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INTERACTION GEOGRAPHY & THE LEARNING SCIENCES

by Ben Rydal Shapiro

Dissertation

Submitted to the Faculty of the
Graduate School of Vanderbilt University
in partial fulfillment of the requirements
for the degree of

Doctor of Philosophy

in

Learning, Teaching, and Diversity

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INTRODUCTION

The problem

There are many approaches that support studies of learning in relation to the physical environment, people's interaction with one another, or people's movement. However, what these approaches achieve in granularity of description, they tend to lose in synthesis and integration and, to date, there are not effective concepts and methods to study learning in relation to all of these dimensions simultaneously.

As a result, separate research perspectives have developed, each seeking to characterize the relation between the physical environment and human learning in different ways. Some perspectives seek to determine whether properties of the physical environment (e.g., circulation and visibility patterns) condition student performance and teacher pedagogy in settings such as classrooms, museums, and university campuses (Tanner, 2009; Cleveland & Fisher, 2014; Imms et al., 2016; Ellis & Goodyear, 2018; Strange & Banning, 2001). Other perspectives seek to illustrate how people use their bodies along with artifacts and segments of the physical environment during face to face interaction to assemble social learning contexts (Erickson, 2004; Leander, 2002; Rowe, 2008). Still other perspectives seek to show how people realize learning opportunities across settings such as urban environments (Taylor & Hall, 2013; Lave et al., 1984; Ma & Munter, 2014). Each of these perspectives has distinct weaknesses that are directly addressed by the strengths of the other perspectives. Missing are conceptual frameworks and resources that integrate these perspectives to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn.

Overview of dissertation

The three papers in this dissertation address this problem in new, interdisciplinary ways. The first paper, in collaboration with others from the Space, Learning & Mobility Lab, outlines our development and use of a new approach to describe, represent, and interpret people's interaction as they move within and across physical environments. We call this approach *interaction geography*. We show how, in comparison to traditional approaches, interaction geography provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings. This paper has been previously published in the *International Journal of Computer-Supported Collaborative Learning* (Shapiro, Hall & Owens, 2017). In the first part of this paper, we illustrate our development and use of interaction geography to study visitor engagement in a cultural heritage museum. In particular, we illustrate *Mondrian Transcription*, a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS)*, a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. In the second part of this paper, we describe one team of museum educators, curators, archivists, and exhibit designers using a computer-supported collaborative learning (CSCL) environment based on

interaction geography. We show how this environment used interaction geography to disrupt the conventional views of visitor engagement and learning that museum professionals hold and then reframe these disruptions to enable museum professionals to perceive visitor engagement and learning in innovative ways that potentially support their future design decisions.

The second paper extends this work by providing a conceptual framework to expand interaction geography in studies of learning. I begin by reviewing and critically interpreting what I see as four historically separate research perspectives. The first and second perspectives, which I call the *responsible* and *response-able teaching settings* perspectives, determine different ways properties of the physical environment condition student performance and teacher pedagogy respectively in settings such as classrooms, museums, and university campuses. The third perspective, which I call the *interaction typologies* perspective, illustrates how people use their bodies along with artifacts and segments of the physical environment during face to face interaction to *assemble* social learning contexts. The fourth perspective, which I call the *movement geographies* perspective, shows how people's movement realizes learning opportunities across settings such as urban environments. My review aims to highlight strengths and weaknesses across these perspectives and to outline a conceptual framework for their integration. Subsequently, I introduce and critically analyze representations produced using interaction geography from Shapiro, Hall & Owens (2017). In particular, I introduce and critically analyze concepts and methods of interaction geography including Mondrian Transcription and the interaction geography slicer (IGS). My analysis shows how interaction geography offers resources to integrate each of the four perspectives in order to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn. I conclude by outlining limitations and necessary next steps to expand interaction geography in studies of learning.

The third paper, in collaboration with Francis A. Pearman II, adapts and uses the IGS to visualize and discuss data about New York City's Stop-And-Frisk Program. This paper has been previously published in the 2017 IEEE Vis Arts Program (Shapiro & Pearman, 2017). In particular, we show how the IGS provides new ways to view, interact with, and query large-scale data sets of stop-and-frisk and crime data over space and through time to support analyses of and public discussion about a controversial social and political issue. In doing so, this paper extends the scope of my dissertation in three primary ways. First, it demonstrates the computational possibilities and potential scalability of interaction geography and in particular, the IGS. Second, it shows the application of interaction geography to fields beyond education including information visualization, urban planning, and statistics. Finally, it further illustrates how interaction geography supports new collaborations across the fields of education, information visualization, architecture, and the arts that are necessary to understand complex phenomena such as learning or stop-and-frisk policing tactics over space and time.

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DEVELOPING & USING INTERACTION GEOGRAPHY IN A MUSEUM

Abstract

There are many approaches that support studies of learning in relation to the physical environment, people's interaction with one another, or people's movement. However, what these approaches achieve in granularity of description, they tend to lose in synthesis and integration, and to date, there are not effective methods and concepts to study learning in relation to all of these dimensions simultaneously. This paper outlines our development and use of a new approach to describing, representing, and interpreting people's interaction as they move within and across physical environments. We call this approach interaction geography. It provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings. The first part of this paper illustrates our development and use of interaction geography to study visitor engagement in a cultural heritage museum. In particular, we illustrate *Mondrian Transcription*, a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS)*, a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. The second part of the paper describes one team of museum educators, curators, archivists, and exhibit designers using a computer-supported collaborative learning (CSCL) environment based on interaction geography. We show how this environment used interaction geography to disrupt the conventional views of visitor engagement and learning that museum professionals hold and then reframe these disruptions to enable museum professionals to perceive visitor engagement and learning in innovative ways that potentially support their future design decisions. We conclude the paper by discussing how this work may serve as a blueprint to guide future efforts to expand interaction geography in ways that explore new collaborations across the fields of education, information visualization, architecture, and the arts.

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Introduction

There are many approaches that support studies of learning in relation to the physical environment, people's interaction with one another, or people's movement. For example, post-occupancy evaluation (Zimring & Reizenstein, 1980; Cleveland & Fisher, 2013) encompasses approaches that support studies of how the physical layout of classrooms, museums, and workplaces influences people's learning by conditioning their behavior (Monahan, 2002; Cleveland, 2009; Scott-Webber, 2004; Wineman et al., 2006; Peponis et al., 1990). Conversation analysis (Erickson, 2004; Ludvigsen et al., 2016; Stahl et al., 2006) and interaction analysis (Jordan & Henderson, 1995; Hall and Stevens, 2015) support studies that unpack how technology-mediated interactions between people make up social learning contexts (Cress, 2008; Stahl et al.,

2014; Suthers et al., 2010; Davidsen & Ryberg, 2017; Leander, 2002). Movement based approaches (Hagerstrand, 1970, Cresswell, 2010; Sheller & Urry, 2006; Kwan and Lee, 2003) support studies that investigate how people realize or miss learning opportunities as they move across contexts over the course of days, months, and even years (Taylor & Hall, 2013; Marin, 2013; Ito et al., 2009).

However, what these approaches achieve in granularity of description, they tend to lose in synthesis and integration. For example, post-occupancy evaluation typically ignores people's conversation and the sequential organization of people's movement (Shapiro, 2017a). Interaction and conversation analysis traditionally disregard the physical environment and people's movement beyond the scale of artifacts and gesture (Flood et al., 2015; Marin, 2013; Lemke, 2000). Movement based approaches do not operate at a scale relevant to people's interaction with one another or the physical environment of settings like classrooms or museum gallery spaces (Scollon, 2008; Hall and Stevens, 2015).

The lack of integrative approaches that simultaneously consider the physical environment, people's interaction with one another, and people's movement hinders learning research and professional design practice particularly in informal learning settings. For example, the assessment of visitor engagement and learning in museums is often simplified to important but basic questions such as how long people remain at exhibits. This is because museum researchers and designers are not able to take account of other factors such as how visitors recruit the attention of family members or peers to engage with the designed content of museum galleries; how they relate one exhibit to another (e.g., making return trips to seek additional information); and how they collect, edit, and share their experiences with one another through their movement across a complete museum visit. Put differently, informal learning settings like museums are places in need of assumptions and methods that are not school-based (Schauble et al., 1997) and ideally require ways to link fine grained analyses of visitor conversation, interaction, and embodied activities at single museum exhibits (Crowley & Jacobs, 2002; Steier, 2014; Stevens & Hall, 1997) with broader analyses of how visitors make sense of intended museum design across gallery spaces and complete museum visits (Tzortzi, 2014).

This paper outlines our development and use of a new approach to describing, representing, and interpreting people's interaction as they move within and across physical environments. We call this approach interaction geography. It provides a more integrative and multi-scalar way to characterize people's interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings. The first part of this paper illustrates our development and use of interaction geography to study visitor engagement in a cultural heritage museum. In particular, we illustrate Mondrian Transcription, a method to map people's movement and conversation over space and time, and the Interaction Geography Slicer (IGS), a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. The second part of the paper describes how a team of museum educators, curators, archivists, and exhibit designers used a computer-supported collaborative learning (CSCL) environment based on interaction geography. We show how this environment used interaction geography to disrupt the conventional views of visitor engagement and learning that museum professionals hold and then reframe these disruptions to enable museum professionals to perceive visitor engagement and learning in innovative ways that potentially support their future design decisions. We conclude the paper by

discussing how this work may guide future efforts to expand interaction geography in ways that explore new collaborations across the fields of education, information visualization, architecture, and the arts.

Museum setting & empirical basis

The setting and empirical basis of this research is a three year project to understand how visitors cultivate interests in and learn about the diverse historical and cultural heritage of American Roots and Country music as they visit a nationally renowned museum located in the mid-South region of the United States.

Three primary research questions guided our work within this museum context. First, we wanted to describe the interaction and conversation patterns of visitors at single museum exhibits in relation to their movement across gallery spaces during their complete museum visit. Second, we wanted to use these descriptions to better understand how visitors furthered their own personal interests, cultural identities, and interest-driven learning. Third, we wanted to see if and how exploration of visitor activity using new types of computer-supported collaborative learning environments could advance the professional insights and vision (Goodwin, 1994) among museum professionals to identify ways to design more equitable, expansive, and productive learning opportunities in museum gallery spaces. These questions required new types of research data as well as new ways to represent and interpret this research data. In particular, the first two questions required detailed, multi-perspective accounts of the conversation, technology-mediated interaction, and movement of groups of visitors across complete museum visits along with new ways to describe, represent, and interpret these accounts that integrated the fields of education, information visualization, architecture, and the arts. The third question required linking the rich body of literature within the CSCL community concerning the use of tools, especially video-based tools, in forms of reflective professional practice (see Erickson, 2007; Zahn et al., 2012; Ligorio & Ritella, 2010; Johansson et al., 2017; Lymer et al., 2009; Cress et al., 2015) with techniques from information visualization and computational information design (Stasko et al., 2008; Fry, 2004) in ways that advanced the work of professional practitioners at this museum.

To answer the first two questions, we collaborated with museum partners and participating visitor groups/families over a period of six weeks to collect a purposive sample of complete museum visits across 22 visitor group cases (2–5 visitors per group), including 11 family groups. Data from these 22 case studies included continuous, multi-perspective video and audio records (72 h total) of visitor group movement, interaction, and social media/technology use. These data were collected through small, unobtrusive cameras worn by visitors (as necklaces) for the duration of their visit with no researchers present (visits ranged from 30 min to 4 h). These data subsequently required developing new ways to organize, represent and make sense of large quantities of multi-perspective audio and video records over space and time (e.g., up to 5 simultaneous streams of audio/video per visitor group) along with detailed transcripts of visitors' conversation and movement. Data also included 1–2 h post-visit interviews with all visitor groups, which often included walks back through the museum with researchers. Data also included traces of online content (e.g., photographs, videos, online conversations) that visitors gathered (e.g.,

with cell phones/cameras) and shared with others on various social media platforms during and after their visit.

To answer the third question, we collected audio, video and survey data from a series of professional development and design workshops with museum educators, curators, archivists, and exhibit designers. These workshops are part of a larger design study (Cobb et al., 2003) that aims to advance museum professionals' learning about how design practice can create opportunities for interest-driven learning in and beyond their gallery spaces.

Visualizing & studying visitor engagement

We now describe our development and use of interaction geography to visually transcribe museum visitors' interaction over space and through time and to study visitor engagement. **Figure 1 - 1** adapts methods of time geography (Hagerstrand, 1970) to map the movement across a museum gallery space of a visitor we call Adhir. Adhir is 25 years old and is one member of a family of five, who we call the "Bluegrass Family". The left of the figure or "floor plan view" shows Adhir's movement as an orange path over a floor plan of the gallery space (i.e., looking down on the space). The right or "space-time view" (Hagerstrand, 1970) extends Adhir's movement on the floor plan horizontally over time. Also included is a rendering showing the gallery space from a point marked on the floor plan.

The floor plan view shows where Adhir goes within the gallery space, while the space-time view shows how he moves within the gallery space over time. For example, after entering the gallery space (top left of floor plan view and beginning of space-time view), Adhir walks towards an exhibit about Hank Williams (marked on the floor plan). Hank Williams is generally regarded as one of the most significant American singers and songwriters in the twentieth Century (Escott et al., 2004). Adhir stands for almost 5 min at the Hank Williams exhibit, and in the audio and video record, he seems to be moved to tears by what he finds there. His standing or deep engagement with the exhibit is indicated by a horizontal orange path in the space-time view that extends from approximately minutes 0–5 and corresponds to the vertical position of the Hank Williams exhibit.

Subsequently, Adhir moves and stands (as indicated by the other horizontal orange lines in the space-time view) for varying lengths of time at four of the five other exhibits that comprise a semicircular set of exhibits. From top to bottom on the floor plan, this semicircle includes exhibits on renowned Bluegrass and early Country musicians Hank Williams, Lester Flatt, Earl Scruggs, Bill Monroe, Maybelle Carter, and Jimmie Rodgers. Adhir concludes his visit to the gallery space by walking quickly back across these exhibits leaving the space where he entered and notably not visiting the Jimmie Rodgers exhibit.

Figure 1 - 2 maps in blue the movement of six-year-old Blake, another member of the Bluegrass Family, during his visit with Adhir to this gallery space. Blake's sister is Adhir's fiancé. All conventions and scaling match the previous figure. Line pattern distinguishes between three horizontal areas of space on the floor plan providing some description of horizontal movement on the floor plan in the space-time view.

Figure 1 - 2 illustrates not only where Blake and Adhir go within the gallery space and how they interact with exhibits but also how they interact with one another over space and time. For

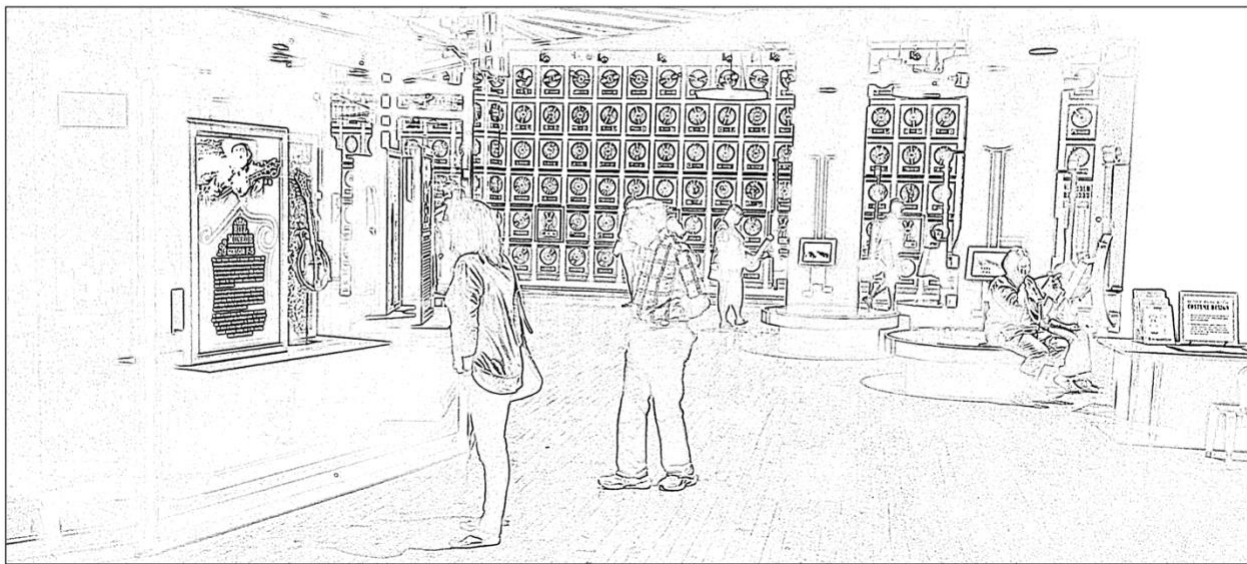
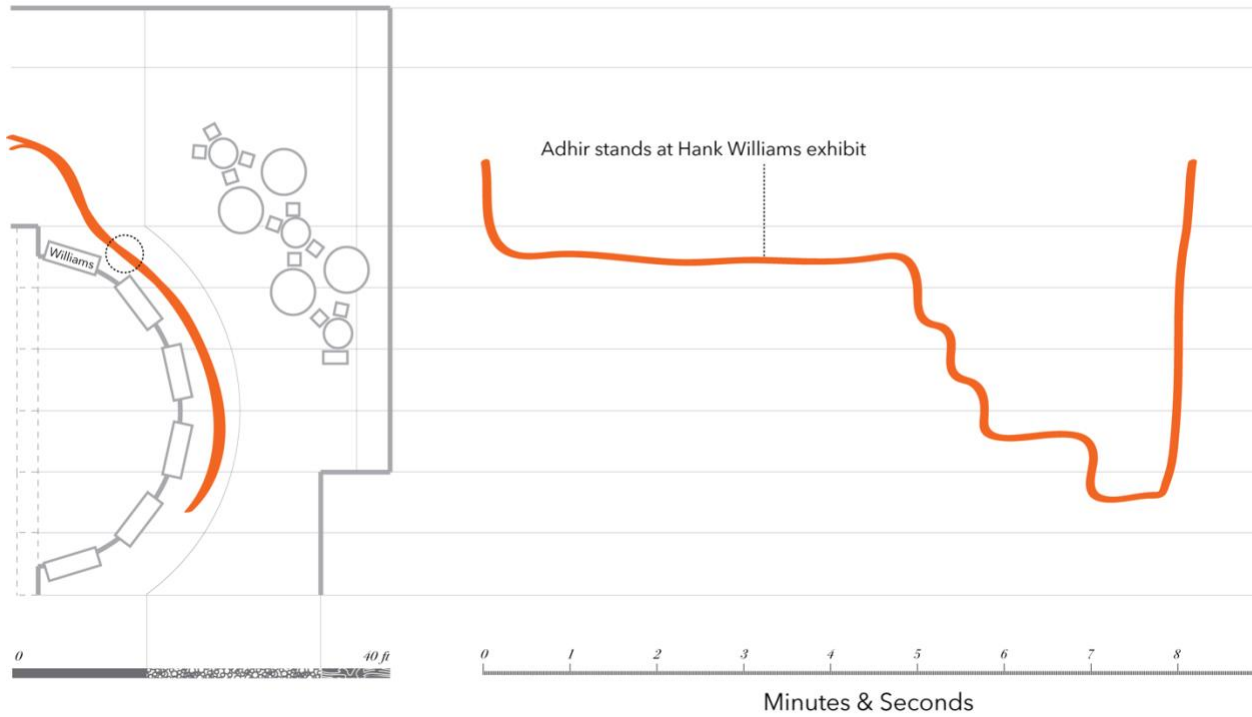


