Social Theory, Social Research, and a Theory of Action." *American Journal of Sociology* 91 (6): 1309–35.

Collins, Patricia Hill. 2007. "Pushing the Boundaries or Business as Usual? Race, Class, and Gender Studies and Sociological Inquiry." In *Sociology in America: A History*, edited by Craig Calhoun, 572–604. Chicago: University of Chicago Press.

Colyvas, Jeannette A. 2007. "Factory, Hazard, and Contamination: The Use of Metaphor in the Commercialization of Recombinant DNA." *Minerva* 45 (2): 143–59.

Colyvas, Jeannette A., and Spiro Maroulis. 2015. "Moving from an Exception to a Rule: Analyzing Mechanisms in Emergence-Based Institutionalization." *Organization Science* 26 (2): 601–21.

Contractor, Noshir, Peter Monge, and Paul M. Leonardi. 2011. "Multidimensional Networks and the Dynamics of Sociomateriality: Bringing Technology Inside the Network." *International Journal of Communication* 5: 682–720.

Coopmans, Catelijne, Janet Vertesi, Michael E. Lynch, and Steve Woolgar. 2014. "Introduction:

Representation in Scientific Practice Revisited." In *Representation in Scientific Practice Revisited*, edited by Catelijne Coopmans, Janet Vertesi, Michael E. Lynch, and Steve Woolgar, 1–12. Cambridge: MIT Press.

Corritore, Matthew, Amir Goldberg, and Sameer B. Srivastava. 2020. "Duality in Diversity: How Intrapersonal and Interpersonal Cultural Heterogeneity Relate to Firm Performance." *Administrative Science Quarterly* 65 (2): 359–94.

Corwin, Ronald G., and Saad Z. Nagi. 1972. "The Case of Educational Research." In *The Social Contexts of Research*. New York: Wiley-Interscience.

Cottrell, Leonard S. 1950. "Some Neglected Problems in Social Psychology." *American Sociological Review* 15 (6): 705–12.

Cottrill, Charlotte A., Everett M. Rogers, and Tamsy Mills. 1989. "Co-Citation Analysis of the Scientific Literature of Innovation Research Traditions." *Knowledge* 11 (2): 181–208.

Cravens, Hamilton. 1978. *The Triumph of Evolution*. Philadelphia: University of Pennsylvania.

Crenshaw, Kimberlé W. 1989. "Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics." *University of Chicago Legal Forum*, no. 1: 139–67.

Cronin, Blaise, and Cassidy R. Sugimoto, eds. 2015. *Scholarly Metrics Under the Microscope: From Citation Analysis to Academic Auditing*. Medford: Information Today, Inc.

Daston, Lorraine J., and Elizabeth Lunbeck. 2011. "Introduction." In *Histories of Scientific Observation*, edited by Lorraine J. Daston and Elizabeth Lunbeck, 1–10. Chicago: University Of Chicago Press.

DiMaggio, Paul. 1997. "Culture and Cognition." *Annual Review of Sociology* 23 (1): 263–87.

DiMaggio, Paul, Manish Nag, and David Blei. 2013. "Exploiting Affinities between Topic

Modeling and the Sociological Perspective on Culture: Application to Newspaper Coverage of U.S. Government Arts Funding." *Poetics* 41 (6): 570–606.

Ding, Chen, and Prabhaker Mateti. 1990. "A Framework for the Automated Drawing of Data Structure Diagrams." *IEEE Transactions on Software Engineering* 16 (5): 543–57.

Donaldson, Joe F., and Barbara K. Townsend. 2007. "Higher Education Journals' Discourse about Adult Undergraduate Students." *The Journal of Higher Education* 78 (1): 27–50.

Duffy, Ryan D., Alex Jadidian, Gregory D. Webster, and Kyle J. Sandell. 2011. "The Research Productivity of Academic Psychologists: Assessment, Trends, and Best Practice Recommendations." *Scientometrics* 89 (1): 207–27.

Edelmann, Achim, Tom Wolff, Danielle Montagne, and Christopher A. Bail. 2020. "Computational Social Science and Sociology." *Annual Review of Sociology* 46: 61–81.

Eisenmann, Linda. 2004. "Integrating Disciplinary Perspectives into Higher Education Research: The Example of History." *The Journal of Higher Education* 75 (1): 7–22.

Emirbayer, Mustafa. 1997. "Manifesto for a Relational Sociology." *American Journal of Sociology* 103 (2): 281–317.

Emirbayer, Mustafa, and Jeff Goodwin. 1994. "Network Analysis, Culture, and the Problem of Agency." *Source: American Journal of Sociology* 99 (6): 1411–54.

Erikson, Emily. 2013. "Formalist and Relationalist Theory in Social Network Analysis." *Sociological Theory* 31 (3): 219–42.

———. 2017. "Networks and Network Theory: Possible Directions for Unification." In *Social Theory Now*, edited by Claudio E. Benzecry, Monika Krause, and Isaac Ariail Reed, 278–304. Chicago: University of Chicago Press.

Erikson, Emily, and Peter S. Bearman. 2006. "Malfeasance and the Foundations for Global

Trade: The Structure of English Trade in the East Indies, 1601–1833." *American Journal of Sociology* 112 (1): 195–230.

Espeland, Wendy Nelson, and Michael Sauder. 2016. *Engines of Anxiety: Academic Rankings, Reputation, and Accountability*. New York: Russell Sage Foundation.

Espeland, Wendy Nelson, and Mitchell L. Stevens. 1998. "Commensuration as a Social Process." *Annual Review of Sociology* 24 (August): 313–43.

———. 2008. "A Sociology of Quantification." *European Journal of Sociology / Archives Européennes de Sociologie* 49 (03): 401–436.

Etzion, Dror, and Fabrizio Ferraro. 2010. "The Role of Analogy in the Institutionalization of Sustainability Reporting." *Organization Science* 21 (5): 1092–1107.

Evans, James A., and Pedro Aceves. 2016. "Machine Translation: Mining Text for Social Theory." *Annual Review of Sociology* 42 (1): 21–50.

Evans, James A., and Jacob G. Foster. 2019. "Computation and the Sociological Imagination." *Contexts* 18 (4): 10–15.

Fligstein, Neil, Jonah Stuart Brundage, and Michael Schultz. 2017. "Seeing Like the Fed: Culture, Cognition, and Framing in the Failure to Anticipate the Financial Crisis of 2008." *American Sociological Review* 82 (5): 879–909.

Florida, Richard. 2002. *The Rise of the Creative Class: And How It's Transforming Work, Leisure, Community and Everyday Life*. New York: Basic Books.

Fortunato, Santo, and Claudio Castellano. 2012. "Community Structure in Graphs." In *Computational Complexity*, edited by Robert A. Meyers, 490–512. New York: Springer.

Freeman, Linton C. 1960. "Conflict and Congruence in Anthropological Theory." In *Selected Papers of the Vth International Congress of Ethnological and Anthropological Sciences*, 93–97. Philadelphia: University of Pennsylvania.

———. 1978. "Centrality in Social Networks Conceptual Clarification." *Social Networks* 1 (3): 215–39.

———. 1984. "Turning a Profit from Mathematics: The Case of Social Networks." *The Journal of Mathematical Sociology* 10 (3–4): 343–60.

———. 2000. "Visualizing Social Networks." *Journal of Social Structure* 1 (1): 1–12.

———. 2004. *The Development of Social Network Analysis: A Study in the Sociology of Science*. Vancouver,: Empirical Press.

———. 2011. "The Development of Social Network Analysis – with an Emphasis on Recent Events." In *The SAGE Handbook of Social Network Analysis*, edited by John Scott and Peter Carrington, 26–39. Thousand Oaks: SAGE Publications.

Fruchterman, Thomas M. J., and Edward M. Reingold. 1991. "Graph Drawing by Force-Directed Placement." *Software: Practice and Experience* 21 (11): 1129–64.

Fuhse, Jan. 2015. "Theorizing Social Networks: The Relational Sociology of and around Harrison White." *International Review of Sociology* 25 (1): 15–44.

Fuhse, Jan, Oscar Stuhler, Jan Riebling, and John Levi Martin. 2020. "Relating Social and Symbolic Relations in Quantitative Text Analysis. A Study of Parliamentary Discourse in the Weimar Republic." *Poetics* 78 (May): 101363.

Garfield, Eugene. 1979. *Citation Indexing-Its Theory and Application in Science, Technology, and Humanities*. Philadelphia: ISI Press.

———. 1998. "Random Thoughts on Citationology Its Theory and Practice." *Scientometrics* 43 (1): 69–76.

———. 2004a. "The Intended Consequences of Robert K. Merton." *Scientometrics* 60 (1): 51–

61.

———. 2004b. “The Unintended and Unanticipated Consequences of Robert K. Merton.” *Social Studies of Science* 34 (6): 845–53.

Geertz, Clifford. 1983. *Local Knowledge: Further Essays in Interpretive Anthropology*. New York: Basic Books.