Figure 1 - 1: Adhir's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

example, the space-time view shows that while Adhir stands at the Hank Williams exhibit, Blake moves quickly (apparently running as indicated by the sharp slope of his movement path) back and forth across the semicircle of exhibits in the gallery space. Closer analysis of Blake's efforts in the audio and video record confirm that his movement path reflects multiple, frantic attempts

Adhir ²⁵ Blake ^{6 years old}

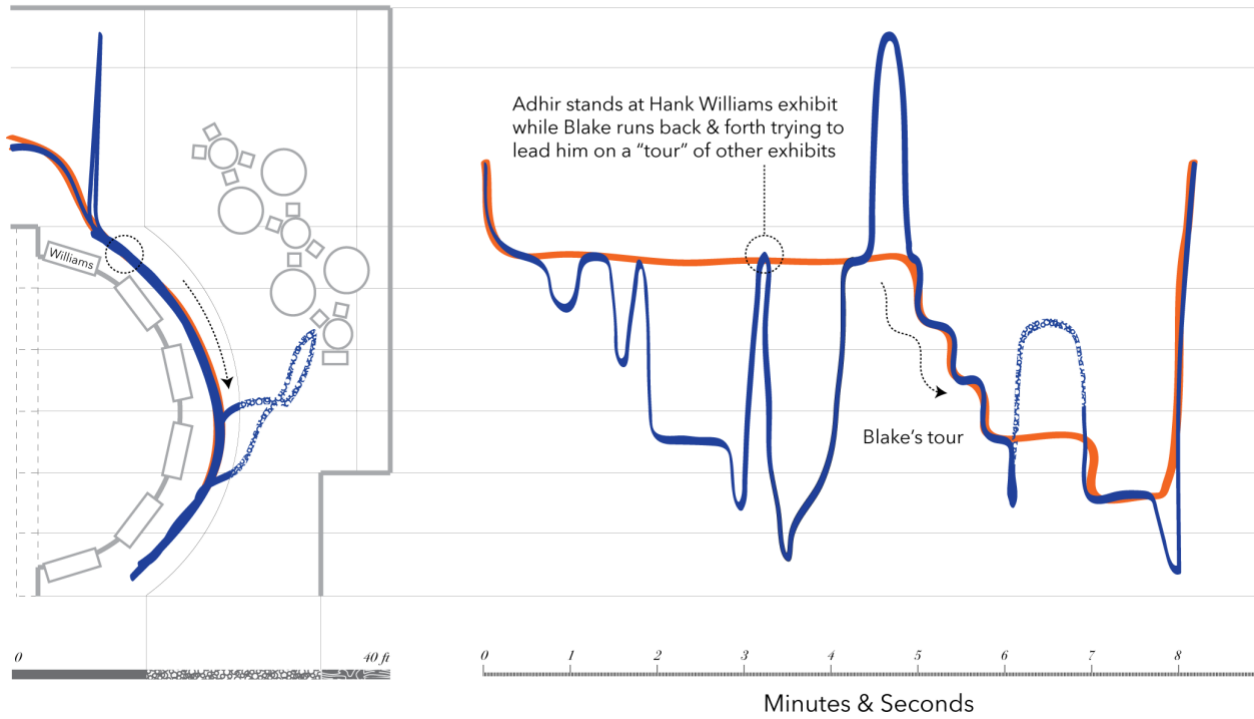


Figure 1 - 2: Blake and Adhir's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

Lily ²⁰ Jeans ¹⁰

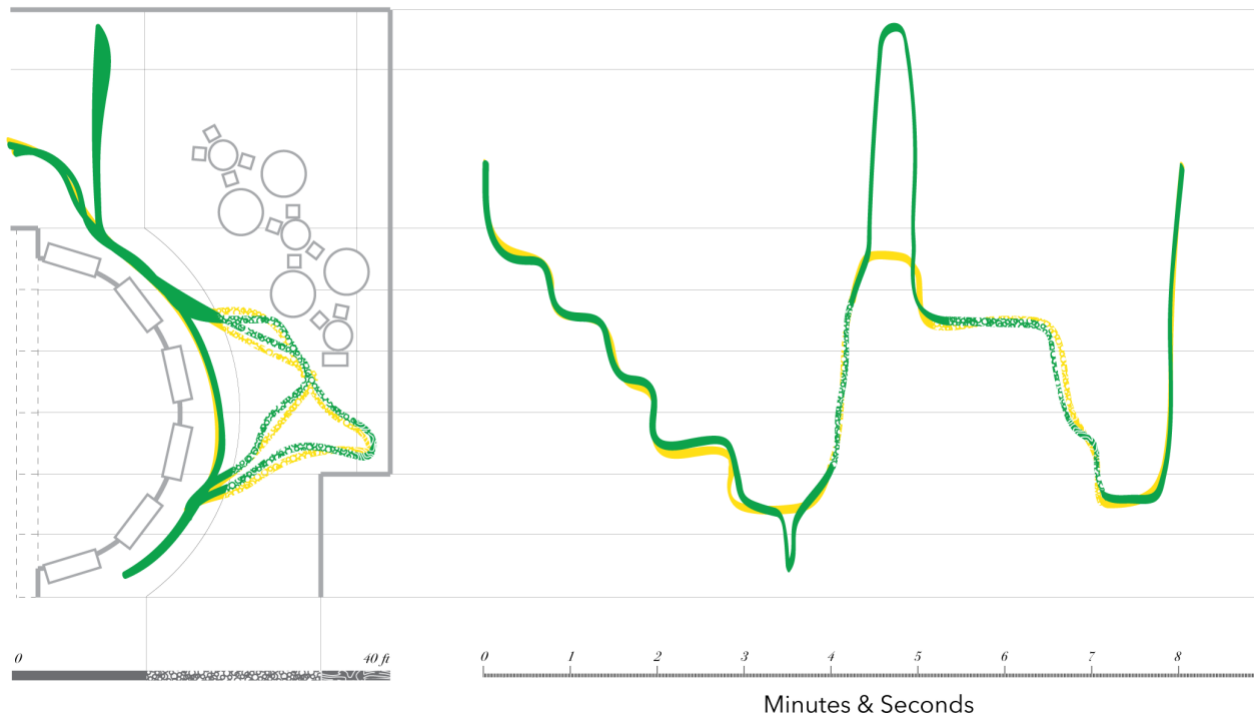


Figure 1 - 3: Jeans and Lily's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

to draw Adhir away from the Hank Williams exhibit. After four failed attempts, Blake finally succeeds in leading Adhir on what we describe as a “tour” of other exhibits in the gallery, which occurs in Figure 1-2 when their movement paths intertwine in space-time from approximately minutes 5–6.

Figure 1 - 3 displays the movement of two other members of the Bluegrass Family, Blake’s brother Jeans (green) and their sister Lily (yellow), during the family’s visit together to this gallery space. The space-time view illustrates how Jeans and Lily nearly always move through the gallery space together (they were apart only during minutes 4–5).

Together, Figures 1 - 2 and 1 - 3 illustrate how pairs within the Bluegrass Family move to engage with exhibits and one another in starkly different ways. While Blake displays a recruitment movement pattern in response to Adhir’s extended pattern of reverence, Jeans and Lily produce intertwined movement, similar to the tour movement pattern later produced by Blake with Adhir.

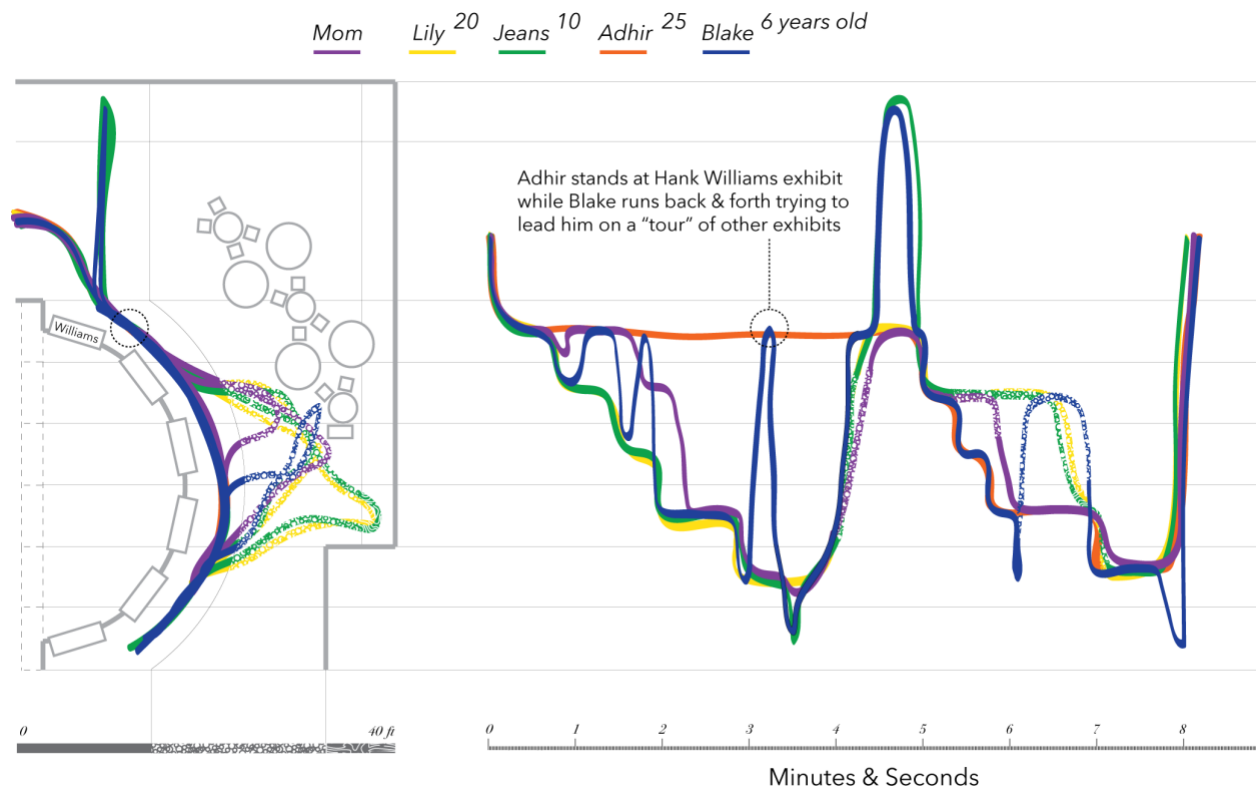


Figure 1 - 4: The Bluegrass Family’s movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

Figure 1 - 4 maps the movement of all 5 members of the Bluegrass family and now includes Blake, Jeans and Lily’s mom, Mae, in purple (e.g., we use the name “Mom” in the figure to emphasize Mae’s role as a parent). The figure shows how the Bluegrass Family is intimately engaged with the semicircle of exhibits dedicated to famous Bluegrass and early Country musicians. On one hand, the figure reveals the family’s dense and focused movement patterns in space and time at and across these exhibits (and not at other exhibits in the gallery). On the other hand, the figure shows visible qualities (e.g., pace, duration, shape, distance) and relationships (e.g.,

intersections, weaving, splitting, proximity) among movement paths that support and deepen different analytical framings of engagement. In particular, these qualities and relationships provide a means to study how the family engages by producing what some call a meshwork of movement (Ingold, 2007), within which they manage personal and social distances (Hall, 1966) between one another in relation to the spatial layout of the space.

For example, Figure 1 - 4 illustrates how Adhir's movement and physical location anchors and influences the movement trajectories of other family members, particularly Blake. Furthermore, the figure suggests that Adhir and Lily are recipients of the younger boys' efforts to show what they have learned in the gallery during the family's visit to this space. As described in their post-visit interview, Blake, Jeans, and Mae had also visited the museum 2 days earlier. Close analysis of Figure 1 - 4 suggests that Jeans, through his close and constant proximity to Lily, and Blake, through his constant efforts to lead Adhir on a tour, are sharing this gallery space with Adhir and Lily through their movement. Finally, the space-time view in Figure 1 - 4 shows how Mae's movement often lags behind her family's movement and how she often re-joins her family at particular moments when they are stopped and gathered together at an exhibit. As we will show in detail later, these patterns helped us understand how Mae manages her children's engagement and learning by joining them at moments of peak engagement to make connections across exhibits for her children. The space-time view is essential to describing, representing, and interpreting visible qualities and relationships among movement paths that support different analytical framings of engagement.

Figure 1 - 5 extends the previous figures to illustrate more fully a way of transcribing people's interaction. We call this Mondrian Transcription, because it bears resemblance to the work of the Modernist artist, Piet Mondrian (1872–1944), particularly to his use of lines in relation to forms (e.g., visitor paths and graded regions of engagement through talk-in-interaction, in our usage). The top half of the figure once again shows the movement of all five members of the Bluegrass Family. The bottom half maps the Bluegrass Family's conversation in relation to their movement (i.e., the family's movement is shown in gray beneath their conversation to link the two halves of the figure).

In Figure 1 - 5, conversation is transcribed and organized in a manner that draws from and extends conventions of conversation analysis used in the learning sciences and CSCL communities (Derry et al., 2010; Jordan & Henderson, 1995; Stahl et al., 2006; also see Erickson, 2004, for analysis using conventions drawn from musical scoring). Given a typical line-ordered transcript, Mondrian Transcription shows each turn at talk as a colored line to indicate which family member contributes (i.e., speaks) that conversation turn (indentations indicate overlapping speech). Second, colored lines of talk are gathered into boxes that group topically related sequences of conversation turns and movement (e.g., usually related to artifacts/musicians). These sequences resemble what Ananda Marin (2013) calls ambulatory sequences or interleaved sequences of movement and talk among multiple people situated in and across the physical environment.

In other words, in the space-time view, each box marks the start, duration, and end of an ambulatory sequence and reveals how moments of conversational engagement are organized sequentially across the gallery space (Marin's work extends Adam Kendon's concept of a facing formation, see Kendon, 1990). For instance, the bottom half of Figure 1 - 5 highlights one box in space-time, where the readable text expands the box of colored lines that, along with people's movement, represent an ambulatory sequence. In the floor plan view, ambulatory sequences

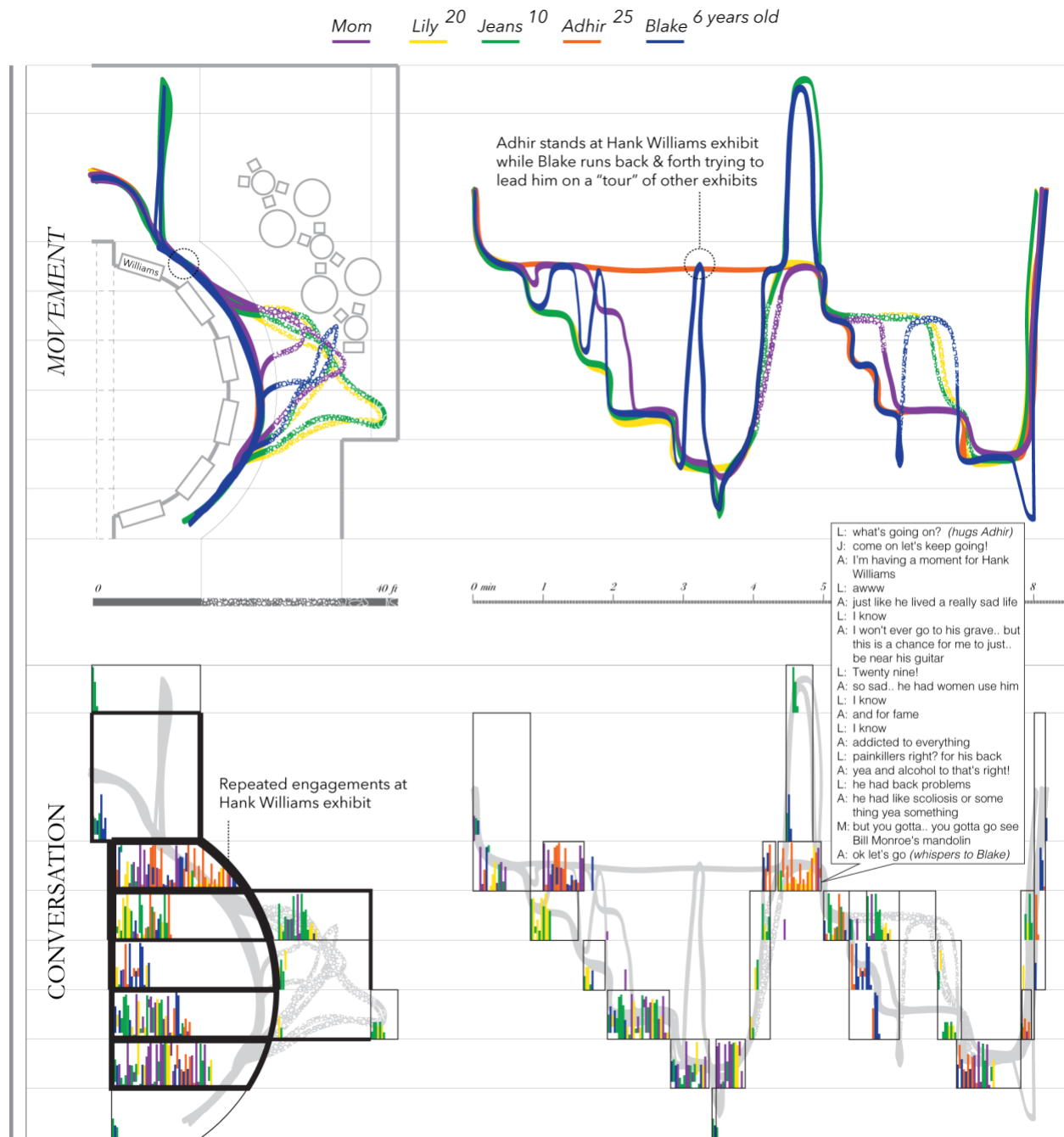


Figure 1 - 5: Mondrian Transcript of the Bluegrass Family's interaction geography. Copyright © by Ben Rydal Shapiro. Reprinted by permission

accumulate over time within regions of gridded space to create what we call engagement footprints (similar to heat maps). For example, the region of space around the Hank Williams exhibit has the largest number of conversation turns (as indicated by the many colored lines of talk) and is enclosed by a dense box that reflects five separate (in time) ambulatory sequences occurring at the Hank Williams exhibit (the box thickness in the floor plan view increasing with each repeated ambulatory sequence). Such a dense engagement footprint indicates that the Bluegrass Family is intensely and repeatedly engaging with the Hank Williams exhibit. It also

shows when and which family members facilitate this engagement through their conversation turns. The boxes in the figure reflect our decisions about what constitutes a thematic topic among interacting speakers; however, other researchers, designers or practitioners could use Mondrian Transcription to group and study conversation turns and movement in ways that suit their needs. Likewise, Mondrian Transcription could potentially incorporate additional types of conventions to, for example, indicate body positions, gestural drawings or the direction of talk (e.g., who is talking to whom).

Figure 1 - 5 conveys how interaction geography provides fundamentally new ways of describing, representing, and interpreting people's interaction in relation to their movement through the physical environment. For example, the ambulatory sequence (highlighted by the readable text) occurring from approximately minutes 4–5 in the space-time view encompasses a complex mesh of activity around the Hank Williams exhibit. This activity builds on the family's previous interaction in the gallery space and extends to other parts of the space. During this meshing of movement paths and talk, the family's movement and conversation in the space-time view become entangled in ways that reveal a complex sequence of interaction between family members in relation to their movement and the environment, during which:

- 1) Lily soothes the emotions of Adhir (her fiancé) by hugging and consoling him as he compares the Hank Williams exhibit to a "grave" (in line 8).
- 2) Jeans gives Lily and Adhir privacy by leading a frustrated Blake away from the Hank Williams exhibit (the extension of their movement paths upwards in the floor plan and space-time views indicating their movement away from the exhibit).
- 3) Blake and Jeans rejoin Lily and Adhir as Adhir continues to share his own account of Hank William's painful life.
- 4) Mae (Mom), who has been standing near Adhir and Lily and observing her family's interaction, helps Blake lead Adhir on a tour of other exhibits by saying to Adhir, "but you gotta.. you gotta go see Bill Monroe's mandolin" (in lines 22–23).
- 5) Evidently fully aware of Blake's ongoing project to lead a tour, Adhir whispers to Blake, "ok let's go" and they move forward together to the next Bluegrass artist (at the end of the highlighted conversation).

Our analysis is not possible without Mondrian Transcription, which provides a means to describe, represent, and interpret people's interaction in relation to their movement through physical environments. Second, our analysis reveals goals and intentions, which would not be visible without the integrative perspective that interaction geography affords. For the Bluegrass Family, these goals and intentions reveal how the family produces a personally edited (Lave et al., 1984; Ma & Munter, 2014) version of the gallery space, in which the exhibits they visit are a subset of what has been designed, and their engagements extend and elaborate the meaning of exhibits in ways relevant to their personal and social history. Third, our analysis characterizes an important ambulatory sequence within the Bluegrass Family's many ambulatory sequences in this gallery space. This sequence reflects a history of engagement that encompasses the sequence that finally releases Adhir from the Hank Williams exhibit to join Blake's tour. We call such important ambulatory sequences "engagement contours." The concept of an engagement contour draws from topographic mapping to provide a way to delineate how, where, and when

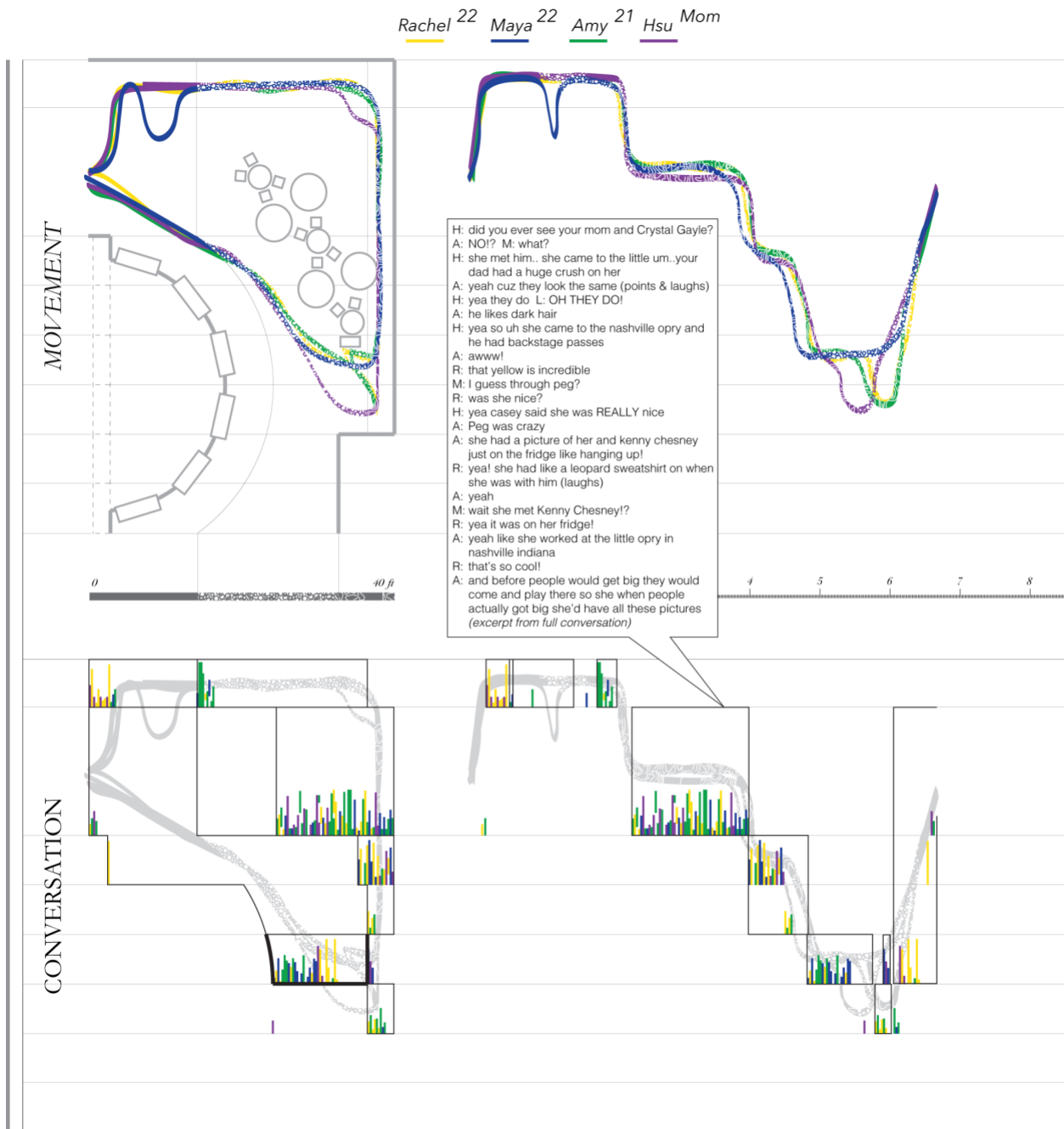


Figure 1 - 6: Mondrian Transcript of the Women in Music Family's interaction geography. Copyright © by Ben Rydal Shapiro. Reprinted by permission

people's interaction builds to produce moments of peak engagement over space and through time. In settings like museums, we suggest these moments may be quite important to how people pursue or realize their own interest-driven learning. Finally, and perhaps most relevant to the learning sciences and CSCL communities, our analysis shows how configurations of bodies and attention are as meaningful as utterances of spoken language, for making sense both of what has come before and what might come next. Just as a turn at talk can assess what has come

before or project to a next topic, a shift in body proxemics can gather paths that have come before and project a next path in joint activity.

Figure 1 - 6 extends the previous analysis and discussion by showing how a different family can produce a very different interaction geography in this same gallery space. “The Women in Music Family” includes a mother (Hsu), her two college age daughters (Rachel and Maya) and their female cousin (Amy). All scales match the previous figure.

The Women in Music Family’s movement over the floor plan indicates how the family engages with entirely different exhibits than those visited by the Bluegrass Family. As the space-time view shows, the family spends the majority their time at a set of exhibits that line the entire right wall of the floor plan. These exhibits are dedicated to Crystal Gayle, the first female country artist to achieve a platinum selling album (*We Must Believe in Magic*, 1977). Likewise, the family’s movement over space-time shows how the family members remain tightly intertwined throughout their visit to this gallery space. Moreover, the family’s engagement footprints (boxes and conversation turns in the floor plan view) are less dense in comparison to those of the Bluegrass Family. The highlighted conversation in the figure shows how the family personalizes exhibit content. During this conversation, Hsu tells a story about how Amy’s mother and father met Crystal Gayle. The daughters comment that Amy’s mother resembles Crystal Gayle and they discuss a photograph of her mother taken with Kenny Chesney.

These observations illustrate how families can engage with the same gallery space in very different ways. Once again, this analysis and related interpretations are not possible without the descriptive and representational power of Mondrian Transcription, which provides a way to unpack people’s movement and conversation at varying levels of detail as they move across the environment to draw comparisons, make associations, and conduct analyses at both individual and group levels.

Figure 1 - 7 and **Figure 1 - 8** are screenshots from a dynamic visualization tool we call the Interaction Geography Slicer (IGS). As we will describe more completely later in this paper, the IGS allows for new forms of interaction and multimodal analysis by using Mondrian Transcription in a variety of ways. The figures compare the movement and conversation of four different families in three different museum gallery spaces. The first screenshot shows movement and the second shows conversation using the conventions described previously. Columns distinguish different families, while rows distinguish different gallery spaces. These spaces roughly correspond to galleries visitors experience at the beginning (Folk Roots Gallery), middle (Bluegrass Gallery) and end (Rotunda Gallery) of their complete museum visit. All displayed information is set to the same scales. Since the Taylor Swift Family did not visit the Rotunda Gallery, we have assembled the movement and conversation of all four visitor groups on a larger floor plan drawing of the entire museum in each figure (i.e., galleries are shown in relation to each other across the entire museum visit and floor space).

These figures support many levels of reading, and like any static figure, possess many limitations. We encourage the reader to study each of these figures and draw their own findings prior to reading the following analysis of these figures.

INTERACTION GEOGRAPHY IN A MUSEUM

Screenshot from Interaction Geography Slicer (IGS) by Ben Rydal Shapiro

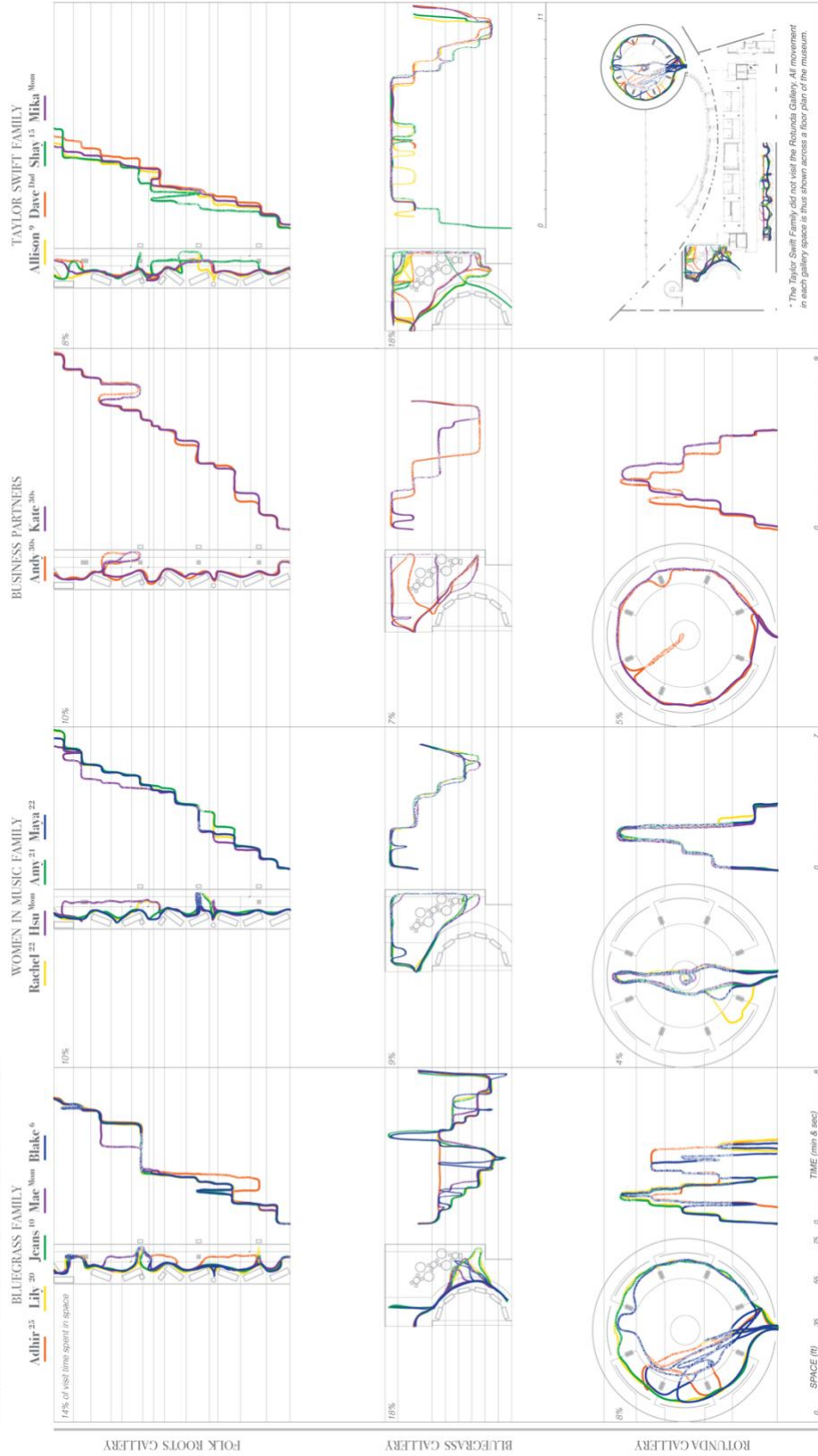


Figure 1 - 7: Screenshot from Interaction Geography Slicer (IGS) showing movement of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

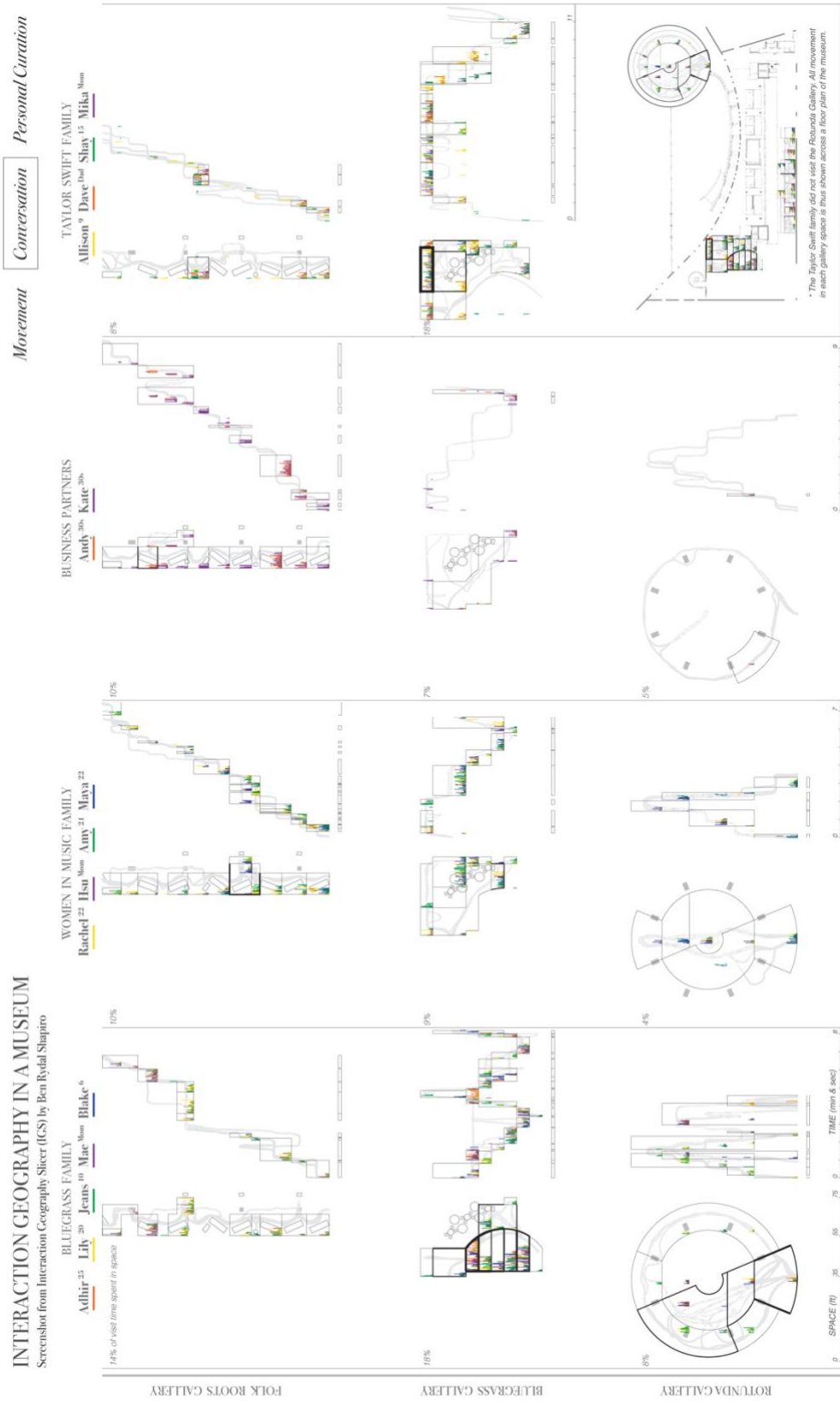


Figure 1 - 8: Screenshot from Interaction Geography Slicer (IGS) showing conversation of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

Figures 1 - 7 and 1 - 8 advance a variety of findings. First, they show how different environmental and syntactical configurations of gallery spaces support and constrain visitors' patterns of movement and conversation. For example, the Folk Roots Gallery (1st row in each screenshot) conditions very linear ways of moving in space-time with few repeated conversational engagements for all families. In contrast, the Bluegrass and Rotunda galleries (2nd and 3rd rows) are both open-plan spaces with a wide variety of supports for sequential engagement, and accordingly, they encourage a wide variety of movement and conversation patterns across visitor groups and individuals within groups. Likewise, while the Business Partners (3rd column) exchange many conversation turns in the Folk Roots Gallery, they produce almost no conversation turns in the other two gallery spaces. Similarly, Blake makes many conversation turns in open plan spaces such as the Bluegrass and Rotunda galleries, but he makes only a single conversation turn in the Folk Roots Gallery (hence there is only one blue line in this space). Thus, the figures show how interaction geography provides ways to conceptualize and compare the ways in which the physical environment conditions the movement and conversation patterns that comprise people's engagement at exhibits and across gallery spaces.

Second, the figures show how visitors' personal and social history, prior knowledge, and relationships to one another guide them to choose particular pathways and configurations through the museum instead of others. To those who know these gallery spaces, it is clear that each visitor group's movement and conversation are distributed in ways that reflect their engagement with particular artists, instruments, and musical genres. For example, the Women in Music Family's movement and conversation often focus around exhibits featuring female artists. As they described in their post-visit interview, the family was deeply concerned with the portrayal of women in music.

Third, the figures allow analysts to ask new types of questions. For example, one can use the figures to ask how young children employ bursts of movement and conversation to attract the attention of their parents and siblings or alternatively, how young children use their families as resources for their own interest-driven learning.

Finally, the figures are static images and therefore have limitations. There are aspects of people's movement and conversations that cannot be interpreted well without more dynamic information. For example, consider the Taylor Swift Family in the Bluegrass Gallery space (4th column, 2nd row). Their movement in space-time indicates that the dad (Dave) enters the gallery 4 min after his daughter, Shay. During this time the two daughters, Allison (9 years old) and Shay (15 years old), appear to be exchanging places and conversation with one another in relation to their mother, who stands for a long time at a large record wall in the gallery space (indicated by her horizontal purple path in space-time with no change in line pattern which is similar to Adhir's path at the Hank Williams exhibit). These observations describe aspects of the family's engagement, but they do not communicate how the daughters are competing for their mother's attention. In fact, their movement and conversation are oriented toward competing about what will be talked about and what content the family will visit in the future. Thus, in some cases, these figures provide only a glimpse of a fuller interaction geography analysis, which would include more dynamic and multi-scalar ways of reading people's interaction as they move through environments.

To review, in this section we described our development and use of interaction geography to study visitor engagement in museum gallery spaces. Our discussion and analysis highlight two important themes of interaction geography.

Theme 1: Interaction geography describes, represents, and supports interpretation of interaction at a spatial and temporal scale that is intermediate in comparison to the spatial and temporal scales used by other contemporary approaches to studying conversation, interaction and movement. More specifically, interaction geography operates at a scale larger than a) interaction analysis (Jordan & Henderson, 1995), which focuses on moments of interaction in space and time, such as single conversations at museum exhibits but smaller than b) time geography (Hagerstrand, 1970), which typically focuses on people's movement across large scales of space and time (e.g., cities over days, weeks and months). However, equally important, interaction geography develops and uses methods that allow for new ways to link these differently scaled approaches to study phenomena like visitor engagement.