Gentner, Dedre. 1983. “Structure-Mapping: A Theoretical Framework for Analogy.” *Cognitive Science* 7 (2): 155–70.

Gentner, Dedre, and Brian F. Bowdle. 2001. “Convention, Form, and Figurative Language Processing.” *Metaphor and Symbol* 16 (3&4): 223–247.

Gibson, James J. 1986. *The Ecologial Approach to Visual Perception*. New York: Taylor & Francis Group.

Giorgi, Simona, and Klaus Weber. 2015. “Marks of Distinction: Framing and Audience Appreciation in the Context of Investment Advice.” *Administrative Science Quarterly* 60 (2): 333–67.

Giraud, Yann. 2014. “Legitimizing Napkin Drawing: The Curious Dispersion of Laffer Curves, 1978–2008.” In *Representation in Scientific Practice Revisited*, edited by Catelijne Coopmans, Janet Vertesi, Michael Lynch, and Steve Woolgar, 269–90. Cambridge: MIT Press.

Goldberg, Amir, Sameer B. Srivastava, V. Govind Manian, William Monroe, and Christopher Potts. 2016. “Fitting In or Standing Out? The Tradeoffs of Structural and Cultural Embeddedness.” *American Sociological Review* 81 (6): 1190–1222.

Golder, Scott A., and Michael W. Macy. 2014. “Digital Footprints: Opportunities and Challenges for Online Social Research.” *Annual Review of Sociology* 40 (1): 129–52.

Griesemer, James R., and William C. Wimsatt. 1989. "Picturing Weismannism: A Case Study of Conceptual Evolution." In , 75–137. Springer, Dordrecht.

Griffiths, Thomas L, and Mark Steyvers. 2004. "Finding Scientific Topics." *Proceedings of the National Academy of Sciences of the United States of America* 101 (suppl 1): 5228–35.

Grimmer, Justin. 2010. "A Bayesian Hierarchical Topic Model for Political Texts: Measuring Expressed Agendas in Senate Press Releases." *Political Analysis* 18 (01): 1–35.

Grimmer, Justin, and Brandon M. Stewart. 2013. "Text as Data: The Promise and Pitfalls of Automatic Content Analysis Methods for Political Texts." *Political Analysis* 21 (03): 267–97.

Griswold, Wendy. 1987. "The Fabrication of Meaning: Literary Interpretation in the United States, Great Britain, and the West Indies." *American Journal of Sociology* 92 (5): 1077–1117.

Hallett, Tim, Orla Stapleton, and Michael Sauder. 2019. "Public Ideas: Their Varieties and Careers." *American Sociological Review* 84 (3): 545–76.

Halliwell, M. 2013. "Working Knowledge: Making the Human Sciences from Parsons to Kuhn." *Journal of American History* 100 (2): 562–562.

Halpern, Orit. 2015. *Beautiful Data: A History of Vision and Reason since 1945*. Durham: Duke University Press.

Hamilton, William L., Jure Leskovec, and Dan Jurafsky. 2016. *Diachronic Word Embeddings Reveal Statistical Laws of Semantic Change*. *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*. Berlin: Association for Computational Linguistics.

Hanneman, Robert A., and Mark Riddle. 2005. *Introduction to Social Network Methods*.

Riverside: University of California, Riverside.

Hart, Jeni. 2006. “Women and Feminism in Higher Education Scholarship: An Analysis of Three Core Journals.” *The Journal of Higher Education* 77 (1): 40–61.

Healy, Kieran, and James Moody. 2014. “Data Visualization in Sociology.” *Annual Review of Sociology* 40 (1): 105–28.

Hedström, Peter, and Petri Ylikoski. 2010. “Causal Mechanisms in the Social Sciences.” *Annual Review of Sociology* 36 (1): 49–67.

Hesse, Mary B. 1966. *Models and Analogies in Science*. Notre Dame: University of Notre Dame Press.

———. 1988. “The Cognitive Claims of Metaphor.” *The Journal of Speculative Philosophy* 2 (1): 1–16.

Hicks, Granville. 1950. “Marquand of Newburyport.” *Harper’s Magazine*, April 1950.

Hindman, Jo. 1958. “Social Engineering for 1984.” *Human Events* 15 (50): 1–4.

Hochschild, Arlie Russell, and Anne Machung. 1989. *The Second Shift: Working Parents and the Revolution at Home*. New York: Viking Penguin Inc.

Hoffman, Mark Anthony, Jean-Philippe Cointet, Philipp Brandt, Newton Key, and Peter S. Bearman. 2018. “The (Protestant) Bible, the (Printed) Sermon, and the Word(s): The Semantic Structure of the Conformist and Dissenting Bible, 1660–1780.” *Poetics* 68 (June): 89–103.

Holland, Paul W., and Samuel Leinhardt. 1979. “The Advanced Research Symposium on Social Networks.” In *Perspectives on Social Network Research*, edited by Paul W. Holland and Samuel Leinhardt, 1–10. New York: Academic Press.

Holley, Karri A. 2009. *Understanding Interdisciplinary Challenges and Opportunities in Higher*

Education. Edited by Karri A. Holley. *Innovations in Higher Education*. Vol. 34.

Homans, George C. 1962. *Sentiments and Activities*. New York: The Free Press of Glencoe.

Hummon, Norman P., and Kathleen M. Carley. 1993. "Social Networks as Normal Science." *Social Networks* 15 (1): 71–106.

Hunter, Deborah E., and George D. Kuh. 1987. "The 'Writing Wing': Characteristics of Prolific Contributors to the Higher Education Literature." *The Journal of Higher Education* 58 (4): 443.

Hutchinson, Susan R., and Cheryl D. Lovell. 2004. "A Review of Methodological Characteristics of Research Published in Key Journals in Higher Education: Implications for Graduate Research Training." *Research in Higher Education* 45 (4): 383–403.

Huutoniemi, Katri, Julie T. Klein, Henrik Bruun, and Janne Hukkinen. 2010. "Analyzing Interdisciplinarity: Typology and Indicators." *Research Policy* 39 (February): 79–88.

Ignatow, Gabriel. 2003. "'Idea Hamsters' on the 'Bleeding Edge': Profane Metaphors in High Technology Jargon." *Poetics* 31 (1): 1–22.

Igo, Sarah E. 2009. *The Averaged American: Surveys, Citizens, and the Making of a Mass Public*. Cambridge: Harvard University Press.

Immerwahr, Daniel. 2015. *Thinking Small: The United States and the Lure of Community Development*. Cambridge: Harvard University Press.

Jacobs, Jerry A. 2013. *In Defense of Disciplines: Interdisciplinarity and Specialization in the Research University*. Chicago: University of Chicago Press.

Jacobs, Jerry A., and Scott Frickel. 2009. "Interdisciplinarity: A Critical Assessment." *Annual Review of Sociology* 35: 43–65.

Jacomy, Mathieu, Tommaso Venturini, Sebastien Heymann, and Mathieu Bastian. 2014.

"ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software." Edited by Mark R. Muldoon. *PLoS ONE* 9 (6): e98679.

Jagoda, Patrick. 2016. *Network Aesthetics*. Chicago, IL: University of Chicago Press.

Jones, Lara L., and Zachary Estes. 2006. "Roosters, Robins, and Alarm Clocks: Aptness and Conventionality in Metaphor Comprehension." *Journal of Memory and Language* 55 (1): 18–32.

Kaiser, David. 2005. *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics*. Chicago: University of Chicago Press.

Kane, Anne E. 1997. "Theorizing Meaning Construction in Social Movements: Symbolic Structures and Interpretation during the Irish Land War, 1879–1882." *Sociological Theory* 15 (3): 249–76.

Keller, Evelyn Fox. 1995. *Refiguring Life: Metaphors of Twentieth-Century Biology*. New York: Columbia University Press.

Kezar, A. 2000. "Higher Education Research at the Millennium: Still Trees Without Fruit?" *Review of Higher Education* 23 (4): 443–68.

Kharchenkova, Svetlana. 2018. "The Market Metaphors: Making Sense of the Emerging Market for Contemporary Art in China." *Poetics* 71 (December): 71–82.

Kimball, Ezekiel W., and Rachel E. Friedensen. 2019. "The Search for Meaning in Higher Education Research: A Discourse Analysis of ASHE Presidential Addresses." *The Review of Higher Education* 42 (4): 1549–74.

Kirchner, Corinne, and John W. Mohr. 2010. "Meanings and Relations: An Introduction to the Study of Language, Discourse and Networks." *Poetics*, Toward a Relational Sociology of Meaning: Language and Socio-cultural Processes, 38 (6): 555–66.

Klapisch-Zuber, Christiane. 1991. "The Genesis of the Family Tree." *I Tatti Studies in the Italian Renaissance* 4 (January): 105–29.

Klein, Julie T. 1990. *Interdisciplinarity: History, Theory, and Practice*. Detroit: Wayne State University Press.

———. 1996. *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities*. Charlottesville: University Press of Virginia.