Theme 2: Interaction geography advances work in the social sciences, shifting analytic attention from “simulating to mapping, from simple explanations to complex observations” (Venturini et al., 2015; also see Becker, 2007). Likewise, interaction geography aims to meet provocations in the social sciences to develop what some call a geographic information systems (GIS) approach to mapping social action (Scollon, 2008) and others call a graphic anthropology (Ingold, 2007).

Extending professional insights & vision

In addition to developing and using interaction geography to study visitor engagement, we also wanted to see if and how interaction geography could be used to support the professional insights and vision (Goodwin, 1994; Gamoran Sherin and Van Es, 2009) of museum professionals working at this museum. In particular, we wanted to see if and how a computer-supported collaborative learning (CSCL) environment based on interaction geography could advance museum professionals' abilities to identify ways to design more equitable, expansive, and productive learning opportunities in museum gallery spaces. Our design and analysis of this environment drew from the rich body of CSCL literature concerning the use of tools, especially video-based tools, in forms of reflective professional practice (see Erickson, 2007; Zahn et al., 2012; Ligorio & Ritella, 2010; Johansson et al., 2017; Lymer et al., 2009; Cress et al., 2015). As stated previously, this work is part of a larger design study that, in close collaboration with our museum partners, aims to advance museum professionals' learning about ways in which design practice can create opportunities for interest-driven learning in and beyond their gallery spaces.

Two starting points informed our development and use of this CSCL environment based on interaction geography. First, visitor learning is not the only, or even primary, task of a museum's design departments (they must also design exhibits, marketing campaigns, and social media presence, for example) and learning programs and activities (e.g., tours and scavenger hunts for children) must often be designed to fit existing museum content and exhibits since the physical artifacts are traditionally designed and built first.

Second, without the information provided by new CSCL tools, museum organizations have a limited understanding of their visitors. Museum professionals rarely have opportunities to see and understand their visitors beyond survey data (i.e. professionals at this museum had not previously seen video of visitors' interactions at this museum). This leaves them dependent on what we describe as an idealized view or model of their visitors and a passive learning model in which museum exhibits are a fixed curriculum that visitors can only succeed or fail to understand. Our following analysis begins by showing an image of 15 museum professionals (e.g., curators, educators, exhibit designers, archivists) using the CSCL learning environment we developed during a half-day workshop. Subsequently, we use this image to describe our design of this learning environment. Finally, we suggest how this learning environment used interaction geography to disrupt conventional views of visitor engagement that museum professionals hold and then reframe these disruptions to enable museum professionals to adopt and consider (in future design decisions) a view of visitor engagement and interaction as an enacted curriculum, where learning is active, interest-driven and in the hands of visitors (Crowley & Jacobs, 2002; Schauble et al., 1997; Azevedo, 2013; Peppler, 2017; Ellenbogen et al., 2004).

Figure 1 - 9 is a snapshot of museum professionals using the CSCL environment. In particular, the environment used the Interaction Geography Slicer (IGS) to support new forms of interaction and multimodal analysis that in turn created opportunities for joint exploration, collaboration, and knowledge building about the ways in which 4 different visitor families/ groups engaged and learned during their visit to 3 different gallery spaces. Some of the dynamic possibilities of the IGS included:

Comparisons: The IGS allowed professionals to quickly and seamlessly compare the movement, conversation and social media/technology use (which we call "personal curation") of families in either a single family/space viewing mode or a small multiple viewing mode. Figure 1 - 9 shows museum professionals studying the Bluegrass Family's movement in the single family/space viewing mode.

Layering: The IGS allowed professionals to add or remove family members or other families. For example, Figure 1 - 9 shows museum professionals studying all members of the Bluegrass Family in a single gallery space. However, museum professionals could use the IGS to select and visualize individual family members (e.g., just Blake and Adhir) or alternatively, visualize all members of all 4 families at once in a single gallery space.

Reading Conversation: The IGS allowed professionals to read conversation in space and space-time. When visualizing conversation, museum professionals could hover over each box using a computer mouse to display and read transcribed talk of that conversation (e.g., similar to the previously highlighted text in **Figure 1 - 5**).

Video & Audio: The IGS allowed professionals to select, view and listen to multi-perspective video and audio at chosen points in space or time. The IGS spatially and temporally syncs video and audio (worn by each member of each visitor group) to Mondrian Transcription. In Figure 1 - 9, we include a screenshot from a video to show how museum professionals could click on points in space and time to play audio/video from the perspective of each family member.

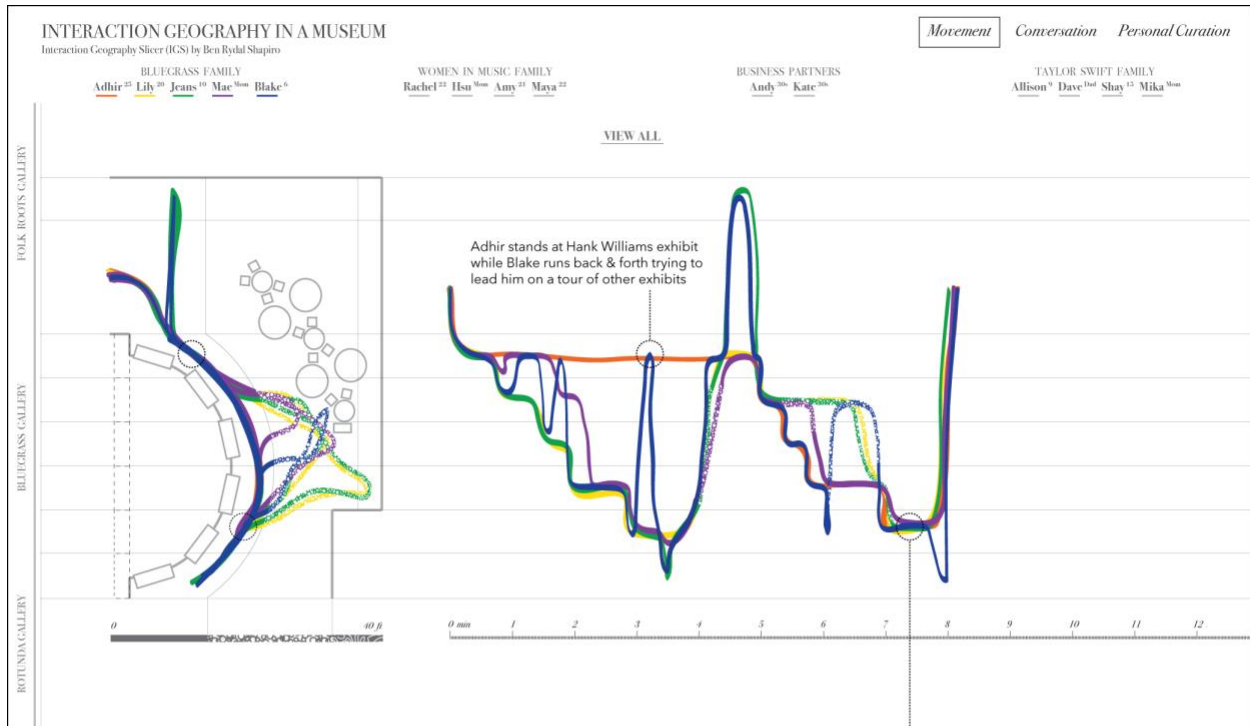


Figure 1 - 9: Museum professionals use a computer-supported collaborative learning environment based on interaction geography and react to Blake's efforts to lead Adhir on a tour within a museum gallery space. Copyright © by Ben Rydal Shapiro. Reprinted by permission

In addition to the IGS, we designed instructional activities that invited participating museum professionals to explore and interpret visitor activity to make evidence-based arguments about visitor engagement and learning within museum gallery spaces. We began the half-day workshop by providing museum professionals with an hour-long introduction to concepts and methods of interaction geography, following a format similar to the first part of this article. In this introduction, we intended to teach museum professionals about a) ways of reading space-time, b) concepts and methods of interaction geography such as using interactive Mondrian Transcripts to find and explore engagement contours, c) how to use the IGS as a tool (e.g., to watch video, listen to audio and read conversation), and d) how to use multi-person, mobile video recordings to make evidence-based arguments about visitor engagement and

learning (e.g., to compare ambulatory sequences that demonstrated strong or weak alignments between exhibit content and family members' sense-making while in gallery spaces). Following this introduction, museum professionals split into two teams (organized primarily by department) to conduct their own analysis using the IGS. Team analysis lasted for approximately two hours. Finally, museum professionals reconvened for approximately one hour to share findings and questions, and to discuss opportunities for using interaction geography in future museum design.

We observed three ways that this CSCL environment based on interaction geography extended the professional insights and vision of museum professionals during the half-day session. A full analysis is beyond the scope of this paper, but we draw from our own interaction analysis of video and audio recordings of the session, our field notes and understanding of the museum setting from longer-term ethnographic analysis, and an analysis of post-session surveys that elicited feedback about the CSCL environment from museum professionals. It is important to note that the departmental backgrounds of museum professionals framed the ways in which they used the CSCL environment to select data, make arguments about visitor engagement and learning, and engage in particular types of practices. For example, museum educators simultaneously used space-time views, video, and transcripts of visitor conversations to focus on the ways in which visitors produced engagement through their movement, conversation, and relationships with other family or group members. In contrast, exhibit designers rarely made use of video and, instead, used floor plan views and transcripts separately to focus on how particular exhibit and gallery layouts influenced visitors' activities. These differences highlight departmental interests and work practices.

Seeing Visitor Engagement and Learning in New Ways: Museum professionals were able to see and study visitor engagement and learning in innovative ways. Previously, many participants viewed young children's erratic movements in museum gallery spaces as childish behavior that prevented engagement and learning. When first confronted with Blake's rapid movements in the Bluegrass gallery space (e.g., their reactions/expressions are shown in Figure 1 - 9), few believed that he could possibly be learning. Some expressed concern that his erratic movement might even be undermining the intended design of exhibits by distracting other members of his family. However, the collaborative use of the IGS provided opportunities for the professionals to unpack and describe Blake's (and other children's) movement and conversation patterns as drivers of engagement contours that supported forms of learning as children moved. Following Blake in the video corpus of recordings turned out to be revealing for museum professionals. After understanding how Blake finally managed to lead Adhir on a tour of Bluegrass musicians, the professionals explored Blake's activity in a different gallery space, the Rotunda Gallery. Here, museum professionals discovered how Blake first failed to get an answer to a question that he posed to Adhir as to who co-starred in the 1970's action/comedy film *Smokey and the Bandit*. Immediately afterward, Blake ran to another gallery space to find and get the correct answer from his brother Jeans. Subsequently, Blake then raced back to Adhir to inform him that it was Jerry Reed, a Grammy-winner country artist, that co-starred in the film. What initially seemed like off-task or disruptive behavior, eventually became recognized as a form of "learning on the move", one that museum

professionals now hoped to be able to support (Taylor, 2017; Marin, 2013; Taylor & Hall, 2013).

We believe these findings were surprising for participating museum professionals because they disrupted their beliefs and perceptions about visitor activity. The ability to observe and study children's interaction geographies across gallery spaces, and to describe these phenomena as drivers of engagement and interest-driven learning, led to a significant shift in the professional insights and vision of some participants. They began to challenge idealized models of museum visitors as relatively passive consumers of intended designs and instead, to see and discuss museum visitors as active producers or curators of their own interest-driven engagement and learning. There were even jokes about hiring Blake as a museum ambassador for Bluegrass music.

Asking New Research Questions: Museum professionals used the CSCL environment to ask questions currently important within museum studies and to ask new types of questions. They began to use the environment to describe, represent, and interpret the ways in which adults coordinated young children's attention and observation, not only at single exhibits, as is typically the case in museum studies, but also as returns or forms of linking across multiple exhibits and gallery spaces. For example, the professionals studied and compared how parents used their movement and conversation to manage their children's engagement and learning across gallery spaces or at particular exhibits and at particular times within gallery spaces. Moreover, museum professionals were able to ask new questions such as how young children manage their families as interpretive resources in and across museum gallery spaces. For instance, the professionals discovered that young children often went to great lengths to explore gallery spaces independently, to gather or retrieve information about exhibit content, and to share what they found with other family members for a variety of purposes. Some children did this in order to physically move adults or parents to other parts of the museum. Other children did so to teach adults about what they had found, and to elicit adults' conversation about exhibit content related to the child's personal interests, or to what the child believed would interest adults. Finally, museum professionals were able to utilize language of interaction geography to, for instance, classify moments of peak engagement or engagement contours and how these moments often revealed trajectories of interest-driven learning within their gallery spaces.

Making Evidence Based Decisions: Many museum professionals felt that, with further development, the CSCL environment along with concepts and methods of interaction geography could provide meaningful ways to support evidence-based design decisions in the museum and to encourage collaborative design across museum departments. In particular, they suggested that this work could provide a way not only to learn about their visitors but also to gather evidence on visitor activity that could inform future, more expansive, and equitable design decisions regarding museum learning programs and activities. They also suggested that the visual and interactive nature of our work could provide ways for different museum departments to work together in new ways. As one museum educator explained in the post-survey:

I recall the productive cross-department conversation about visitor behavior, engagement, learning. We seldom (never?) have the opportunity to discuss visitor experience in the gallery—with our content—across departments. I also enjoyed and benefited from the visitor conversations in relation to specific space and artifacts—good to “see” the exhibit through their eyes and mind rather than assume their view, takeaways, paths, etc.

Conclusion, limitations & next steps

We began this paper by illustrating the significant and unmet need to develop integrative approaches to study learning that simultaneously consider learning in relation to the physical environment, people’s interaction with one another, and people’s movement. Subsequently, we introduced interaction geography, a new approach to describing, representing, and interpreting people’s interaction. We argued that interaction geography provides a more integrative and multi-scalar way to characterize people’s interaction and movement in relation to the physical environment and is particularly relevant to learning research and professional design practice in informal learning settings.

We illustrated this approach with data from a museum, but we consider interaction geography to be general purpose and applicable to many other settings including more formal learning settings. For instance, interaction geography can be used in classroom and school settings to study the alignment of space and pedagogy (Monahan, 2002; Cleveland, 2009) and to address research challenges such as how to “observe 12 children simultaneously playing in up to six different areas in the preschool classroom (e.g., blocks center, manipulative center) or on the playground (e.g., bikes, climbing structure)” (Rowe & Neitzel, 2010, pg. 172). Similarly, interaction geography can be extended to outdoor spaces to provide a new framework for the design and analysis of place-based or mobility centered learning activities (see Hall et al., 2017; Shapiro & Hall, 2017; Taylor, 2017). Moreover, with respect to the CSCL community, interaction geography provides new ways to understand group interactions over time in technology-mediated environments (Stahl, 2017) and to incorporate multi-perspective audio/video recordings in reflective professional practice.

We expect that ongoing technical and conceptual development of interaction geography can support new collaborations across the fields of education, information visualization, architecture, and the arts. Collaborations like these are increasingly becoming central as researchers and practitioners explore opportunities and potential for learning in people’s everyday lives. We conclude by pointing out three limitations of this work and by delineating potential next steps for expanding this work in collaboration with others.

First, our report is restricted to an exploratory study within a particular type of setting for informal learning. As we define and increase the utility of interaction geography, we will need to advance concepts and methods discussed in this paper to other types of settings and institutional contexts. We are especially interested in involving professional practitioners in in-depth analyses of interaction geography. They are in the best position to make sense of detailed traces of interaction and to use that information to enhance opportunities and contexts for learning.

Second, important questions concerning the generalizability of methods of interaction geography are as yet to be explored. Of particular interest is the ways in which other researchers,

educators, and designers might use and advance these methods in a range of contexts. Mondrian Transcription and the Interaction Geography Slicer described in this article were intended to serve as artifacts to communicate interaction geography to a broad audience and to guide future computational development of both qualitative transcription software and quantitative information visualization and visual analytics software. For example, current versions of the IGS are written in Java, the Processing Programming Language (Reas & Fry, 2007) and Unfolding Maps Library (Nagel et al., 2013) and support multiple 2D & 3D representational views, floor plan or map rotation to explore patterns in ambulatory sequences, engagement contours, and aggregate meshworks of visitor engagement (addressing questions as to whether, for example, interpretations in one floor plan view hold up over changes in orientation and scale in other views), along with ways for users to layer different digital base maps or floor plans underneath people's activity (see Shapiro et al., 2017 and Shapiro, 2017b for adaptations of the IGS to visualize New York City's controversial Stop-and-Frisk Program and to advance social studies teaching). With further support, we hope to make these methods and software widely available to others working in a variety of settings and to develop custom methods and software tailored for particular types of settings and institutions. Further information on our progress and development will be available at <https://benrydal.com>. We welcome partnerships and collaborations with other institutions, researchers, designers, and practitioners to advance these efforts.

Third, there are significant ethical considerations that require attention in interaction geography. Our work was made possible by many generous families/people who volunteered their time to participate in this research—at the end of their visits, nearly all families/groups went out of their way to report that they thoroughly enjoyed participating in this research and found it to be unobtrusive (e.g., most forgot they were wearing small cameras as necklaces within a few minutes). However, additional thought needs to be given as to how and when to seek permission from participants, and how that request may affect their interactions. In our future work we will explore issues regarding informed consent (from the perspective of ethical research practice) and fair use of media in public or private spaces (from a perspective on intellectual property). These issues are beyond the scope of this article but remain a serious concern.

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INTERACTION GEOGRAPHY & LEARNING: A CONCEPTUAL FRAMEWORK

Abstract

This paper contributes to research that seeks to characterize the relation between the physical environment and human learning. I begin by reviewing and critically interpreting what I see as four historically separate research perspectives that characterize the relation between the physical environment and human learning in different ways. My review highlights strengths and weaknesses across these perspectives and outlines a conceptual framework for their integration. Subsequently, I introduce and critically analyze representations produced using interaction geography, a new approach I have developed with others at the Space, Learning & Mobility Lab to describe, represent, and interpret people's interaction as they move within and across physical environments. My analysis shows how interaction geography offers resources to integrate each of the four perspectives in order to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn. I conclude by outlining limitations and necessary next steps to expand studies of learning that use interaction geography.

Introduction

This paper contributes to research that seeks to characterize the relation between the physical environment and human learning. I begin by reviewing and critically interpreting what I see as four historically separate research perspectives. The first and second perspectives, which I call the *responsible* and *response-able teaching settings* perspectives, determine different ways properties of the physical environment (e.g., circulation and visibility patterns) condition student performance and teacher pedagogy respectively in settings such as classrooms, museums, and university campuses. The third perspective, which I call the *interaction typologies* perspective, illustrates how people use their bodies along with artifacts and segments of the physical environment during face to face interaction to *assemble* social learning contexts. The fourth perspective, which I call the *movement geographies* perspective, shows how people's movement realizes learning opportunities across settings such as urban environments.

The vast majority of studies in my review are empirically based, and from scholarly, peer-reviewed academic journals across a range of academic disciplines, including education, architecture, the learning and social sciences, literacy, and geography. My review is representative rather than exhaustive. This allows me to intentionally select studies that illustrate foundational types of visual representations used within each perspective. My focus on representations used in these publications reflects a belief that they make visible how each perspective represents the relation between the physical environment and people's activity in order to study learning. Put in Becker's (2007) terms, these representations are ways of "telling about the geography of learning" that reveal how each perspective construes and constructs the relation between the physical environment and human learning.

My review highlights strengths and weaknesses across these four perspectives and outlines a conceptual framework for their integration. Specifically, my review shows how each of these perspectives has distinct weaknesses that are directly addressed by the strengths of the

other perspectives: Missing are resources that integrate these perspectives to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn.

Subsequently, I introduce and critically analyze representations produced using interaction geography, a new approach I have developed with others at the Space, Learning & Mobility Lab to describe, represent, and interpret people's interaction as they move within and across physical environments (Shapiro, Hall & Owens, 2017). In particular, I introduce and critically analyze concepts and methods of interaction geography such as *Mondrian Transcription*, a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS)*, a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. My analysis shows how interaction geography offers resources to integrate each of the four perspectives to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn. I conclude by outlining limitations and necessary next steps to expand studies of learning that incorporate interaction geography.

Responsible settings

The responsible settings perspective studies how physical environments such as classrooms, schools, libraries, and museums are settings that condition occupants' learning. In particular, this perspective focuses on how the physical design of settings shapes the measurable learning performance of people who are characterized as occupants or users.

Figure 2 - 1 exemplifies how the responsible settings perspective represents settings. The figure depicts drawings of the 2nd floor of the High Museum of Art in Atlanta, by renowned architect and architectural scholar John Peponis, as originally designed by Richard Meier in 1983 (Peponis, 2005, pg. 129).

Peponis uses powerful tools from professional design disciplines to represent the design or "spatial syntax" of the 2nd floor of the High Museum of Art as a setting (Hillier & Hanson, 1989). For example, diagram (a) in the figure shows a floor plan of the 2nd floor (i.e., looking down on the 2nd floor); diagram (b) isolates the underlying structural "grid" of the 2nd floor to reveal the positioning of columns (represented as points/dots) and three square exhibition rooms as well as an amphitheater that is "rotated" to make space for a quarter circle atrium (shown in the floor plan); diagrams (c) and (d) show areas of accessibility (darker shading indicates more accessible spaces) and lines of potential movement/circulation respectively; the final diagram (f) shows a "visibility polygon," which indicates the areas of the setting directly visible from a marked location on the floor plan (Peponis, 2005, pg. 129-130). These diagrams should be read in relation to one another and represent spatial relationships and hierarchies of settings that are invisible without such representations.

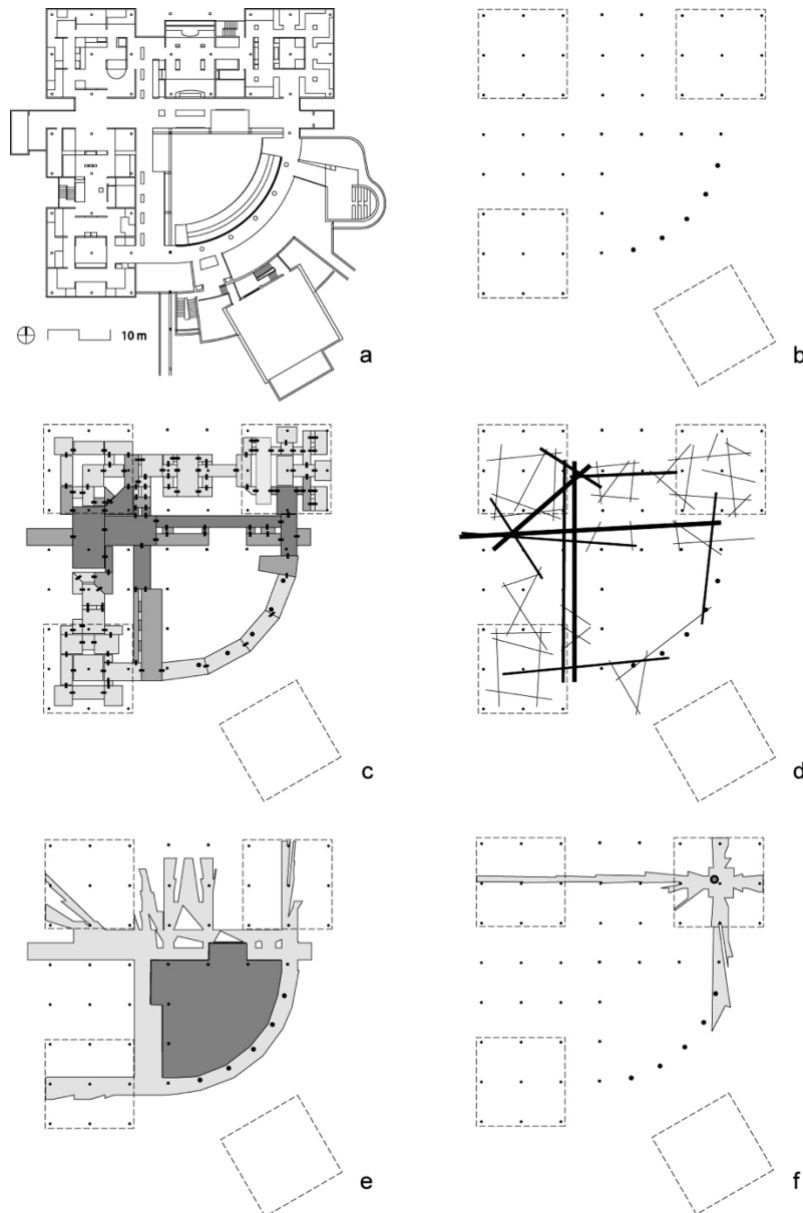


Figure 2 - 1: Floor plan and diagrams showing the spatial syntax of The High Museum of Art, Atlanta, as originally designed by Richard Meier. Drawings by John Peponis (Peponis, 2005). Copyright © Taylor & Francis. Reprinted by Permission

The responsible settings perspective uses these types of representations to evaluate the performance of particular properties of settings. For instance, these representations are used to evaluate properties described by researchers such as Hillier (2008) and Zimring & Reizenstein (1980). These properties include: *Configurational properties*, how segments of a setting are related and influenced by relationships to other segments of a setting; *inter-visibility properties*, visual access routes that reveal what people can see and have access to from particular locations; *co-presence properties*, the likelihood that particular places within a setting support people's interaction with one another; and *indoor environment quality factors* such as thermal comfort, acoustics, natural lighting and air quality (see Cleveland & Fisher, 2014; Soccio, 2016; Sanoff, 2001). Some work also supplements these representations with other forms of data collection

including simulations of occupants' movement as "paths" over floor plan drawings, occupancy surveys, and questionnaires (i.e., self-reported measures of occupants' activity).

Thus, these representations are powerful tools to evaluate complex, often hierarchical spatial relationships within and across settings (e.g., methods of space syntax can be applied at the scale of cities). Likewise, these tools can also support correlational studies to associate measured properties of settings (e.g., whether a region in a setting is visible or accessible, and whether occupants could potentially talk and work together in the region) with simulated, self-reported, or more rarely, observed types of activity (e.g., the density of planning or production activities in a region of the workspace). However, these tools are not designed to show people's activity (e.g., conversation, interaction, sequentially organized movement) and they characterize people as occupants. As a result, they are poorly suited, for example, to describe how settings are used by people.

The responsible settings perspective has not developed a strong empirical base to use such representations to characterize the relation between the physical environment and human learning. This perspective more typically uses such representations to make "many sweeping claims about the possible effects of various aspects of learning spaces on student learning that are not substantiated empirically" (Tanner 2000 as cited in Blackmore et al., pg. 5). The few empirical studies that have been conducted demonstrate two primary issues. First, there are a "lack of research methods capable of controlling the complex variables inherent to space and education" (Imms & Byers, 2017). Second, findings are limited because studies continue to focus "on the quality of conditions and not educational practices or how space is used, and with what effect" (Blackmore et al., 2011, pg. 5; also see Cleveland & Fisher, 2014; Higgins et al., 2005). As a result, learning is conceptualized as an outcome of occupancy exposure and people's activities (e.g., student interactions, engagement, pedagogy) are considered "intangible measures" of learning (Blackmore et al., pg. 4).

As an example of the strengths and weaknesses of the empirical studies that do exist, consider a study titled the "Effects of School Design on Student Outcomes" (Tanner, 2009). The study begins from the premise that there remain a significant lack of concepts, methods, and languages to "describe and explain how a building and environment interacts with students" (pg. 382). The study draws extensively from the work of an influential architect Christopher Alexander and his ideas concerning a pattern language (Alexander, 1979; Alexander, Ishikawa, & Silverstein, 1977). In particular, Alexander's work provides a way to represent and evaluate the design and performance of school settings in a manner that, like Peponis's representations, characterizes patterns of the physical environment in powerful ways but is not intended to represent people's activity. Drawing directly from Alexander, the study defines three types of school design patterns with sub-patterns. These include: 1) movement & circulation patterns with sub-dimensions of outside walkways, pathways, public areas, and outdoor spaces, 2) day lighting patterns with sub-dimensions of natural light and sources of light, 3) visibility patterns with sub dimensions of overlooking life, unrestricted views, living views, functional views, and green areas. The study uses a set of survey-based instruments (e.g., assessments of site observations and floor plans of schools) designed by the School Design and Planning Laboratory (pg. 387-389) to assess the strength (i.e., the prevalence) of each design pattern and sub-pattern at 71 rural and suburban elementary schools in 19 Georgia school districts. The study then compares these findings regarding pattern strength with each school's performance on the 2008 Iowa Test of Basic Skills

(ITBS). Using reduced regression models to predict components of the ITBS using the three types of school design pattern sets, while controlling for SES, the study found that 1) movement/circulation patterns had some influence on the variance in reading comprehension, language arts, math and science test scores, 2) day lighting patterns had some impact on the variance of science and reading vocabulary test scores, and 3) view patterns had some influence on the variance in reading vocabulary, language arts, and mathematics test scores (pg. 394). Notably, the predictive utility of measured aspects of the physical environment is relatively weak by comparison with the predictive power of SES alone. For example, only 10% of the remaining variance in language arts achievement is explained by measured aspects of the physical environment.

Findings from this study and the few empirical studies that do exist should (as the authors acknowledge) be viewed as early explorations to develop methods that can support a stronger empirical research base. Findings are rarely suggested as generalizable and efforts are rarely made to replicate them. In my view, the contribution of this study and the responsible settings perspective is a genuine, important, and challenging effort to translate powerful methods from professional design disciplines (e.g., architecture, urban planning, interior design) to characterize a type of relation between the physical environment and learning. This relation is a one-way, conditional relationship in which the physical environment conditions learning as assessed through standardized measures of individual achievement.

As I have demonstrated, the responsible settings perspective relies on representations that characterize the physical environment but ignores people's activity. As a result, the questions and types of analyses this perspective is able to conduct with respect to learning are quite limited. For example, with methods that considered both the physical environment and people's activity, this perspective might be able to ask and answer questions such as how different classroom configurations condition or do not condition particular types of discipline specific work (e.g., in domains such as social studies, mathematics, or science). In addition, the responsible settings perspective only considers learning as a measurable outcome assessed through standardized measures of individual achievement. As a result, this perspective is only able to suggest that there is a relation between the physical environment and human learning, but it provides few ways to understand how and why this relation may exist.

In summary, the responsible settings perspective represents settings using powerful tools from professional design disciplines. It uses these representations to describe how particular properties of settings shape the measurable performance of occupants in order to develop "design level theories" (Hillier, 2008) that can guide the re-modeling or creation of new settings as more innovative learning environments. Moreover, the responsible settings perspective provides a rich vocabulary for describing settings and the complex, hierarchical spatial relationships within and across different settings.

However, people are referred to as occupants. This perspective does not provide concepts and methods to represent the details of people's activity beyond occasional traces or simulations of occupants' movement over drawings such as architectural floor plans (e.g., it does not use or develop representations of people's interaction or conversation). Learning is conceptualized as an outcome of occupancy exposure. Research in this perspective lacks methods to control the complex variables inherent to space and education and it does not focus on educational practices within settings or how occupants such as teachers use settings. As a

result, its findings at best indicate that there are relations between the physical environment and human learning but have little to offer regarding how or why these relations are observed in correlational analysis.

Response-able teaching settings

The response-able teaching settings perspective derives its name from research in conjunction with Australia's recent \$16 Billion Building Education Revolution, a large-scale government initiative to build or re-model educational infrastructure throughout the country (see Newton & Fisher, 2009). Similar to the responsible settings perspective, this perspective studies how physical environments, such as classrooms, schools, libraries, and museums, as settings that condition occupants' learning. However, the response-able teaching settings perspective focuses on how the physical design of settings is aligned with pedagogy to characterize learning, for example, by evaluating whether learners have access to a variety of pedagogies and/or personalized instruction.

The response-able teaching settings perspective is informed by research concerning the 1970's open plan school movement. The open plan school movement was an international movement, driven in large part by research from the responsible settings perspective (Cleveland & Woodman, 2009). It resulted in radical new designs of educational settings through the construction or re-modeling of many school classrooms and buildings. These educational spaces were "open" spaces and schools (i.e., classrooms with no walls) that were perceived by researchers and designers as highly flexible and innovative learning settings. The open plan school movement, however, is viewed as a significant educational design failure. As recent research suggests, the movement 1) did not consider the needs of teachers and students, forcing teachers and students to occupy settings that were "responsible" to researchers and designers but not "response-able" to the needs and training of teachers and 2) did not provide ways for teachers to customize large, open settings in ways that could support their existing or new types of pedagogy (Newton & Fisher, 2009). One widely acknowledged result is that teachers often re-built walls within open plan classrooms in order to teach in ways that aligned with their traditional pedagogical orientation (Cleveland & Woodman, 2009).

The response-able teaching settings perspective is only beginning to develop an empirical base to characterize the relation between the physical environment and human learning (see Ellis & Goodyear, 2018; Imms, Cleveland & Fisher, 2016). Empirical studies that have been conducted draw heavily from the responsible settings perspective to represent the physical environment. However, these studies interpret these representations from a pedagogical point of view and supplement these representations with ethnographic observations and fieldwork. These empirical studies primarily develop concepts to describe the alignment between settings and pedagogy in order to better inform practitioners and designers' efforts to structure spaces for participation and teaching. As one example, I review the evolution of a set of related concepts, called built pedagogy, equitable pedagogical spaces, and reflexive spaces.



Figure 2 - 2: A disempowering built pedagogy (Monahan, 2003). Copyright © Torin Monahan. Reprinted by Permission

Torin Monahan developed the concept of built pedagogy during a yearlong ethnographic project in Los Angeles' Unified School District (Monahan, 2003, 2002, 2000). The concept draws from Monahan's analysis of floor plans and photographs of classroom and school settings supplemented by ethnographic work (i.e., participant observation) in these settings. He uses these analyses to characterize how a settings' flexibility (e.g., ability to support visibility and circulation patterns, possibilities for co-presence) determines students' access to instruction and whether teachers can customize a setting to support diverse types of pedagogy. For instance, **Figure 2 - 2** illustrates what Monahan describes as a disempowering built pedagogy, one that he argues is very difficult for teachers and students to customize to support diverse forms of participation and teaching.

Ben Cleveland's concepts of equitable pedagogical spaces (Cleveland, 2009a) and reflexive spaces (2009b) extend built pedagogy in two ways. Cleveland used methods identical to Monahan's work to develop these concepts during a multi-year ethnographic study of the physical design of middle school settings amidst Australia's Building Education Revolution. Cleveland uses the concept of equitable pedagogical spaces to assert that settings should support "spatial differentiation" (i.e., a space should not simply be "open" but should support many different and intentionally designed types of spatial arrangements) in order to personalize the

learning experience for students/learners. He uses reflexive spaces to further argue that achieving empowering built pedagogies and equitable pedagogical spaces is desirable and necessitates settings that also “suggest to users how they might participate in learning activities and enable them to fine-tune learning settings to suit their pedagogical needs” (pg. 255).

The evolution of these concepts shows how the response-able teaching settings perspective extends the responsible settings perspective to study educational practices and how people use, participate, and teach in settings such as classrooms, schools, museums, and libraries. It asserts that settings and pedagogy must be aligned to support human learning. This perspective embodies a belief that the physical environment (particularly flexible and customizable settings) is a powerful and underutilized pedagogical tool. Likewise, this perspective strongly advocates for teachers to receive professional development training in ways of using existing or new types of physical environments to support their teaching.

Nevertheless, empirical work in the response-able teaching settings perspective remains in its infancy. Currently, this perspective primarily advocates for new directions in future research seeking to characterize the complex relation between the physical environment and human learning (see Ellis & Goodyear, 2018; Cleveland & Fisher, 2014; Imms, Cleveland & Fisher, 2016). Likewise, though this perspective is intimately concerned with characterizing people’s activity (i.e., educational practices and how settings are used), the response-able teaching settings perspective does not study the details of people’s activity (e.g., by collecting data to study people’s conversation and interaction) beyond what can be described by supplementing representations from the responsible settings perspective (e.g., floor plans, photographs) with participant observation and survey-based occupancy evaluations. As Cleveland’s description of reflexive spaces illustrates, one result is that people often continue to be referred to as occupants, users, or as a generalized teacher or learner. Another result is that this perspective does not study human learning directly. Instead it equates learning with teaching and learners’ access to diverse or personalized forms of instruction. Similarly, though it suggests that there is a bidirectional relation between the physical environment and human learning, it typically continues to focus on showing that settings condition pedagogy (and hence learning) in a one way/unidirectional manner.

Interaction typologies

The interaction typologies perspective studies how people use their bodies along with artifacts and segments of the physical environment during face to face interaction to assemble social contexts for learning. In contrast to the responsible or response-able teaching settings perspectives, this body of research studies learning as distributed across people, tools, and learning environments (Cole, 1996; Gutiérrez, Morales, & Martinez, 2009; Vygotsky, 1980). Likewise, it focuses on how people learn through participation in socially and culturally organized practices of a community (Lave & Wenger, 1991). Moreover, this perspective characterizes the relation between the physical environment and learning as bidirectional, one in which both the setting and people’s interaction are co-constructed in social interaction in ways that produce learning (see Erickson, Artiles & Dorn, 2016).