———. 2006. "Afterword: The Emergent Literature on Interdisciplinary and Transdisciplinary Research Evaluation." *Research Evaluation* 15 (1): 75–80.

———. 2017. "Typologies of Interdisciplinarity: The Boundary Work of Definition." In *The Oxford Handbook of Interdisciplinarity*, edited by Robert Frodeman, Julie T. Klein, and Roberto C. S. Pacheco, 21–34. Oxford: Oxford University Press.

Klingenstein, Sara, Tim Hitchcock, and Simon DeDeo. 2014. "The Civilizing Process in London's Old Bailey." *Proceedings of the National Academy of Sciences of the United States of America* 111 (26): 9419–24.

Knight, David B., Lisa R. Lattuca, Ezekiel W. Kimball, and Robert D. Reason. 2013. "Understanding Interdisciplinarity: Curricular and Organizational Features of Undergraduate Interdisciplinary Programs." *Innovative Higher Education* 38 (2): 143–58.

Koppman, Sharon, and Erin Leahey. 2019. "Who Moves to the Methodological Edge? Factors That Encourage Scientists to Use Unconventional Methods." *Research Policy* 48 (9): 103807.

Kozlowski, Austin C., Matt Taddy, and James A. Evans. 2019. "The Geometry of Culture: Analyzing the Meanings of Class through Word Embeddings." *American Sociological Review* 84 (5): 905–49.

Krempel, Lothar. 2011. “Network Visualization.” In *The SAGE Handbook of Social Network Analysis*, edited by John Scott and Peter Carrington, 558–77. Thousand Oaks: SAGE Publications.

Kroeber, Alfred L. 1919. “On the Principle of Order in Civilization as Exemplified by Changes of Fashion.” *American Anthropologist* 21 (3): 235–63.

Kulkarni, Vivek, Rami Al-Rfou, Bryan Perozzi, and Steven Skiena. 2015. “Statistically Significant Detection of Linguistic Change.” In *WWW ’15: Proceedings of the 24th International Conference on World Wide Web*, 625–35. New York: Association for Computing Machinery.

Laird, Thomas F Nelson, Rick Shoup, George D Kuh, and Michael J Schwarz. 2008. “The Effects of Discipline on Deep Approaches to Student Learning and College Outcomes.” *Research in Higher Education* 49 (6): 469–494.

Lakoff, George, and Mark Johnson. 1980. *Metaphors We Live By*. Chicago: University of Chicago Press.

Lamont, Michèle. 2009. *How Professors Think: Inside the Curious World of Academic Judgment*. Cambridge: Harvard University Press.

Lamont, Michèle, and Katri Huutoniemi. 2011. “Comparing Customary Rules of Fairness: Evaluative Practices in Various Types of Peer Review Panels.” In *Social Knowledge in the Making*, edited by Charles Camic, Neil Gross, and Michèle Lamont, 209–232. Chicago: University of Chicago Press.

Lamont, Michèle, Grégoire Mallard, and Joshua Guetzkow. 2006. “Beyond Blind Faith: Overcoming the Obstacles to Interdisciplinary Evaluation.” *Research Evaluation* 15 (1): 43–55.

Lattuca, Lisa R. 2001. *Creating Interdisciplinarity: Interdisciplinary Research and Teaching among College and University Faculty*. Nashville: Vanderbilt University Press.

Laumann, Edward O., and David Knoke. 1986. "Network Analysis." In *Approaches to Social Theory*, edited by Siegwart Lindenberg, James S. Coleman, and Stefan Nowak, 81–104. New York: Russell Sage Foundation.

Lazer, David, Alex Pentland, Lada Adamic, Sinan Aral, Albert László Barabási, Devon Brewer, Nicholas Christakis, et al. 2009. "Computational Social Science." *Science* 323 (5915): 721–23.

Leahey, Erin. 2008. "Methodological Memes and Mores: Toward a Sociology of Social Research." *Annual Review of Sociology* 34: 33–53.

Lee, Monica, and John Levi Martin. 2015. "Coding, Counting and Cultural Cartography." *American Journal of Cultural Sociology* 3 (1): 1–33.

———. 2018. "Doorway to the Dharma of Duality." *Poetics* 68 (June): 18–30.

Leinhardt, Samuel. 1977. *Social Networks: A Developing Paradigm*. New York: Academic Press.

Lewin, Kurt. 1935. *A Dynamic Theory of Personality: Selected Papers*. New York: McGraw-Hill.

———. 1936. *Principles of Topological Psychology*. New York: McGraw-Hill.

———. 1938. *The Conceptual Representation and the Measurement of Psychological Forces*. Durham: Duke University Press.

———. 1945. "The Research Center for Group Dynamics at Massachusetts Institute of Technology." *Sociometry* 8 (2): 126–36.

———. 1986. "'Everything Within Me Rebels': A Letter from Kurt Lewin to Wolfgang Köhler, 1933." *Journal of Social Issues* 42 (4): 39–47.

Leydesdorff, Loet, and Ismael Rafols. 2011. "Indicators of the Interdisciplinarity of Journals: Diversity, Centrality, and Citations." *Journal of Informetrics* 5 (1): 87–100.

Leydesdorff, Loet, Caroline S. Wagner, and Lutz Bornmann. 2017. "Betweenness and Diversity in Journal Citation Networks as Measures of Interdisciplinarity—A Tribute to Eugene Garfield." *Scientometrics* 114: 567–592.

Lima, Manuel. 2011. *Visual Complexity: Mapping Patterns of Information*. New York: Princeton Architectural Press.

Lin, Jianhua. 1991. "Divergence Measures Based on the Shannon Entropy." *IEEE Transactions On Information Theory* 37 (I): 145–51.

Liu, Alan. 2004. *The Laws of Cool: Knowledge Work and the Culture of Information*. Chicago: University of Chicago Press.

Lizardo, Omar. 2006. "How Cultural Tastes Shape Personal Networks." *American Sociological Review* 71 (5): 778–807.

———. 2017. "Improving Cultural Analysis: Considering Personal Culture in Its Declarative and Nondeclarative Modes." *American Sociological Review* 82 (1): 88–115.

Lorrain, François, and Harrison C. White. 1971. "Structural Equivalence of Individuals in Social Networks." *The Journal of Mathematical Sociology* 1 (1): 49–80.

Lungeanu, Alina, Dorothy R. Carter, Leslie A. DeChurch, and Noshir S. Contractor. 2018. "How Team Interlock Ecosystems Shape the Assembly of Scientific Teams: A Hypergraph Approach." *Communication Methods and Measures* 12 (2–3): 174–98.

Lynch, Michael, and Samuel Edgerton. 1988. "Aesthetics and Digital Image Processing: Representational Craft in Contemporary Astronomy." In *Picturing Power: Visual Depiction* *and Social Relations*, edited by Gordon Fyfe, 184–220. London: Routledge.

Maaten, Laurens van der, and Geoffrey Hinton. 2008. "Visualizing Data Using T-SNE." *Journal of Machine Learning Research* 9: 2579–2605.

Machotka, Otakar. 1949. "Is Sociology a Natural Science?" *American Journal of Sociology* 55 (1): 10–17.

MacIver, Robert M. 1931. "Is Sociology a Natural Science?" In *Publications of the American Sociological Society*, 25–35.

Mansilla, Veronica Boix. 2006. "Assessing Expert Interdisciplinary Work at the Frontier: An Empirical Exploration." *Research Evaluation* 15 (1): 17–29.

Mansilla, Veronica Boix, and Elizabeth Dawes Duraising. 2007. "Targeted Assessment of Students' Interdisciplinary Work: An Empirically Grounded Framework Proposed." *The Journal of Higher Education* 78 (2): 215–37.

Mansilla, Veronica Boix, Michèle Lamont, and Kyoko Sato. 2016. "Shared Cognitive-Emotional-Interactional Platforms: Markers and Conditions for Successful Interdisciplinary Collaborations." *Science, Technology, & Human Values* 41 (4): 571–612.

Marquand, John P. 1949. *Point of No Return*. Boston: Little, Brown and Company.

Marrow, Alfred J. 1969. *The Practical Theorist: The Life and Work of Kurt Lewin*. New York: Basic Books.

Mars, Matthew M., and Cecilia Rios-Aguilar. 2010. "Academic Entrepreneurship (Re)Defined: Significance and Implications for the Scholarship Of." *Higher Education* 59 (4): 441–60.

Martin, Ben R. 1996. "The Use of Multiple Indicators in the Assessment of Basic Research." *Scientometrics* 36 (3): 343–62.

Martin, Ben R., and John Irvine. 1983. "Assessing Basic Research: Some Partial Indicators of

Scientific Progress in Radio Astronomy." *Research Policy* 12 (2): 61–90.

Martin, John Levi. 2003. "What Is Field Theory?" *American Journal of Sociology* 109 (1): 1–49.

———. 2010. "Life's a Beach but You're an Ant, and Other Unwelcome News for the Sociology of Culture." *Poetics*, Brain, Mind and Cultural Sociology, 38 (2): 229–44.

Massengill, Rebekah Peeples. 2008. "Prayers of the People: Moral Metaphors in the Right-to-Life and Faith-Based Labor Movements." *Poetics* 36 (5–6): 338–57.

Mattelart, Armand. 1999. "Mapping Modernity: Utopia and Communications Networks." In *Mappings*, edited by Denis E. Cosgrove, 169–92. London: Reaktion Books.

McCallum, Daniel C., G. H. Henshaw, and New York and Erie Railroad Company. 1855. "New York and Erie Railroad Diagram Representing a Plan of Organization: Exhibiting the Division of Academic Duties and Showing the Number and Class of Employés Engaged in Each Department: From the Returns of September." Map. New York: New York and Erie Railroad Company.

McCulloh, Ian, Helen Armstrong, and Anthony Johnson. 2013. *Social Network Analysis with Applications*. New York: John Wiley & Sons.

McDonnell, Terence E., and Steven J. Tepper. 2014. "Culture in Crisis: Deploying Metaphor in Defense of Art." *Poetics* 43 (April): 20–42.

McGrath, Cathleen, Jim Blythe, and David Krackhardt. 1997. "The Effect of Spatial Arrangement on Judgments and Errors in Interpreting Graphs." *Social Networks* 19 (3): 223–42.

Merton, Robert K. 1942. "Science and Technology in a Democratic Order." *Journal of Legal and Political Sociology* 1: 115–26.

———. 1957. "Priorities in Scientific Discovery: A Chapter in the Sociology of Science."

American Sociological Review 22 (6): 635–59.

———. 1968a. *Social Theory and Social Structure*. 3rd ed. New York: The Free Press.

———. 1968b. "The Matthew Effect in Science." *Science* 159 (3810): 56–63.

———. 1988. "The Matthew Effect in Science, II: Cumulative Advantage and the Symbolism of Intellectual Property." *Isis* 79 (4): 606–23.

Michel, Jean-Baptiste, Yuan Kui Shen, Aviva Presser Aiden, Adrian Veres, Matthew K Gray, The Google Books Team, Joseph P Pickett, et al. 2011. "Quantitative Analysis of Culture Using Millions of Digitized Books." *Science* 331 (6014): 176–82.

Mikolov, Tomas, Ilya Sutskever, Kai Chen, Greg Corrado, and Jeffrey Dean. 2013. "Distributed Representations of Words and Phrases and Their Compositionality." In *NIPS'13: Proceedings of the 26th International Conference on Neural Information Processing Systems - Volume 2*, 3111–19. Red Hook: Curran Associates Inc.

Milam, John H. Jr. 1991. "The Presence of Paradigms in the Core Higher Education Journal Literature." *Research in Higher Education* 32 (6): 651–68.

Mills, C. Wright. 1942. "Reviewed Work: The Social Life of a Modern Community." *American Sociological Review* 7 (2): 263–71.

Mimno, David, Hanna M. Wallach, Edmund Talley, Miriam Leenders, and Andrew McCallum. 2011. "Optimizing Semantic Coherence in Topic Models." In *Proceedings of the Conference on Empirical Methods in Natural Language Processing*, 262–272. Stroudsburg: Association for Computational Linguistics.

Mische, Ann. 2011. "Relational Sociology, Culture, and Agency." In *The SAGE Handbook of Social Network Analysis*, edited by John Scott and Peter J. Carrington, 80–98. London: SAGE Publications.

Mohr, John W. 1998. “Measuring Meaning Structures.” *Annual Review of Sociology* 24 (1): 345–70.

———. 2005. “‘Implicit Terrains: Meaning, Measurement, and Spatial Metaphors in Organizational Theory’ (Unpublished Manuscript, May 22 2011, Typescript).” Santa Barbara.

Mohr, John W., and Petko Bogdanov. 2013. “Introduction—Topic Models: What They Are and Why They Matter.” *Poetics* 41 (6): 545–69.

Mohr, John W., and Vincent Duquenne. 1997. “The Duality of Culture and Practice: Poverty Relief in New York City, 1888-1917.” *Theory and Society* 26: 305–56.

Mohr, John W., and Craig Rawlings. 2012. “Four Ways to Measure Culture: Social Science, Hermeneutics, and the Cultural Turn.” In *The Oxford Handbook of Cultural Sociology*, edited by Jeffrey C. Alexander, Ronald N. Jacobs, and Philip Smith, 70–116. Oxford: Oxford University Press.

Mohr, John W., Robin Wagner-Pacifici, and Ronald L. Breiger. 2015. “Toward a Computational Hermeneutics.” *Big Data & Society* 2 (2): 1–8.

Mohr, John W., Robin Wagner-Pacifici, Ronald L. Breiger, and Petko Bogdanov. 2013. “Graphing the Grammar of Motives in National Security Strategies: Cultural Interpretation, Automated Text Analysis and the Drama of Global Politics.” *Poetics* 41 (6): 670–700.

Molina, Mario, and Filiz Garip. 2019. “Machine Learning for Sociology.” *Annual Review of Sociology* 45: 27–45.

Moreno, Jacob L. 1934. *Who Shall Survive: A New Approach to the Problem of Human Interrelations*. Washington, DC: Nervous and Mental Disease Publishing Co.

———. 1937. “Sociometry in Relation to Other Social Sciences.” *Sociometry* 1 (1/2): 206–19.

———. 1953. “How Kurt Lewin’s ‘Research Center for Group Dynamics’ Started.” *Sociometry* 16 (1): 101–4.

Morillo, Fernanda, María Bordons, and Isabel Gómez. 2003. “Interdisciplinarity in Science: A Tentative Typology of Disciplines and Research Areas.” *Journal of the American Society for Information Science and Technology* 54 (13): 1237–49.

Morris, Aldon D. 2015. *The Scholar Denied: W. E. B. Du Bois and the Birth of Modern Sociology*. Oakland: University of California Press.

Mullins, Nicholas C., and Carolyn J. Mullins. 1973. *Theories and Theory Groups in Contemporary American Sociology*. New York: Harper & Row.

Murphy, Gardner. 1955. “New Evaluation of Sociometry.” *Sociometry* 18 (4): 37–38.

Myers, Natasha. 2008. “Molecular Embodiments and the Body-Work of Modeling in Protein Crystallography.” *Social Studies of Science* 38 (2): 163–99.

Nadel, Siegfried F. 1957. *The Theory of Social Structure*. London: Cohen & West.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2005. *Facilitating Interdisciplinary Research*. Washington, DC: National Academies Press.

National Science and Technology Council. 2018. “Charting a Course for Success: America’s Strategy for STEM Education.” Washington.

National Science Foundation. n.d. “Introduction to Interdisciplinary Research.” Accessed October 9, 2020.

Newman, Mark. 2010. *Networks: An Introduction*. Oxford: Oxford University Press.

Ni, Chaoqun, Cassidy R. Sugimoto, and Jiepu Jiang. 2011. “Degree, Closeness, and Betweenness: Application of Group Centrality Measurements to Explore Macro-Disciplinary Evolution Diachronically.” In *Proceedings of the 13th International*

Conference of the International Society for Scientometrics and Informetrics, 605–17. Durban, South Africa: ISSI.

Nikitina, Svetlana. 2005. "Pathways of Interdisciplinary Cognition." *Cognition and Instruction* 23 (3): 389–425.

O'Rourke, Michael, Stephen Crowley, Sanford D. Eigenbrode, and J. D. Wulfhorst, eds. 2014. *Enhancing Communication & Collaboration in Interdisciplinary Research*. Thousand Oaks: SAGE Publications.

Opler, Morris Edward. 1942. "Reviewed Work: The Status System of a Modern Community." *American Sociological Review* 7 (5): 719–22.

Opsahl, Tore, Filip Agneessens, and John Skvoretz. 2010. "Node Centrality in Weighted Networks: Generalizing Degree and Shortest Paths." *Social Networks* 32 (3): 245–51.

Pachucki, Mark C., and Ronald L. Breiger. 2010. "Cultural Holes: Beyond Relationality in Social Networks and Culture." *Annual Review of Sociology* 36: 205–24.

———. 2018. "Network Theories." *Cambridge Handbook of Social Theory*. Cambridge: Cambridge University Press.

Pachucki, Mark C., Paul F. Jacques, and Nicholas A. Christakis. 2011. "Social Network Concordance in Food Choice Among Spouses, Friends, and Siblings." *American Journal of Public Health* 101 (11): 2170–77.

Padgett, John F., and Christopher K. Ansell. 1993. "Robust Action and the Rise of the Medici, 1400-1434." *American Journal of Sociology*. The University of Chicago Press.

Padgett, John F., and Walter W. Powell. 2012. "The Problem of Emergence." In *The Emergence of Organizations and Markets*, edited by John F. Padgett and Walter W. Powell, 1–30. Princeton: Princeton University Press.

Parsons, Talcott. 1948. "The Position of Sociological Theory." *American Sociological Review* 13 (2): 156–71.