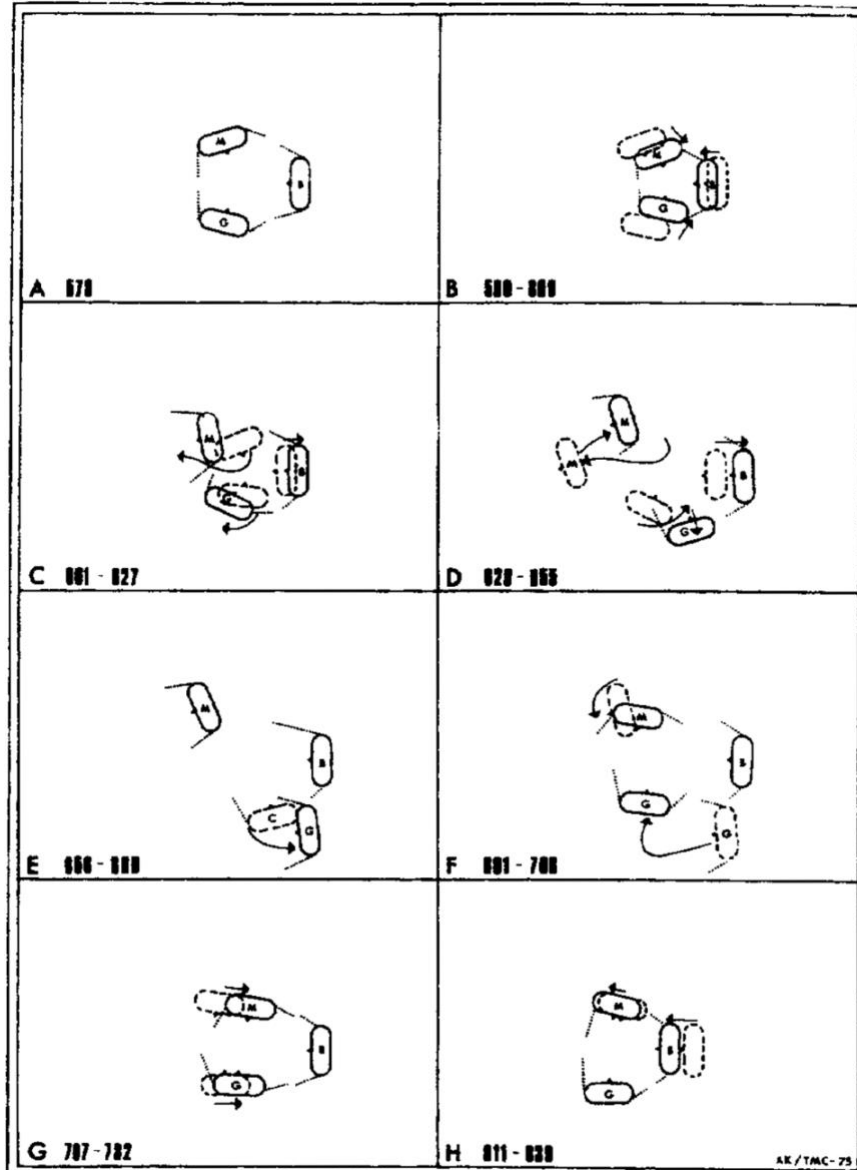


Figure 2 - 3: Facing formation systems diagrams by Adam Kendon (Kendon, 1990). Copyright © by Cambridge University Press. Reprinted by permission

Figure 2 - 3 exemplifies how the interaction typologies perspective represents the structural organization of people's bodies during face to face interaction. The figure shows a sequence of diagrams drawn by Adam Kendon that represent a group of people as they face one another during interaction. Each diagram represents a moment in time during which a group of people maintain a conversation during face to face interaction. The diagrams are drawn from above or in "floor plan view" just like Peponis's drawings of the High Museum of Art in Atlanta. People are depicted as ovals and dotted lines/arrows imply subtle shifts in how each person changes their body position over the interactional sequence. As Kendon describes, the diagrams reveal the "conditions within which participants can effectively exchange the glances, gestures, and words out of which conversations are constructed" (Ciolek & Kendon, 1980, pg. 237).

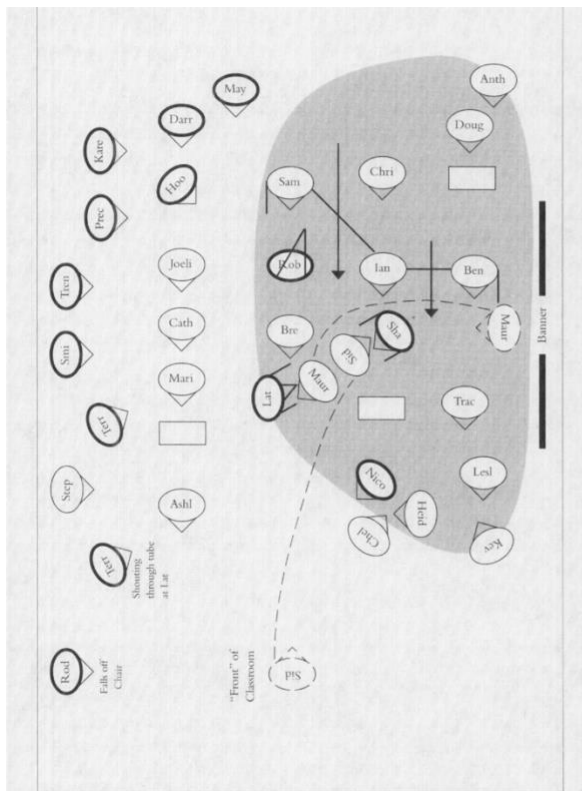


Figure 4. Embodied spaces during interaction Segment 3.

Latanya:	()	I DON'T CARE ()
Shameen:			*	
Terrence:				
Tony:	WHAT ARE YOU TALKIN ABOUT?		STOP**CHILLIN'TANYA	
33 Others:				
Notes:			*Laughing	**Hitting cardboard tube on leg.

Latanya:	ALL Y'ALL
Terrence:	Chow-chow chow mein, do:wn.
Tim:	**
Male:	TIME OUT!
Smitty:	WHAT'S REALLY GOIN' ON?
Hooper:	*
Maureen:	***
Heidi:	****
Tony:	He ain't talkin' about you, Tanya!
27 Others:	
Notes:	*Leans back in seat, folds arms. **Laughing. ***Takes position between Latanya and Ben. ****Looks up at Kevin, filming.

Latanya:	YOU TALK ABOUT THE 'GHETTO, I AIN'T NEVER BEEN IN
Terrence:	
Smitty:	
Mayoosha:	Straight up
Tony:	Tanya!
32 Others:	
Notes:	*Repeatedly pointing at Shameen while speaking.

Latanya:	NO GHETTO, MY MAMA'S ALWAYS GOT A HOUSE AND WE AIN'T
Shameen:	*YE:::AH
Tony:	Alright, thank
33 Others:	
Notes:	*Broadly swings left arm in air, toward Latanya.

Figure 5. Score-based transcript.

Figure 2 - 4: Two transcripts of embodied spaces (left) and conversation (right) of classroom interaction. Transcripts by Kevin Leander (Leander, 2002). Copyright © 2002 by the National Council of Teachers of English. Reprinted by permission

In other words, the diagrams show how people use their bodies to maintain social contexts (e.g., for conversation) during face to face interaction. Kendon's diagrams are useful to represent structural units of interaction that make social contexts possible. For example, he uses these drawings to characterize a circular participation unit called an F-Formation (also see Goffman, 1983 and Hall, 1966 for examples of different types of participation units). Importantly, these representations remove all description of settings as represented in the responsible and response-able teaching settings perspectives.

Figure 2 - 4 illustrates representations from Kevin Leander's 10-month ethnographic study of identity production in a public high school classroom (Leander, 2002). These representations are different transcripts from the same sequence of classroom interaction. These representations illustrate one way studies of learning use representations such as Kendon's F-Formation diagrams to interpret how social learning contexts are assembled.

Leander's transcripts illustrate two representations from the same sequence of classroom interaction during a teaching unit on civil rights and racism. Leander focused on this particular sequence of interaction because it reflected a moment of intense engagement during the classroom lesson, and it was highly memorable for all students in the class. These students universally stated (in interviews) that this sequence positioned a student named Latanya negatively with respect to other students in the classroom. Leander suggests that this sequence of interaction stabilized Latanya's short and potentially long-term identity in the classroom.

The first transcript uses Kendon's diagrams to show the positioning and subtle shifts of students' bodies. As Leander describes, ovals represent students, triangles on each oval indicate the direction each student is facing, and dotted lines provide some description of students' movement and shifts in body position. The transcript also includes some description of desks (rectangles) and indicates the placement of a classroom banner, which is essential to Leander's analysis (along the right wall of the classroom). It also shows students' visual access to particular artifacts such as the classroom banner. The second transcript charts the sequential organization of conversation turns between students and teachers. This transcript illustrates techniques of conversation analysis to chart the sequential organization of conversation turns (see Erickson, 2004; Jordan & Henderson, 1995). For example, the transcript reads from top to bottom. Horizontal lines separate temporal sequences (in seconds) of conversation that occur one after the other. In each sequence, speakers are listed and time extends from left to right. Thus, the starting position of text on the page indicates when each turn of talk occurred in relation to others (see Leander, 2002 pg. 215-216 for other conventions).

Leander uses these transcripts for two primary purposes. On one hand, he suggests these transcripts reveal power relations within the classroom that are only visible by considering students' bodies and their conversation together. In particular, these transcripts show how students use their bodies and conversation to position one student named Latanya as "ghetto" (a derogatory term) and in an "antagonistic relationship" with a fellow white student, Ian (pg. 233). Such power relations are not visible in the responsible and response-able teaching settings perspectives. On the other hand, Leander uses these transcripts to re-characterize artifacts in the classroom as "identity artifacts." For example, Leander notes how student's visual access to artifacts (visible in these transcripts) allowed students to bring artifacts into classroom conversations during which students used these artifacts to construct and stabilize Latanya's identity as ghetto. Most notably, students transformed the classroom banner into an identity artifact: The classroom banner displayed a set of "derogatory terms" (i.e., terms with a negative connotation) that were recruited by students into their conversation to characterize Latanya as ghetto.

As another example of how the interaction typologies perspective represents the relation between the physical environment and people's activity to study learning, consider **Figure 2 - 5**, which is from Deborah Rowe's nine-month ethnographic study titled "The Social Construction of Intentionality: Two-Year-Olds' and Adults' Participation at a Preschool Writing Center" (Rowe, 2008).

Rowe uses this image to highlight particular material features of the writing table that contribute to a social learning context. These features include the low vertical height of the writing table and nearby shelving unit as well as the positioning of writing artifacts and materials such as pens and paper (pg. 408-409). Moreover, she uses these types of images to show the positioning of students' and teachers' bodies in relation to these material features that also comprise a social learning context. Most importantly, Rowe uses this image to reveal how the seemingly mundane relations between bodies and material artifacts can determine how and whether young children engage in writing events with knowledgeable adults and other children. These events allow children to become more central participants in writing practices. For instance, she shows how adults use their bodies to guide children's authoring of texts by positioning paper, texts, and other materials in front of children (409). As Rowe describes, access



Figure 2 - 5: Embodied features and spatial relations between children at the pre-school writing table (Rowe, 2008). Copyright © 2008 by the National Council of Teachers of English. Reprinted by permission

to these materials allow children to explore the “physical potentials of these media without first seeking adult permission” while the “absence of materials such as letter cards or worksheets for tracing letters decreased the likelihood that children’s writing would focus on individual letters” (pg. 408-409). In other words, Rowe illustrates how learning is both a “social and material accomplishment” where a shared work space is assembled through the sequential organization of bodies, conversation, and materials (pg. 425).

Leander and Rowe’s work illustrates how the interaction typologies perspective develops and interprets representations that show how people’s interaction (e.g., conversation, bodies, artifacts) assembles social learning contexts. Likewise, their work demonstrates how the interaction typologies perspective uses these representations to characterize a bidirectional relation between the physical environment and people’s activity where learning is distributed across people, tools, and learning environments and people learn through participation in socially and culturally organized practices of a community. People are not characterized as occupants, but rather as social actors using methods that claim to capture aspects and experiences from the social actors’ point of view.

Nevertheless, representations used by the interaction typologies perspective necessitate a focus on very temporally short (i.e., over seconds and minutes) and spatially small (e.g., a

writing table) sequences of interaction. Similarly, these representations are unable to characterize settings beyond the scale of artifacts, for example, to study how interaction accumulates or repeats over space and time particularly when people move across settings such as classrooms or museums (Hall & Stevens, 2015; also see Marin, 2013; Lemke, 2000; Flood et al., 2015). Kendon's diagrams erase settings completely. Leander's diagrams characterize settings in a superficial manner. Rowe relies on snapshots in time of small portions of a setting. Furthermore, as Leander's two separate transcripts clearly show, the interaction typologies perspective struggles to link studies of bodies with studies of conversation. Put simply, there are no adequate transcript conventions to simultaneously map the organization of bodies and conversation over space and through time in ways that are essential to characterizing a bidirectional relation between the physical environment and human learning.

Movement geographies

The movement geographies perspective studies how the geography of people's movement realizes learning opportunities across settings. Like the interaction typologies perspective, the movement geographies perspective draws from socio-cultural and social practice theories of learning to focus on how learning is distributed across people, tools, and learning environments and how people learn through participation in socially and culturally organized practices of a community. However, it also draws from indigenous and place-based epistemologies (Bang, Medin & Atran, 2007; Bang & Marin, 2015; Cajete, 2000; Gruenewald, 2003; Gruenewald & Smith, 2008; Nespore, 2008), as well as research outside of education that studies how people and things move (Sheller & Urry, 2006, Hagerstrand, 1970; Cresswell, 2010; Ingold, 2007). It often studies learning outside of formal learning settings.

The movement geographies perspective suggests that education research has historically ignored or been unable to study people's movement to understand how it is relevant to human learning even when people engage in activities (e.g., museum visits, nature walks, walking-scale tours of urban environments) that require movement to learn (Hall & Stevens, 2015). To best illustrate the movement geographies perspective, I review various ways this perspective characterizes the relation between the physical environment and people's activity to study learning.

The first way is through a concept called "personal editing" (Lave, Murtaugh & de la Rocha, 1984; also see de la Rocha, 1986). Similar to the interaction typologies perspective and in contrast to the responsible and response-able teaching settings perspective, personal editing proposes a more complex notion of a setting as a dialectical relation between an "arena" or a "physically, economically, politically, and socially organized space-in-time" and a setting that can be personally edited by people through their movement and activity (Lave et al., 1984, pg. 71). More specifically, personal editing can be understood as the movement trajectories or "paths" people produce as they move through settings, which in Lave, Murtaugh and de la Rocha's original work is a supermarket. In their work these movement paths reflect how people or shoppers have learned to locate foods relevant to their home practices (e.g., cooking) during repeated trips to the supermarket. These pathways are informed by many visits to a particular supermarket and are part of a more broadly organized arena of food distribution with personal

relations to home and family practices (e.g., parents' knowledge of what foods children in the home prefer).

Ma and Munter (2014) extend this concept by showing how personal editing of available spaces for activity (a smaller version of the arena) can produce productive or unproductive learning alignments for skaters in skateparks. In their work, learning opportunities refer to the ways skaters, through their movement or skating trajectories, participate and make contributions to the shared goals of the local (skating) community at a particular skatepark. For example, their analysis describes "converging edits" where skaters' movement across a skatepark align to make "seeking teaching spaces" in which novices can be critiqued by more experienced peers to learn new tricks and techniques to avoid getting hurt (pgs. 254-255). Alternatively, they describe "conflicting edits" where a skater's movement through a skatepark can violate particular practices of the local skating community. In one case, they describe how a group of established skaters "snaked" or forced a young skater to leave the skatepark after his use of the park conflicted with their preferred ways of skating and violated a shared goal/understanding of the community (i.e., to avoid skating in the path of others, pg. 252).

In extending the concept of personal editing, Ma & Munter illustrate a second way the movement geographies perspective characterizes the relation between the physical environment and people's activity in order to study learning. Namely, by describing how people "make places" for learning (Hall & Stevens, 2015). Such work extends concepts like personal editing along with work in the interaction typologies perspective to describe more specifically how people's movement accumulates over time to produce important moments (i.e., to make seeking teaching places) where people participate and make contributions to the shared goals of a community (i.e., to realize learning opportunities).

Notions of personal editing and making places for learning emphasize the empirical study of people's activity as movement trajectories or paths over space and time to characterize different ways people can realize learning opportunities across the physical environment. However, these ideas rely entirely on representations from the interaction typologies perspective (e.g., diagrams of F-Formations, separate transcripts of conversation and/or photographs of bodies). Put simply, these diagrams are inadequate to study people's movement and significantly limit the use and expansion of this work by others.

Figure 2 - 6 illustrates representations that show people's "personal time geographies" in ways that support studies of learning (Taylor & Hall, 2013; also see Taylor, 2017; Kahn, 2017; Craig, Mahoney & Danish, 2016). Time geography is a geographical approach that integrates studies of space and time, in particular, to study constraints on human movement over space and time (Hagerstrand, 1970; also see Kwan & Jiyeong, 2003; Miller, 1999; Sui, 2012; Ellegard & Svedin, 2012). Figure 2 - 6 provides a context to discuss various ways the movement geographies perspective uses new types of representations (new in comparison to the previously discussed research) to characterize the relation between the physical environment and people's activity to study learning.

The figure shows a group of university students in class using a computer-supported collaborative learning environment called *Re-Shape* to study their daily and weekly movement over different types of digital maps (Shapiro, 2017; Shapiro & Hostetler, 2018). The large top image in the figure magnifies the screen of a group of students at the front of the classroom analyzing the individual movement (as orange paths) of their entire class (of 21 students over the

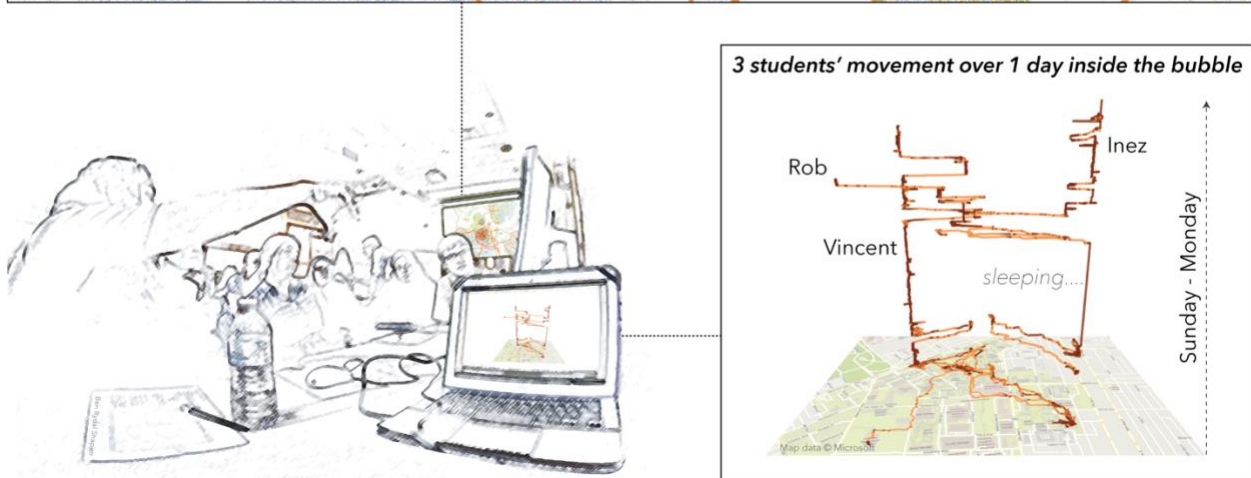
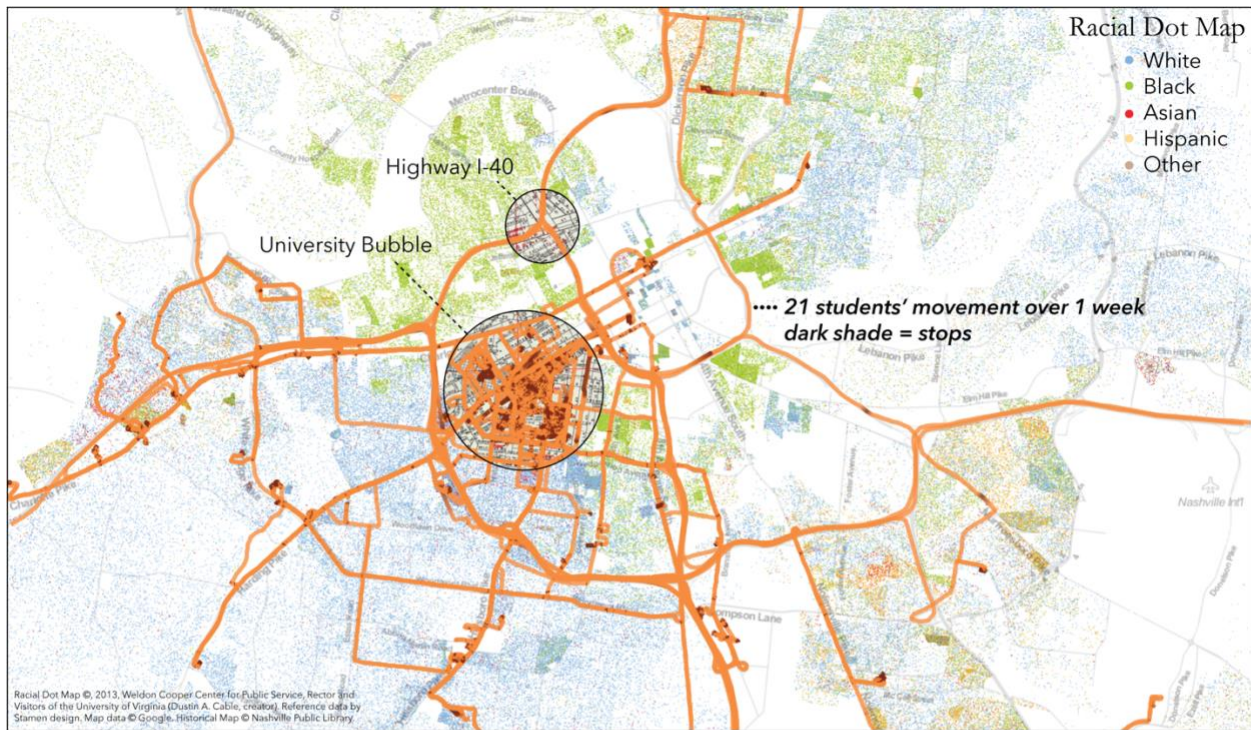


Figure 2 - 6: Students study their personal time geographies using Re-Shape (Shapiro, 2017). Racial dot map Copyright ©, 2013, Weldon Cooper Center for Public Service, Rector and Visitors of the University of Virginia (Dustin A. Cable, creator). Reference data by Stamen design, Map data © Google, Historical Map © Nashville Public Library, Map data © Microsoft

“racial dot map.” Each dot on the racial dot map indicates a person in the U.S. at the location they reported during the 2010 Census. Dot color indicates each individual’s race (e.g., green indicates African American). The bottom right image magnifies the screen of students using a 3D space-time cube, a method of time geography (Hagerstrand, 1970). The screen shows three students’ movement on a map (again as orange paths) and also as their movement extends upwards in “space-time” over a single day (e.g., the long straight lines that extend upwards in time indicate Sunday evening/night when students are sleeping/not moving).