Pechenick, Eitan Adam, Christopher M. Danforth, and Peter Sheridan Dodds. 2015. "Characterizing the Google Books Corpus: Strong Limits to Inferences of Socio-Cultural and Linguistic Evolution." Edited by Alain Barrat. *PLOS ONE* 10 (10): e0137041.

Platt, Jennifer. 1996. *A History of Sociological Research Methods in America, 1920–1960*. Cambridge: Cambridge University Press.

Porter, Theodore M. 1995. *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton: Princeton University Press.

Powell, Walter W., and Achim Oberg. 2017. "Networks and Institutions." In *The SAGE Handbook of Organizational Institutionalism*, edited by Royston Greenwood, Christine Oliver, Thomas B. Lawrence, and Renate E. Meyer, 2nd 2nd, 446–76. London: SAGE Publications.

Purchase, Helen C. 1997. "Which Aesthetic Has the Greatest Effect on Human Understanding?" In , 248–61. Springer Berlin Heidelberg.

———. 2002. "Metrics for Graph Drawing Aesthetics." *Journal of Visual Languages & Computing* 13 (5): 501–16.

Rafols, Ismael, Loet Leydesdorff, Alice O'Hare, Paul Nightingale, and Andy Stirling. 2012. "How Journal Rankings Can Suppress Interdisciplinary Research: A Comparison Between Innovation Studies and Business and Management." *Research Policy* 41 (September): 1262–82.

Rafols, Ismael, and Martin Meyer. 2010. "Diversity and Network Coherence as Indicators of Interdisciplinarity: Case Studies in Bionanoscience." *Scientometrics* 82 (2): 263–87.

Renn, Kristen A. 2020. "Reimagining the Study of Higher Education: Generous Thinking, Chaos, and Order in a Low Consensus Field." *The Review of Higher Education* 43 (4): 917–34.

Roethlisberger, Fritz J., and William J. Dickson. 1939. *Management and the Worker*. Cambridge: Harvard University Press.

Rogers, Maria. 1946. "Problems of Human Relations in Industry." *Sociometry* 9 (4): 350–71.

Rosen-Zvi, Michal, Thomas Griffiths, Mark Steyvers, and Padhraic Smyth. 2004. "The Author-Topic Model for Authors and Documents." In *Proceedings of the Twentieth Conference on Uncertainty in Artificial Intelligence*, 487–494. AUAI Press.

Ross, Dorothy. 1991. *The Origins of American Social Science*. Cambridge: Cambridge University Press.

———. 1993. "An Historian's View of American Social Science." *Journal of the History of the Behavioral Sciences* 29 (2): 99–112.

Rule, Alix, Jean-Philippe Cointet, and Peter S. Bearman. 2015. "Lexical Shifts, Substantive Changes, and Continuity in State of the Union Discourse, 1790-2014." *Proceedings of the National Academy of Sciences of the United States of America* 112 (35): 10837–44.

Schurman, Rachel. 2004. "Fighting 'Frankenfoods': Industry Opportunity Structures and the Efficacy of the Anti-Biotech Movement in Western Europe." *Social Problems* 51 (2): 243–68.

Scott, John. 2000. *Social Network Analysis: A Handbook*. 2nd ed. London: SAGE Publications.

———. 2017. *Social Network Analysis*. 4th ed. London: SAGE Publications.

Silverman, Robert J. 1984. "Publishing Patterns Evidenced in the Core Higher Education Journals." *Research in Higher Education* 21 (2): 159–77.

———. 1985. "Higher Education as a Maturing Field? Evidence from Referencing Practices." *Research in Higher Education* 23 (2): 150–83.

———. 1987. "How We Know What We Know: A Study of Higher Education Journal Articles." *The Review of Higher Education* 11 (1): 39–59.

Simmel, Georg. 1972. *Georg Simmel on Individuality and Social Forms*. Chicago: University of Chicago Press.

Snow, David A., E. Burke Rochford, Steven K. Worden, and Robert D. Benford. 1986. "Frame Alignment Processes, Micromobilization, and Movement Participation." *American Sociological Review* 51 (4): 464–81.

Somers, Margaret R. 1995. "What's Political or Cultural about Political Culture and the Public Sphere? Toward an Historical Sociology of Concept Formation." *Sociological Theory* 13 (2): 113–44.

Sorokin, Pitirim A. 1956. *Fads and Foibles in Modern Sociology and Related Sciences*. Chicago: Henry Regnery Co.

Srivastava, Sameer B., Amir Goldberg, V. Govind Manian, and Christopher Potts. 2017. "Enculturation Trajectories: Language, Cultural Adaptation, and Individual Outcomes in Organizations." *Management Science* 64 (4): 1348–64.

Steingart, Alma. 2014. "A Four-Dimensional Cinema: Computer Graphics, Higher Dimensions and the Geometrical Imagination." In *Visualization in the Age of Computerization*, 170–96. New York: Routledge.

Stevens, Stanley S. 1946. "On the Theory of Scales of Measurement." *Science* 103 (2684): 677–80.

Stinchcombe, Arthur L. 1968. *Constructing Social Theories*. Chicago: University of Chicago

Press.

Swedberg, Richard. 2017. "Theorizing in Sociological Research: A New Perspective, a New Departure?" *Annual Review of Sociology* 43 (1): 189–206.

———. 2019. "How Do You Make Sociology out of Data? Robert K. Merton's Course in Theorizing (Soc 213–214)." *American Sociologist* 50 (1): 85–120.

Terenzini, Patrick T. 1996. "Rediscovering Roots: Public Policy and Higher Education Research." *Review of Higher Education* 20 (1): 5–13.

Thibodeau, Paul H., and Lera Boroditsky. 2015. "Measuring Effects of Metaphor in a Dynamic Opinion Landscape." *PLOS ONE* 10 (7): e0133939.

Thomas, William I. 1917. "The Persistence of Primary-Group Norms in Present-Day Society and Their Influence in Our Educational System." In *Suggestions of Modern Science Concerning Education*, edited by Herbert S. Jennings, John B. Watson, Adolf Meyer, and William I. Thomas, 157–97. New York: Macmillan.

Thursby, Marie, Jerry Thursby, and Swasti Gupta-Mukherjee. 2007. "Are There Real Effects of Licensing on Academic Research? A Life Cycle View." *Journal of Economic Behavior & Organization* 63 (4): 577–98.

Tight, Malcolm. 2007. "Bridging the Divide: A Comparative Analysis of Articles in Higher Education Journals Published inside and Outside North America." *Higher Education* 53 (2): 235–53.

Timmermans, Stefan, and Iddo Tavory. 2012. "Theory Construction in Qualitative Research: From Grounded Theory to Abductive Analysis." *Sociological Theory* 30 (3): 167–86.

Tolman, Edward C. 1948. "Kurt Lewin: 1890-1947." *Psychological Review* 55 (1): 1–4.

U.S. Department of Education. 2016. *STEM 2026 Vision*. Washington DC: Department of

Education.

University of Michigan. 2010. "New Round of Interdisciplinary Junior Faculty Approved." *The University Record Online*, November 1, 2010.

Vaughan, Diane. 2014. "Analogy, Cases, and Comparative Social Organization." In *Theorizing in Social Science*, edited by Richard Swedberg, 61–84. Stanford: Stanford University Press.

Vertesi, Janet. 2015. *Seeing Like a Rover: How Robots, Teams, and Images Craft Knowledge of Mars*. Chicago: University of California Press.

Wagner-Pacifici, Robin, John W Mohr, and Ronald L Breiger. 2015. "Ontologies, Methodologies, and New Uses of Big Data in the Social and Cultural Sciences." *Big Data & Society* 2 (2): 1–11.

Waldby, Cathy. 2000. *The Visible Human Project: Informatic Bodies and Posthuman Medicine*. New York: Routledge.

Warner, W. Lloyd. 1941. "Social Anthropology and the Modern Community." *American Journal of Sociology* 46 (6): 785–96.

Warner, W. Lloyd, and Paul S. Lunt. 1942. *The Status System of a Modern Community*. *Yankee City Series*. Vol. 2. New Haven: Yale University Press.

Wasserman, Stanley, and Katherine Faust. 1994. *Social Network Analysis: Methods and Applications*. Cambridge: Cambridge University Press.

Weick, Karl E. 2005. "The Experience of Theorizing: Sensemaking as Topic and Resource." In *Great Minds in Management: The Process of Theory Development*, edited by Ken G. Smith and Michael A. Hitt, 394–413. Oxford: Oxford University Press.

White, Harrison C. 2008. *Identity and Control: How Social Formations Emerge*. Princeton: Princeton University Press.

White, Harrison C., Scott A. Boorman, and Ronald L. Breiger. 1976. "Social Structure from Multiple Networks. I. Blockmodels of Roles and Positions." *American Journal of Sociology* 81 (4): 730–80.

White, Howard D., and Katherine W. McCain. 1998. "Visualizing a Discipline: An Author Cocitation Analysis of Information Science." *Journal of the American Society for Information* 49 (4): 327–55.

Whyte, William Foote. 1941. "Corner Boys: A Study of Clique Behavior." *American Journal of Sociology* 46 (5): 647–64.

Williamson, Ian O., and Daniel M. Cable. 2003. "Predicting Early Career Research Productivity: The Case of Management Faculty." *Journal of Organizational Behavior* 24 (1): 25–44.

Wolfe, Alvin W. 1978. "The Rise of Network Thinking in Anthropology." *Social Networks* 1 (1): 53–64.

Yan, Erjia, and Ying Ding. 2012. "Scholarly Network Similarities: How Bibliographic Coupling Networks, Citation Networks, Cocitation Networks, Topical Networks, Coauthorship Networks, and Coword Networks Relate to Each Other." *Journal of the American Society for Information Science and Technology* 63 (7): 1313–26.

Yan, Erjia, Ying Ding, and Elin K. Jacob. 2012. "Overlaying Communities and Topics: An Analysis on Publication Networks." *Scientometrics* 90 (2): 499–513.

Yin, Robert K. 1994. *Case Study Research: Design and Methods*. 2nd ed. New York: SAGE Publications.

Zuckerman, Harriet, and Robert K. Merton. 1971. "Patterns of Evaluation in Science: Institutionalisation, Structure and Functions of the Referee System." *Minerva* 9 (1): 66–100.

Zurn, Perry, Danielle S. Bassett, and Nicole C. Rust. 2020. "The Citation Diversity Statement: A

Practice of Transparency, A Way of Life." *Scientific Life* 24 (9): 669–72.

APPENDIX

1. Article 2 Appendix

1.1. Disambiguation of Authorship and Author Names for Co-Citation Network

As previously noted, a severe limitation of the SSCI is that it lists records by first author only. Indeed, identifying authorship through authorial names is not a straightforward process, as the SSCI indexes only an author's last name and initials. Many individuals share the same names and the names of authors can change over time (e.g., through marriage). Furthermore, the SSCI may identify an author using a number of synonyms. For example, Robert Merton's name might be categorized by the SSCI as "Merton R. K", "Merton R. K.", "Merton R.K.", "Merton R.", "Merton R", or "Merton Robert" which would be recognized by a script as four authors coded "Merton R", "Merton RK", and "Merton Rob".

In order to address this issue, duplicates were recoded by hand. For authors cited more than 1 time, I manually recoded the authorial name designated by Web of Knowledge (SSCI) into the author's surname followed by first letter of their first name (or first letters of their first name, middle name, or maiden name). For example, Patricia Hill Collins' authorial name is commonly formatted by the SSCI as Collins Patricia Hill or Collins P. H. In this case, I would reformat Collins' authorial name into Collins PH. However, the algorithm used by the WOK to assign authorial names is not straightforward. It is not uncommon to find an author cited under different authorial names, particularly when an author has a compound surname. This may even occur for an author whose works are cited in the same bibliography. For example, Collins is listed as Hill P. and Hill-Collins P. in the WOK record for Patton's (2009) examination of mentoring experiences among African American women in post-secondary training. More troubling, the misspelling of surnames, while not frequent, may occur. Bourdieu's surname is recorded as Bourdieu, Bordieu, and Bourieu. In addition, names abbreviated in the SSCI record might include only the first letter of the author's first name, or might also include the first letters of the author's first and middle names. For example, Hardy D and Hardy DE are both used to identify author David E. Hardy.

In cases where it was not clear whether one author was the same as another, I searched the SSCI for the actual cited publications to confirm whether the two names represented the same author. This process includes examining individual cited papers to confirm whether, for example, a Harris M. who has authored about religious education is the same as a Harris M. who has published in the Review of Finance is the same as a Harris M. S. who has published an article in Innovative Higher Education (they are all different authors). Furthermore, the SSCI record itself is not immune from clerical errors missed during the copyediting process. In addition to misspellings of authorial names, some cited works may be improperly cited or may lack a designated author. In cases where a cited author is absent, I searched the bibliography of the article to find the original reference to ensure that a first author, if present, is properly cited. In cases where no first author actually exists (a frequent occurrence among cited news reports) I created a substitute authorial name for the citation (e.g., UnnamedChronicle Author, UnnamedAssociatedP Author, etc.).

Given the presence of duplicates and errors, manual processing of citation data pulled from the SSCI is preferential, if not a prerequisite, to an author citation analysis. Manually reprocessing authorial names for a dataset containing 76,571 lines of text is feasible, albeit time-consuming. I repeated this process until none of the cited authors sampled contained duplicates in the population of 4,260 article bibliographies. Given the variety of authorial names and the presence of authors that share the same first name and surname, any larger project seeking to correct authorial names would require the assistance of automated text-processing algorithm along with manual processing. For example, Johnnella E. Butler and Judith Butler are both recorded in SSCI record as Butler J. Clarifying this ambiguity requires one to look up the actual cited publication, a process that is not easily incorporated into an automated text-processing script.

1.2. Processing Text

1.2.1. Filter Stopwords

After extracting text from the articles, I removed bibliographies and filtered general and domain-specific stopwords. Stopwords are high frequency words used across a corpus that add relatively little meaning to the text. They can be both general (i.e., words with little lexical meaning such as 'the', 'and', 'while', etc.) and domain specific (i.e., words that are used quite often and provide relatively little more information than what we would already expect). General stopwords provide more information about writing conventions and writing styles than information about content. Retaining general stopwords will result in low-quality topics flooded with words such as 'the', 'and', 'in', etc.

Domain-specific stopwords still retain some pertinent information (i.e., often represent taken-for-granted institutional vocabulary). At the same time, domain-specific stopwords will flood topics with words that provide little semantic information about what the topics mean. In a research article, for example, the words "abstract", "experiment", "method", "introduction", "model", "conclusion", etc. represent domain-specific stopwords.

Following Blei 2003, I calculate the term frequency-inverse document frequency (TF-IDF) for each stemmed term and cull the top 200 terms with the lowest weighted-average TF-IDF scores. These terms represent domain-specific stopwords. TF-IDF is calculated by multiplying the frequency of a term i within document j by the log of its inverse-document frequency over the entire corpus. Words with low TF-IDF scores are frequent within documents and common across documents in a corpus.

1.2.2. Stemming Words

After removing stopwords, I stemmed the terms in my corpus. Stemmers work by consolidating similar words (e.g., happy and happiness are consolidated into happi). There are a variety of stemmers that vary in the degree to which they stem works. The most commonly used stemmer is the Porter algorithm Porter (1980), which I use to stem the words in my corpus. There are obvious unintentional consequences of using stemmers, particularly because stemmers do not recognize phrases (e.g., "Apple Computing" would be recognized as "apple" and "comput"). Futhermore, words with the same stem but different meanings (operational, operating, operative) would still be reduced to the same stem (operat).

1.3. Obtaining and Processing Author Biographical Information

1.3.1. For Co-Citation Network

Naming conventions used by the Web of Knowledge limited the identification of authors to surname and first name initial ("Merton R."). In some cases, a middle name initial was provided ("Merton R.K."). Obtaining biographical information on authors through a web search often necessitated the use of a full, unabbreviated name. To obtain an author's full name, I searched for the author's cited publication, which often provided a full name and biographical "clues" such as the author's departmental affiliation and institution. I used this information to conduct a fuller web search, focusing specifically on results that could provide me an author's personal website, curriculum vita, obituary, and/or biographical sketch. When such information could not be found, I searched cached or archived departmental webpages (https://archive.org/) corresponding to the department listed in the author's cited publication. With the exception of the author's current or last occupation, these webpages provided biographical details that were otherwise absent in search results of the current web.

Using these details, I took note of the author's race, gender, and educational background. I identified the author's race and gender by photographs, which could often be found on the author's personal or departmental website. In the few cases where a photograph was not found, I estimated the race and gender of the author based on the author's name. Given that webpages are prone to change and often not static, I saved copies of the author's website, curriculum vita, other such sources containing an author's biographical account, and links to these sources. Author's race was coded as either White, Black, Asian, Latino, or other. Gender was coded as either female or male. Although data was collected for each author's earned degrees, I used an author's postgraduate degree to represent educational background, if available. Several authors listed multiple postgraduate degrees. In cases where an author earned multiple postgraduate degrees or did not earn any postgraduate degrees, I used the most recent degree listed on an author's curriculum vita or an author's departmental website.

1.3.2. For Recoding Degrees

To classify and recode academic degrees, I used the 2010 release of the Classification of Instructional Program (CIP), a taxonomic scheme of academic disciplines developed by the US Department of Education's National Center for Education Statistics. The CIP taxonomy codes academic disciplines according to three codes: a 2-digit CIP, a 4-digit CIP, and a 6-digit CIP. Each code represents a progressively granular distinction in academic discipline. For example, a doctorate in Higher Education can be classified by the 2-digit CIP code 13 (Education), the 4-digit CIP code 13.04 (Educational Administration and Supervision), and the 6-digit CIP code 13.0406 (Higher Education/Higher Education Administration). For some academic disciplines, however, the codes do not necessarily provide greater distinctions. For example, a doctorate in

Sociology can be classified by the 2-digit CIP code 45 (Social Sciences), the 4-digit CIP code 45.11 (Sociology), and the 6-digit CIP code 45.1101 (Sociology).