Some use these types of representations to ask new questions such as how is people's personal mobility both the means and content for learning and what is the relationship between mobility and identity in learning and teaching arrangements? (Hall, Taylor & Marin, 2017). Others use these representations to identify "hot spots" in people's lives (e.g., points of interest in the physical environment) that suggest where people have opportunities to develop deep knowledge and affiliations with particular places. For example, Roger Hart's work concerning the "child's experience of place" uses similar representations (captured via young children's geographical diaries as part of his research) to show where students repeatedly visit to engage with others, how children's movement accumulates over time (i.e., over days or weeks in his work) in particular places, revealing children's knowledge of places, and how children's learning can be understood as the opportunities they have to explore their local geography with other children or with and without their parents (Hart, 1979; Hart, 1986). Still others use such representations to study, as Taylor, Takeuchi & Stevens describe, "the movement of digital media practices, where they are located, and how digital co-participation within families is distributed across time and space" (Taylor, Takeuchi & Stevens, in press; also see Leander et al., 2010). This work suggests that these types of representations provide researchers with ways to study where and when children have access to digital media learning opportunities. Still others use such representations to study the affective or rhythmic qualities of people's movement as they cross or move (physically or virtually) between settings (see Ehret, Hollett & Jocius, 2016; Hollett, Phillips & Leander, in press). This work develops ways to conceptualize when and where people's learning may be affectively organized, constrained, or "charged" to realize learning opportunities from a post-structural point of view.

In comparison to other work in the movement geographies perspective, these studies draw from representations that represent people's movement at much larger scales of space and time. In doing so these studies illustrate the need to study learning through people's movement at different scales while also demonstrating possibilities of studying people's movement across the physical environment using new forms of data (e.g., generated by location aware technologies). However, these studies use representations from other disciplines that operate at a scale which ignores the details of people's activity (i.e., interaction and conversation) and descriptions of settings beyond what is visible on a modern digital map. As a result, these studies are unable to characterize learning opportunities in a specific manner. Often these studies describe only where and when people may realize learning opportunities.

In summary, the movement geographies perspective represents the geography of people's movement as people's movement paths or trajectories across different scales of the physical environment. This perspective provides new ways to conceptualize how learning opportunities are realized across different types of settings (e.g., through habitual routines, efforts to make places for learning, constraints on people's movement). Likewise, this perspective illustrates the possibilities for studying people's movement in relation to the physical environment through new types of personal mobility data. People continue to be referred to as social actors or as "people acting in settings" (see de la Rocha, 1986). However, this perspective either uses methods from the interaction typologies perspective that are poorly suited to study movement or adapts methods from other disciplines that operate at a scale which ignores the details of people's activity and descriptions of settings beyond what is visible on a modern digital map. Altogether, this perspective highlights the significant need for multi-scalar concepts and

methods to describe, represent, and interpret people's movement across the physical environment while maintaining ways to study the details of people's interaction and settings.

Summary of Review

Each perspective in the above review has distinct strengths and weaknesses. The weaknesses within each perspective are directly addressed by the strengths of the other perspectives. The responsible and response-able teaching settings perspectives provide powerful ways to represent and characterize the physical design of settings but ignore the details of people's activity. The interaction typologies perspective provides rich ways to represent and interpret the details of people's interaction but ignores people's movement and settings beyond the scale of artifacts. The movement geographies perspective struggles to maintain a focus on people's interaction and settings in an effort to develop new ways to study and theorize people's movement. Put simply, what is missing are resources that integrate these perspectives to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn.

Interaction Geography

In this section, I introduce and critically analyze representations (5 total) produced using interaction geography. Interaction geography is a new approach I have developed with others at the Space, Learning & Mobility Lab to describe, represent, and interpret people's interaction as they move within and across physical environments (Shapiro, Hall & Owens, 2017). Though these representations use data from a museum context, I use them to discuss the potential application of interaction geography across a variety of settings. Moreover, though these representations appear static in this paper, I use them to discuss highly dynamic ways of reading these representations made possible by methods I have developed that include: *Mondrian Transcription*, a method to map people's movement and conversation over space and time, and the *Interaction Geography Slicer (IGS)*, a dynamic visualization tool that supports new forms of interaction and multi-modal analysis. These representations are complex and necessitate new ways of reading the physical environment, people's activity, and people's movement simultaneously. Thus, I begin by describing these representations (adapted from Shapiro, Hall & Owens, 2017). Subsequently, I discuss how these representations offer resources to study how talk, movement, and responses to, or actions on, the physical environment lead people to learn.

Interaction Geography Representations

Figure 2 - 7 maps the movement of a six-year-old boy, Blake (blue path), and his sister's fiancé, Adhir (orange path), as they visit a museum gallery together. Blake and Adhir are two of five members of a family I call The Bluegrass Family who visit this gallery space together. Also included in Figure 2 - 7 is a rendering showing the gallery space from a point marked on the floor plan.

The left of the figure or "floor plan view" shows their movement over a floor plan of the gallery space (i.e., looking down on the space just like Peponis's representations). This view shows where Blake and Adhir go within the gallery space. The right or "space-time view" extends

Adhir 25 Blake 6 years old

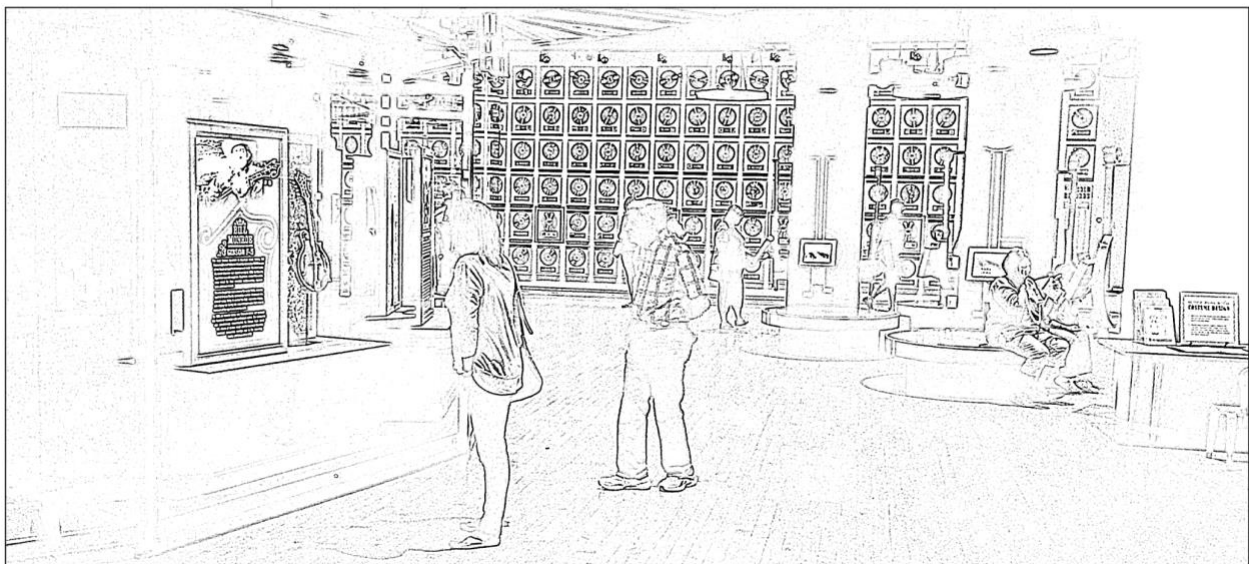
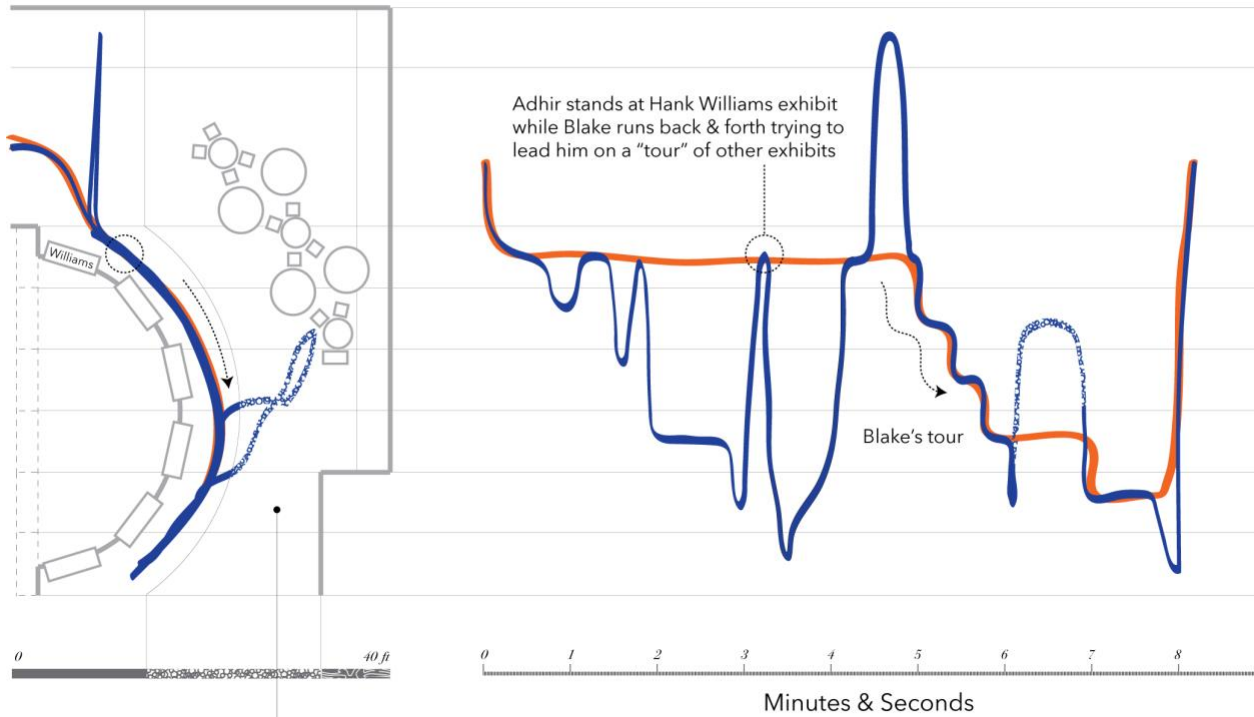


Figure 2 - 7: Blake and Adhir's movement in a museum gallery space is shown over space and space-time. Copyright © by Ben Rydal Shapiro. Reprinted by permission

Blake and Adhir's movement on the floor plan horizontally over time. This view shows how they interact with exhibits and one another over time. For example, using the space-time view, one can see that after entering the gallery space (top left of floor plan view and beginning of space-time view), Adhir and Blake walk together towards an exhibit about Hank Williams (marked on the floor plan). Subsequently, Adhir stands for almost 5 minutes at the Hank Williams exhibit as indicated by his horizontal orange path in the space-time view that extends from approximately

minutes 0–5 and corresponds to the vertical position of the Hank Williams exhibit. In the meantime, while Adhir is standing, Blake is moving quickly (apparently running) back and forth across the gallery space (i.e., across the semi-circle of exhibits on the floor plan) in what appears to be multiple, frantic attempts to draw Adhir away from the Hank Williams exhibit. After four failed attempts, Blake finally appears to succeed in leading Adhir on what is described as a “tour” of other exhibits in the gallery, indicated by their intertwined paths from approximately minutes 5-6. Line pattern distinguishes between three horizontal areas of space on the floor plan providing some description of horizontal movement on the floor plan in the space-time view.

Figure 2 - 8 extends the previous figure and uses Mondrian Transcription to map the movement and conversation of all 5 members of the Bluegrass Family, now including Jeans (green), Lily (yellow), and Mae, referred to as “Mom” (purple, the mother of Blake, Jeans and Lily). The top half of the figure shows the family’s movement and the bottom half shows their conversation in relation to their movement (i.e., the family’s movement is shown in gray beneath their conversation to link the two halves of the figure).

Conversation is transcribed and organized in a manner that draws from and extends conventions from the interaction typologies perspective. First, each turn at talk is shown as a colored line to indicate which family member speaks that conversation turn (indentations indicate overlapping speech). Second, colored lines of talk are gathered into boxes that group topically related sequences of conversation turns and movement (e.g., usually related to artifacts/musicians in this setting). These sequences are structural units of interaction where members of the Bluegrass Family arrange their bodies to maintain social contexts for interaction and conversation (i.e., similar to Kendon’s work). Thus, in the space-time view, each box marks the start, duration, and end of a sequence or social context. In the floor plan view, conversation turns and separate (in time) sequences accumulate within regions of gridded space--the box thickness in the floor plan view increases with each repeated sequence within a region of space. For example, the region of space around the Hank Williams exhibit has the largest number of conversation turns (as indicated by the many colored lines of talk) and is enclosed by a dense box that reflects five separate (in time) sequences occurring at the Hank Williams exhibit. The highlighted sequence (i.e., readable conversation) in the space-time view expands the conversation turns of one particular sequence. This is made possible by the interaction geography slicer or IGS. The grouping of these sequences is determined by my analysis, but Mondrian Transcription allows conversation and movement to be grouped in a variety of ways and also potentially supports a variety of transcript conventions (e.g., to show the direction of speech).

Figure 2 - 9, Figure 2 - 10, and Figure 2 - 11 extend the previous figures to convey the multi-scalar and comparative possibilities of interaction geography as well as more of the technical possibilities of the IGS (see <https://benrydal.com> for higher resolution figures). The figures are screenshots from the IGS and use the previously described conventions to compare the movement, conversation, and “personal curation” respectively over space and time of four different families (columns), including the Bluegrass Family, in three different museum gallery spaces (rows). Personal curation indicates traces of movement where people are using personal information devices (e.g., cell phones, cameras) and/or social media to capture, edit, and share information from the museum with others who are typically not present (i.e., a socio-technical practice called personal curation; see Shapiro, Hall & Owens, 2017). Thus, in Figure 2 – 11, shorter lines in space and space-time (i.e., appearing as dots of movement) are typically moments where

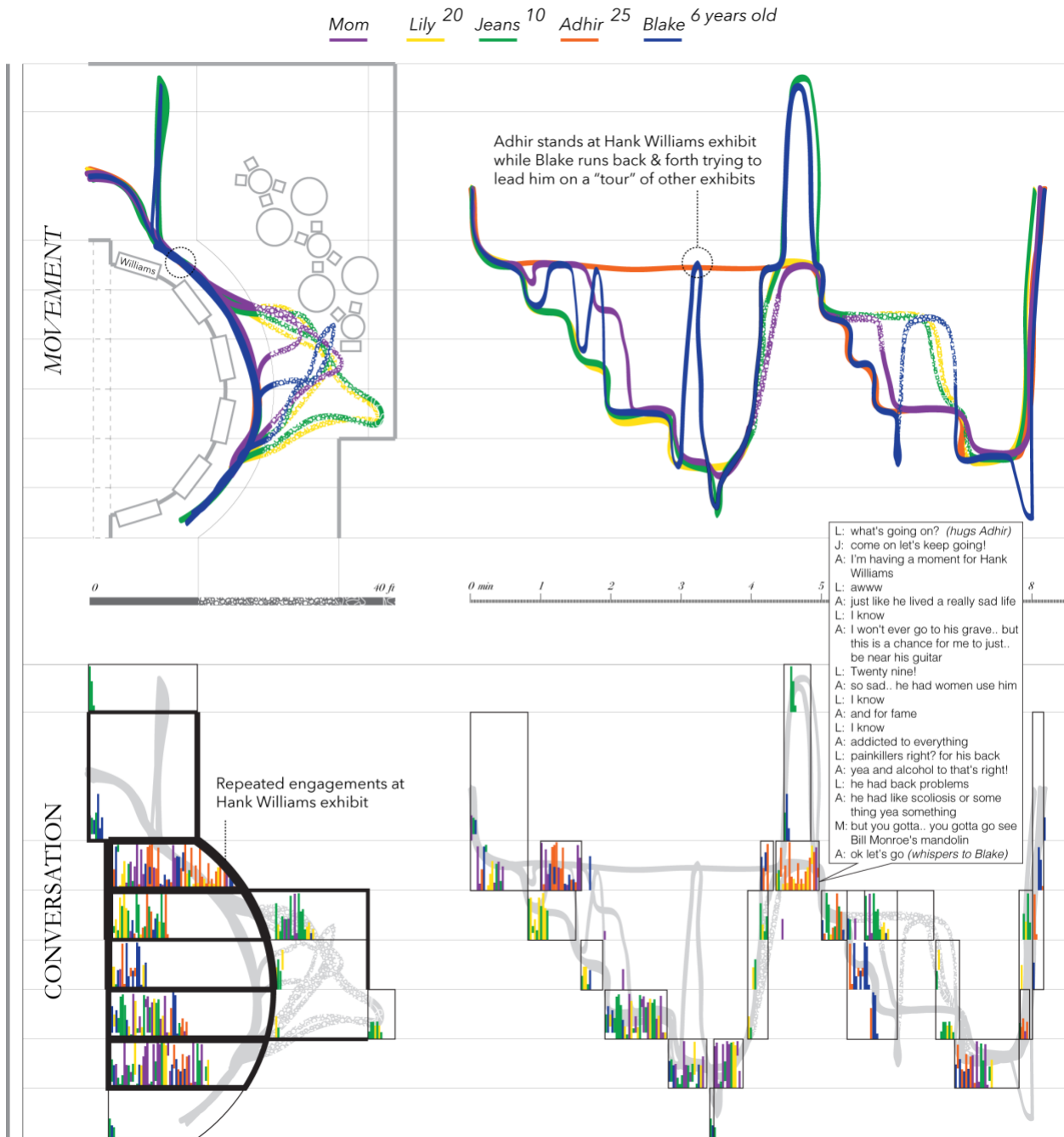


Figure 2 - 8: Mondrian Transcript of the Bluegrass Family's interaction geography. Copyright © by Ben Rydal Shapiro. Reprinted by permission

visitors take a photograph while longer lines are typically sequences where visitors capture information (e.g., a photograph or video) and immediately edit (e.g., write a message) and share this information on social media with family and friends not present. All displayed information across each of these figures is set to the same scales. The Taylor Swift Family did not visit the Rotunda Gallery thus all groups' movement, conversation, and personal curation is assembled on a larger floor plan drawing of the entire museum in each respective figure.