For the purposes of this paper, I used the 2-digit CIP code to represent degree area and the 4-digit CIP code to represent degree field. I conducted separate analyses according to an author's degree field and degree concentration. The 4-digit CIP code provided a means to make finer degree distinctions within the sample. For example, the 2-digit CIP degree field Social Sciences can be disaggregated into the 4-digit CIP degree concentrations Sociology (45.11), Political Science and Government (45.10), Economics (45.06), Anthropology (45.02), and Social Sciences (General) (45.01).

In one case, however, I used the 6-digit CIP code degree to disaggregate the corresponding 4-digit CIP degree field. A sizable number of the authors sampled obtained their degree in an academic discipline coded by the NCES as Higher Education/Higher Education Administration, a discipline coded by a 6-digit CIP code (13.0406). To make this sub-sample of authors apparent, I divided authors who obtained a degree in the degree field Educational Administration and Supervision (13.04) into those who received a degree in Higher Education/Higher Education Administration, (13.0406) and those who did not. The former is coded as "Educational Administration and Supervision (Higher Education)," while the latter is coded as "Educational Administration and Supervision (Other)."

1.3.3. For Carnegie Classification

To characterize the institution where an author obtained his/her postgraduate degree or most recent degree, I used the 2010 Carnegie Classification of Institutions of Higher Education, a framework for categorizing and comparing institutions on the basis of several shared measures. The Carnegie Classification is based largely on data generated by NCES and made available through IPEDS, but it is also based on data pulled from the College Board Annual Survey of Colleges.

The Carnegie Classification framework is comprised of seven classifications that provide information ranging from an institution's undergraduate selectivity to the percentage of undergraduates living on campus. Six all-inclusive classifications were used for this analysis. A seventh elective classification based on community engagement was excluded from this analysis. This classification is only available for those institutions who choose to provide detailed documentation to the Carnegie Foundation. Each classification aggregates several measures to create descriptive institutional profiles. To make these profiles more tractable, I disaggregated the measures to create several categorical and dummy variables.

After data cleaning, the final sample contains 300 authors. This sample was imported into Gephi for analysis. A discussion of the citation and co-citation analysis will be provided in the proceeding methods section.

1.3.4. For Topic Model

To identify the first authors in the article corpus, I repeated the same search I conducted for the authors in the co-citation network. Given that the authors published between 2000 and 2016, information about these authors was relatively easier to find. I used the ProQuest Dissertations and Theses (PQDT) database to identify the degree field of each author. If the author was not listed on PQDT, I conducted the same web search for the author outlined above. I classified degrees using the same procedure outlined above. The total number of unique first authors is 811.

1.4. Descriptive Statistics for Sample of Co-Cited Authors

A majority of the authors sampled are white (84.3%) and male (70.3%) (Figure 1). In addition, an overwhelming majority of authors have obtained doctoral training (94%), although a few entered into academic publishing with a master's degree (2.66%) or a law degree (3%) (Figure 2). The years these degrees were earned range from 1886 to 2008 (Figure 3).
While a majority of the authors earned their highest degree in the Midwest (35.33%) and the Northwest (33.67%), California is the state where the highest number of authors received postsecondary training (20.33%). In contrast, the South is the region with the lowest (5.33%) (Figure 4).

About half of the authors sampled obtained their highest degree at a public university (50.67%), while almost half (45.67%) attended a private, not-for-profit university. Most of these universities are classified as large, four-year universities. A majority of the authors (88%) attended a university with a level of research activity classified as "very high" under the Carnegie Classification. Overall, about half of the authors sampled (48.7%) attended large, public, four-year, doctoral research universities with a very high level of research activity; over a third (35.7%) attended large, private, four-year doctoral research universities with a very high level of research activity (Figure 5).

The size of the student population at these universities range from small (1,384 students) to large (68,064 students), with an average student population of 29,427 students. A majority of these universities (96.85%) offer professional degrees and medical or veterinarian degrees (76.2%) in addition to doctoral degrees. In addition, a majority of these universities offer a high correspondence of graduate degrees in the same fields as undergraduate degrees (92.3%).
While the sample contains 300 authors, only 68 universities are represented. Over a third (39.3%) of the sampled authors received training at the top five most frequent universities: Harvard University (11.7%), University of Michigan-Ann Arbor (9%), University of California-Los Angeles (7.7%), Stanford University (6%), and University of Chicago (5%). Universities with more than one alumnus in the sample (30 in total) trained 87% of the sampled authors.
Figure 6 summarizes authors' highest degree by degree field (2-digit CIP) and degree concentration (4-Digit CIP). The Social Sciences represents the degree field for the greatest number of authors sampled (36%), followed by Education (33.3%), Psychology (12.67%) and Public Administration and Social Services (6.67%).

Educational Administration and Supervision represents the degree concentration for the greatest number of authors sampled (23.6%). In the interest of distinguishing sub-concentrations nestled within the field of Educational Administration and Supervision, the degree field was disaggregated and recoded into two categories: (1) Higher Education and (2) Educational Administration and Supervision (Other). After disaggregation, Higher Education represents the degree field for the greatest number of authors sampled (22%), followed by Sociology (20%), Economics (13%), Education (General) (6.33%), and Psychology (General) (5%).

1.5. Citation Frequencies

1.5.1 By Gender and Race

Although the mean number of total citations is higher for men (57.82) than women (42.31), 95% confidence intervals for these estimates reveal suggest these means do not significantly differ (Figure 7). Similarly, the mean number of papers citing men (38.18) is higher than that for women (29.15). However, the 95% confidence interval estimates for these means do not overlap; men have a significantly higher mean number of papers citing their work. The mean ratio between number of citations and number of citing articles received by men and women does not significantly differ.

Examining citation patterns by race reveals several disparities (Figure 8). While the number of black authors contained within the sample is small (13), black authors have a significantly lower mean total number of citations and mean number of papers citing their work in comparison to whites. The mean ratio between number of citations and number of citing articles does not significantly differ by race.

1.5.2 By Degree Area/Field

The mean total number of citations of the degree fields with the greatest representation, the Social Sciences (57.22), Education (51.07), Psychology (55.11), and Public Administration and Social Service Professions (53.5) are similar and do not significantly differ (Figure 9). Furthermore, the mean number of papers citing authors from these degree fields and the mean ratio between number of citations and number of citing articles do not significantly differ. Inspecting the degree concentrations with the greatest representation by mean total number citation reveals additional similarities. Economics (64.15) has the highest mean total number of citations, followed by Education (General) (62.11), Sociology (53.5), Higher Education (50.27), and finally Psychology (General) (42.6). Psychology (General) has a significantly lower mean total number of citations than Economics.

Inspecting these degree concentrations by mean number of citing papers reveals a similar pattern: Economics (39.74) has the highest mean, followed by Education (General) (38.89), Higher Education (36.76), Sociology (37.2), and finally Psychology (General) (29.67). Sociology and Higher Education are the only fields with significantly higher means than Psychology (General). The mean ratio between number of citations and number of citing articles for these degree fields do not significantly differ.

1.6. Measures of Centrality

1.6.1. Node Degree

Men have a significantly higher mean degree (165.74) compared to women (151.70) (Figure 10). The mean degree, in contrast, does not significantly vary by race (Figure 11).

Of the degree concentrations with the greatest representation, Public Administration and Social Service Professions has the highest mean degree (179), followed by the Social Sciences (171.85), Education (157.56), and Psychology (145.47) (Figure 12). Psychology has a significantly lower mean degree than the Social Sciences.

Of the degree concentrations with the greatest representation, Higher Education has the highest mean degree (173.41), followed closely by Education (General) (173.16), Economics (159.36), Sociology (157.97), and Psychology (General) (152.27). However, these mean estimates do not significantly differ.

1.6.2. Mean Centrality: Eigenvector, Betweenness, Closeness

1.6.2.1. By Gender and Race

The mean eigenvector centrality is higher for men (0.614) than women (0.565), the mean closeness centrality is higher for women (1.493) than men (1.446), and the mean betweenness centrality is higher for men (73.89) than women (56.42) (Figure 13). However, these mean estimates do not significantly differ between men and women.

Latinos have the highest mean eigenvector centrality score (0.648), followed by Whites (0.601), Blacks (0.577), and Asians (0.555) (Figure 14). Asians have the highest mean closeness centrality score (1.508), followed by Blacks (1.488), Whites (1.457), Latinos (1.414). Latinos have the highest mean betweenness centrality score (83.96), followed by Whites (70.11), Blacks (53.35), and Asians (47.85). However, none of the three mean estimates of centrality significantly differ by race.

1.5.2.2. By Degree Field/Concentration

Of the degree fields with the greatest representation, Public Administration has the highest mean eigenvector centrality (0.66), followed by Education (0.63), Social Sciences (0.59), and Psychology (0.54). Psychology has a significantly lower mean eigenvector centrality than Education and Social Sciences.

Of the degree concentrations with the greatest representation, Higher Education has the highest mean eigenvector centrality 0.6376), closely followed by Education (General) (0.6370), Economics (0.5951), Sociology (0.5887), and Psychology (General) (0.5347). However, these mean estimates do not significantly differ.

Of the degree fields with the greatest representation, Public Administration has the highest mean betweenness centrality (83.75), followed by Education (81.85), Social Sciences (61.97), and Psychology (56.2). However, these mean estimates do not significantly differ.

Of the degree concentrations with the greatest representation, Education (General) has the highest mean betweenness centrality (84.95), followed by Higher Education (82.41), Sociology (62.75), Economics (62.35), and Psychology (General) (59.41). However, these mean estimates do not significantly differ.

Of the degree fields with the greatest representation, Psychology has the highest closeness centrality (1.5135), followed by Social Sciences (1.4731), Education (1.4253), and Public Administration (1.4013). Education has a significantly lower closeness centrality than Psychology.

Of the degree concentrations with the greatest representation, Psychology (General) has the highest closeness centrality ((1.5148), followed by Economics (1.4670), Sociology (1.4717), Higher Education (1.4200), and Education (General) (1.4209). However, these mean estimates do not significantly differ.

2. Article 3 Appendix

2.1 Corpus Processing

The Google Books Ngram corpus was first released in 2009 in multiple languages. An update followed in 2012. Each version has the option to download ngrams 1- through 5-grams in size. Furthermore, each set of ngrams is split into multiple files in consideration of bandwidth and space. I use the English set of 5-grams released in 2012.

Each file used for this study is comprised of a tab-separated document, where each line corresponds to an ngram with four corresponding pieces of data: the ngram, the year the ngram was in use, the number of times the ngram occurred for that year, and the number of books containing the ngram for that year. Only ngrams that appear over 40 times across the corpus are included in the Google Books Ngram corpus.

To identify the subcorpus of 5-grams for my analysis, I isolated 5-grams containing the term "network". I isolate the top 1,000 terms V over the subset of 5-grams by selecting the terms by term frequency-inverse document frequency (tf-idf). To do so, I treat each unique ngram as a document. I calculate each term's frequency across ngrams by number of books, across years. After filtering for stopwords, I isolate the top 500, 1,000, and 1,500 terms by tf-idf. I use this set of terms to compute the network's jurisdiction and temporality.

2.2 Jurisdiction

I follow the method outlined by Hoffman et al. (2018) to sparsify the semantic network of the network metaphor. Specifically, I use use a cutoff point for the proximity score that maximizes the number of edges and the quality of the assignment of nodes to communities in the largest connected component of the network in the form $\log(n) * modularity$.

2.3 Temporality

I follow the method of periodization outlined by Rule, Cointet, and Bearman (2015) to calculate the annual relative change in use of the network metaphor and identify significant changes in its career. The year that minimizes the global heterogeneity of the partition, defined as the average pairwise cosine distances for the partition, is 1940. This minimum is observed across multiple sizes of V.

The period corresponding to the Cold War (1945-1990) marked an increasing divergence in the heterogeneity of the pre- and post-partition. The rate of change in heterogeneity of the post-partition began to plateau in 1991. The period corresponding to 1813-1840 observed rapid fluctuations in the heterogeneity of the pre-partition.

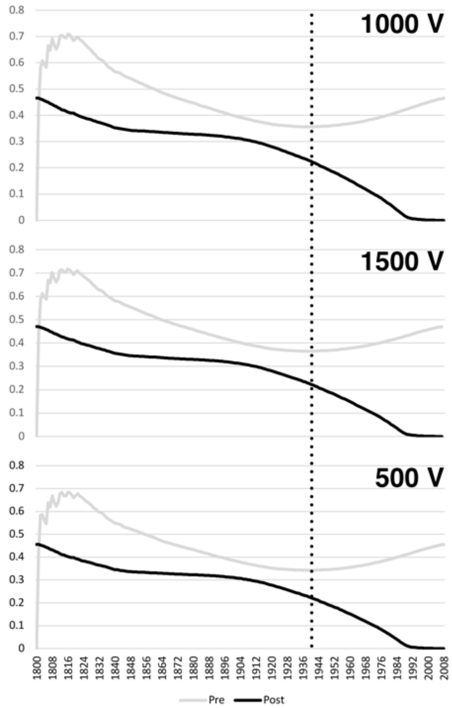

Figure 1. Average, heterogeneity of the pre- and post-partition periods, by year demarcating partition.

2.4 Ecology

I follow Hamilton, Leskovec, and Jurafsky (2016) to identify changes over time in the network metaphor's word embedding. I use sequential embeddings trained on decade-long time-periods over the entire span of the corpus. The size of the embedding vector is typically 300 dimensions, a parameter that yields the most performant SGNS model across multiple benchmarks (Mikolov et al. 2013; Kozlowski, Taddy, and Evans 2019). Due to the stochastic nature of SGNS, embeddings trained on sets of data from different time-periods will not be aligned across time, precluding the comparison of a word across time. To align embeddings across time-periods, Hamilton, Leskovec, and Jurafsky (2016) use orthogonal Procrustes to produce a rotational alignment that optimizes the preservation of cosine similarities across time-periods. That is, it produces an alignment across time-periods that maximizes cosine similarity over the entire vocabulary.

A basic neural network consists of three distinct layers of neurons (or nodes): an input layer that takes in a signal, a hidden layer that amplifies or reduces the signal by weights, and an output layer that transforms the signal into predictions. In word2vec, the input layer is the same as the hidden layer (Figure 1). A layer distributes the signal it receives according to weights between its individual neurons and the neurons of the proceeding layer. A neuron with a higher weight sends an amplified signal while a neuron with a lower weight reduces the signal. Over time, as the network sees more examples of training data, it will adjust the weights such that it improves the distribution of the signal in the network. In word2vec, the are 2 sets of weights: the weights corresponding to the upper embedding layer (here, a weight matrix of dimension 100K*300) and weights corresponding to the lower output layer (here, a weight matrix of dimension 300*100K).

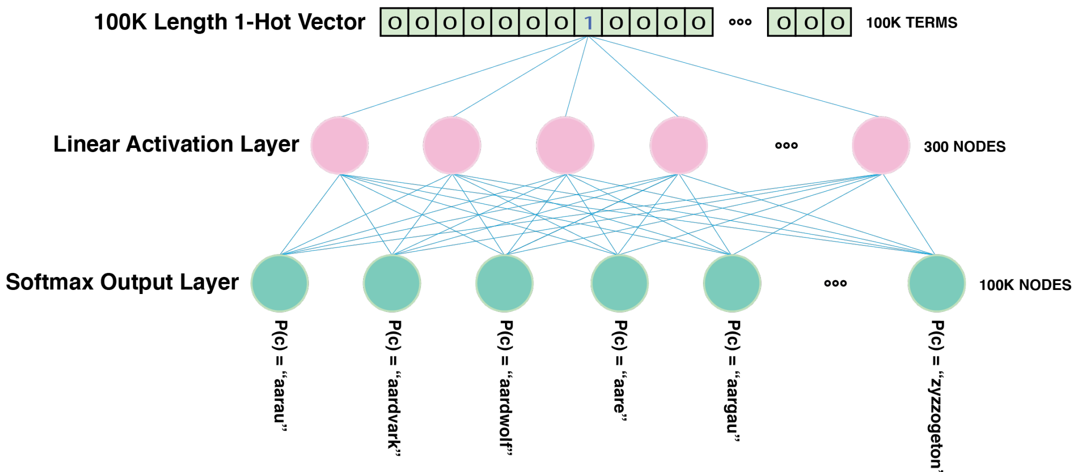

Figure 2. Generalized 2-layer architecture of word2vec.

Neural networks learn models of data using a given objective function(s). The *objective function* or *task* is what the model ultimately uses as its benchmark for success. When the final signal in a neural model reaches the output layer, the signal is processed using the objective function, which outputs a signal that is the model's prediction given the data. We compare this prediction to the actual known value (e.g., the actual probability a word is a context word of the focal word). If the predicted probability is off, we backpropagate the error of the prediction (predicted minus actual) in a process that distributes the error according to the model's weights and adjusts the weights accordingly. The objective of SGNS is to maximize the log probability of a word being a context or neighboring word of a given word, defined using the softmax function.

2.5 Conventionality

I follow Gentner and Bowdle (2001) and Bowdle and Gentner (2005) and define the simile form of a metaphor ("like a") as a comparison and the metaphor form ("is a") as a categorization. To examine the use of the network metaphor in comparisons or categorizations over time, I use the subcorpus of 5-grams containing the term "network" and compare the frequencies of "is a network" and "like a network" across books across years.