INTERACTION GEOGRAPHY IN A MUSEUM

Screenshot from Interaction Geography Slicer (IGS) by Ben Rydal Shapiro

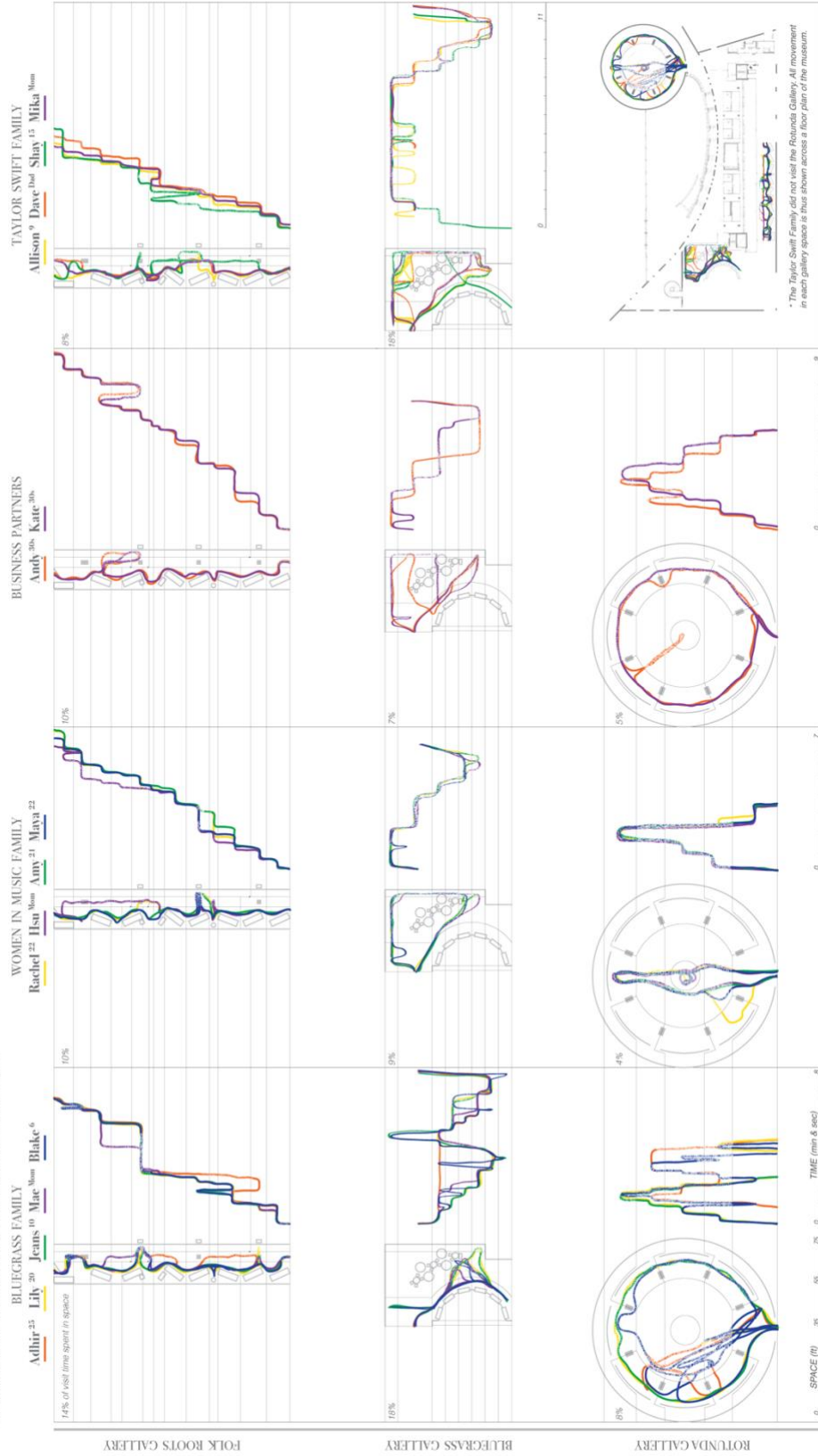


Figure 2 - 9: Screenshot from Interaction Geography Slicer (IGS) showing movement of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

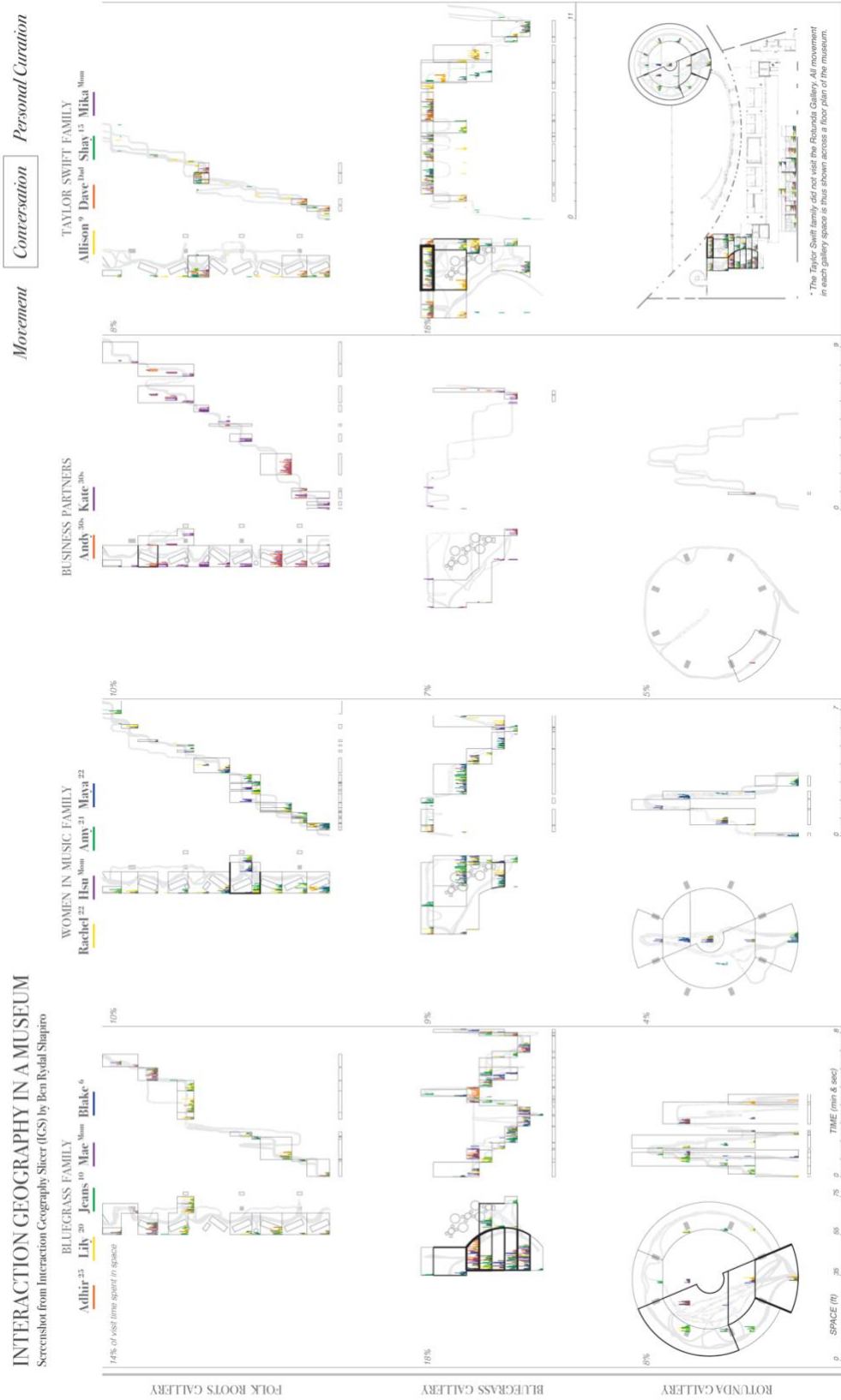


Figure 2 - 10: Screenshot from Interaction Geography Slicer (IGS) showing conversation of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

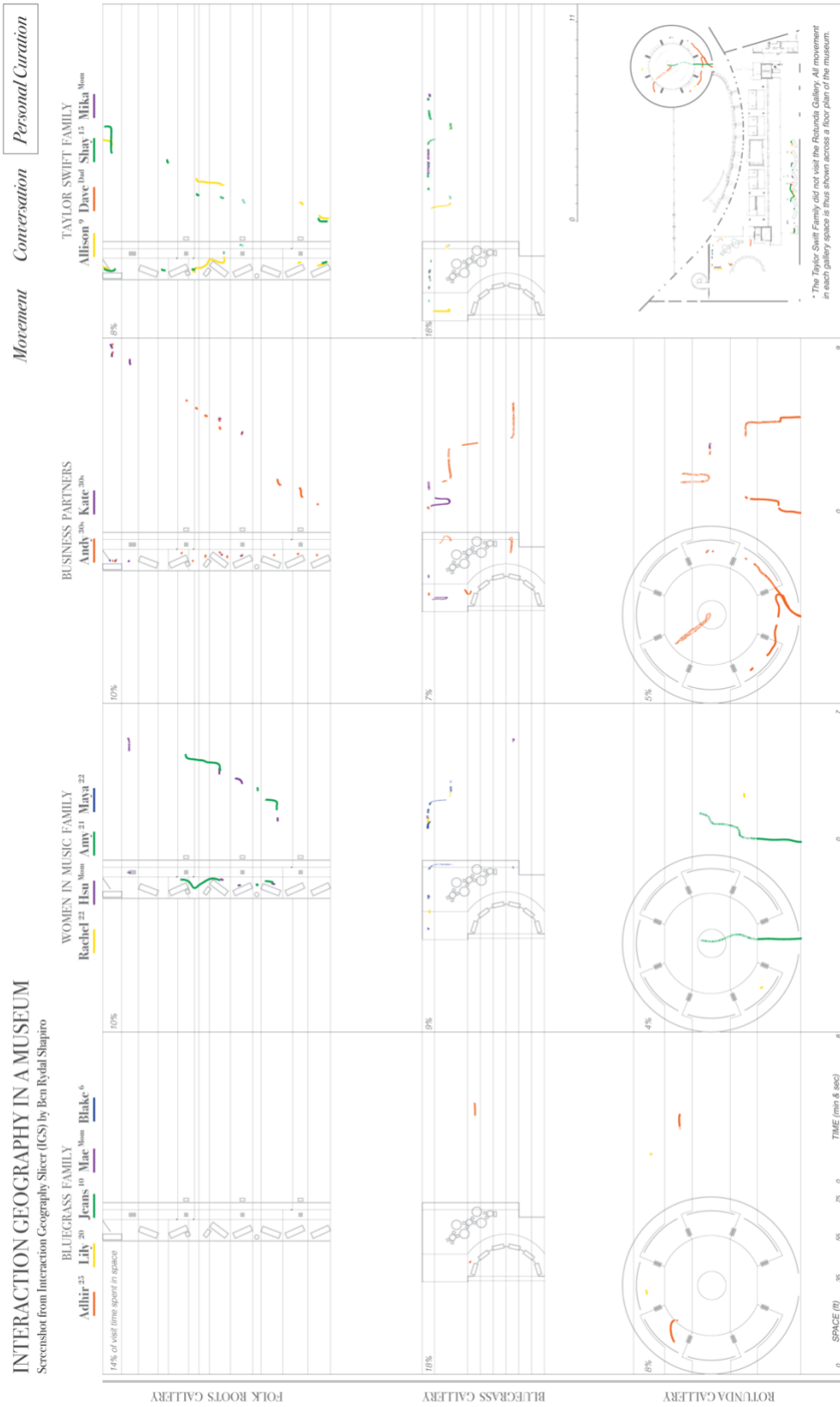


Figure 2 - 11: Screenshot from Interaction Geography Slicer (IGS) showing personal curation of 4 visitor groups (columns) in 3 gallery spaces (rows). Copyright © by Ben Rydal Shapiro. Reprinted by permission

Integrating static representations to create dynamic information visualizations

The previous figures show how interaction geography uses Mondrian Transcription to integrate representations from each of the four perspectives in my review. These representations include architectural floor plans, multiple types of conversational transcripts, and personal time geography. This makes new types of multi-scalar analyses possible that link fine-grained analyses of interaction and conversation at locations in the physical environment with analyses of people's conversation, bodies, movement and other forms of interaction (e.g., personal curation) across the physical environment at larger scales.

Moreover, the previous figures hint at the possibilities to dynamically interact with representations produced using interaction geography through the IGS. As my review demonstrated, representations used to study the relation between the physical environment and human learning have historically been static (e.g., snapshots of the physical environment or people's activity in space and time). For example, the previous figures only begin to convey how researchers or research participants (e.g., museum visitors, students) can use the IGS, for example, to select/de-select individual movement paths and conversation turns, select sequences of time and space to listen to and watch audio and video from the perspective of each family member that was gathered as part of this research (allowing for traditional forms of interaction and conversation analysis), re-scale and zoom in and out in space and time (e.g., to see and read conversation and movement at a single exhibit over a few seconds or across an entire museum floor over longer periods of time), and seamlessly compare different families' movement, conversation, and personal curation across different scales (see Shapiro, Hall & Owens, 2017 for full discussion; also see Shapiro & Pearman, 2017 for work that adapts the IGS to visualize and discuss New York City's controversial Stop-And-Frisk Program). The ability to use dynamic information visualizations as opposed to static representations offers more possibilities to study the physical environment, people's activity, and people's movement simultaneously across different scales.

Reading interaction geography visualizations for learning

The previous figures show that reading interaction geography visualizations is not trivial. Reading these visualizations using dynamic tools such as the IGS only raises new challenges. Likewise, interaction geography is an interdisciplinary approach, and it can be expected that different people and disciplines will read these dynamic information visualizations in different ways. Moreover, these visualizations have many limitations and, like any representation, they show certain phenomena and hide other phenomena (see Monmonier, 2014; Becker, 2007).

However, these visualizations provide ways to interpret how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn. For example, the highlighted sequence in Figure 2 - 9 from approximately minutes 4–5 in the space-time view encompasses a complex mesh of activity around the Hank Williams exhibit. As described by Shapiro, Hall & Owens (2017), reading this sequence of activity in relation to the rest of the figure shows how:

- 1) Lily soothes the emotions of Adhir (her fiancé) by hugging and consoling him as he compares the Hank Williams exhibit to a "grave" (in line 8).

- 2) Jeans gives Lily and Adhir privacy by leading a frustrated Blake away from the Hank Williams exhibit (the extension of their movement paths upwards in the floor plan and space-time views indicating their movement away from the exhibit).
- 3) Blake and Jeans rejoin Lily and Adhir as Adhir continues to share his own account of Hank William's painful life.
- 4) Mae (Mom), who has been standing near Adhir and Lily and observing her family's interaction, helps Blake lead Adhir on a tour of other exhibits by saying to Adhir, "but you gotta.. you gotta go see Bill Monroe's mandolin" (in lines 22–23).
- 5) Evidently fully aware of Blake's ongoing project to lead a tour, Adhir whispers to Blake, "ok let's go" and they move forward together to the next Bluegrass artist (at the end of the highlighted conversation).

These interpretations reveal phenomena (e.g., Blake's tour) not visible without methods of interaction geography. These interpretations require multi-scalar ways to a) analyze structural properties of settings alongside visual patterns of people's conversation and movement, b) read individual conversation turns and situate these conversation turns with respect to simultaneous conversations occurring in different parts of a museum gallery space, and c) watch/listen to video/audio from the perspective of each family member gathered as part of this research. Likewise, some of these interpretations show that phenomena such as Blake's tour, which are often seen as antithetical to learning (i.e., a young child running across a gallery space is distracting), can reflect very intentional efforts to learn, in this case, by participating with and teaching other family members about the cultural heritage content of a museum gallery space.

Figures 2 - 9, 2 - 10, and 2 - 11 convey the comparative possibilities and potential generalizability of interaction geography. For example, in this setting, these figures show how individuals and groups use their movement, conversation, and personal curation to align and engage with cultural heritage content at different exhibits and across different types of museum gallery spaces. Likewise, these figures show how interaction geography can be used to describe structural properties of a variety of settings (e.g., through floor plans) that can be studied in relation to (and possibly correlated to) patterns and qualities (e.g., pace, digital media use) of people's activity in order to interpret how settings (and changes made to settings) support or do not support participation and access to pedagogy (e.g., consider such work within a preschool classroom, makerspace, or laboratory setting). Furthermore, these figures make particular patterns of activity visible (e.g., heightened moments of movement, conversation, or personal curation) that indicate potential moments where people respond to and act on the physical environment. Using the IGS, these moments can be unpacked to understand in this setting, for example, not only how parents structure young children's conversation to learn but also how young children use their families as interpretive resources for learning.

Conclusion

I began this paper by reviewing and critically interpreting what I see as four historically separate research perspectives that characterize the relation between the physical environment and human learning in different ways. My review illustrated how each of these perspectives has distinct weaknesses that are directly addressed by the strengths of the other perspectives:

Missing are conceptual frameworks and resources that integrate these perspectives to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn. Subsequently, I introduced and critically analyzed representations produced using interaction geography. My analysis demonstrated how interaction geography offers resources to integrate each of the four perspectives in order to study how people's interaction, movement, and responses to, or actions on, the physical environment lead people to learn.

Altogether, this paper aimed to provide a conceptual framework to expand interaction geography in studies of learning. However, there are many limitations in this early work. I conclude by outlining some of these limitations along with necessary next steps to address these limitations in future work.

First, as I have described, reading visualizations produced through interaction geography is challenging and necessitates both interdisciplinary thinking and close collaboration with practitioners working in the settings where this approach is used. Future research must explore questions such as how do different disciplines and practitioners working in different disciplines (e.g., architecture, learning sciences, information visualization, geography, museum studies) interpret representations of interaction geography? What insights do different disciplines and practitioners provide to interpret complex representations of interaction geography from a learning perspective? For instance, using Blake's tour as a starting point, what is a taxonomy of interaction geography patterns and how can these patterns be read to study productive or unproductive learning or pedagogical alignments?

Second, important questions about how to generalize methods of interaction geography in an ethically appropriate manner are as yet to be explored (see Shapiro, Hall & Owens, 2017 for full discussion). Future research must explore questions including how tools of interaction geography (i.e., Mondrian Transcription and the interaction geography slicer) can be generalized, customized, and adapted by researchers, designers, and practitioners working in a variety of different settings and institutional contexts. What settings and institutional contexts are these tools ethically and not ethically appropriate? What forms of support or professional development are needed to use these tools to interpret representations of interaction geography from a learning perspective? What instructional supports are necessary to prevent or reduce misconceptions when using these tools to make arguments about learning (or other phenomena)?

Third, interaction geography is a new approach that is only beginning to be applied beyond the museum setting described in this paper. Further research must test and assess the utility of interaction geography in a variety of settings. Such work is necessary to advance interaction geography as an approach, but also to develop comparative questions and analyses that are essential to its' potential use to study learning (and other phenomena). Future research should explore questions such as what are productive spatial and temporal scales or boundaries of settings that enable comparative work based on interaction geography? What types of mappings (e.g., of people, artifacts, sound) does interaction geography support? What is the variation of phenomena such as young children's "tours" in the same setting or across different settings?

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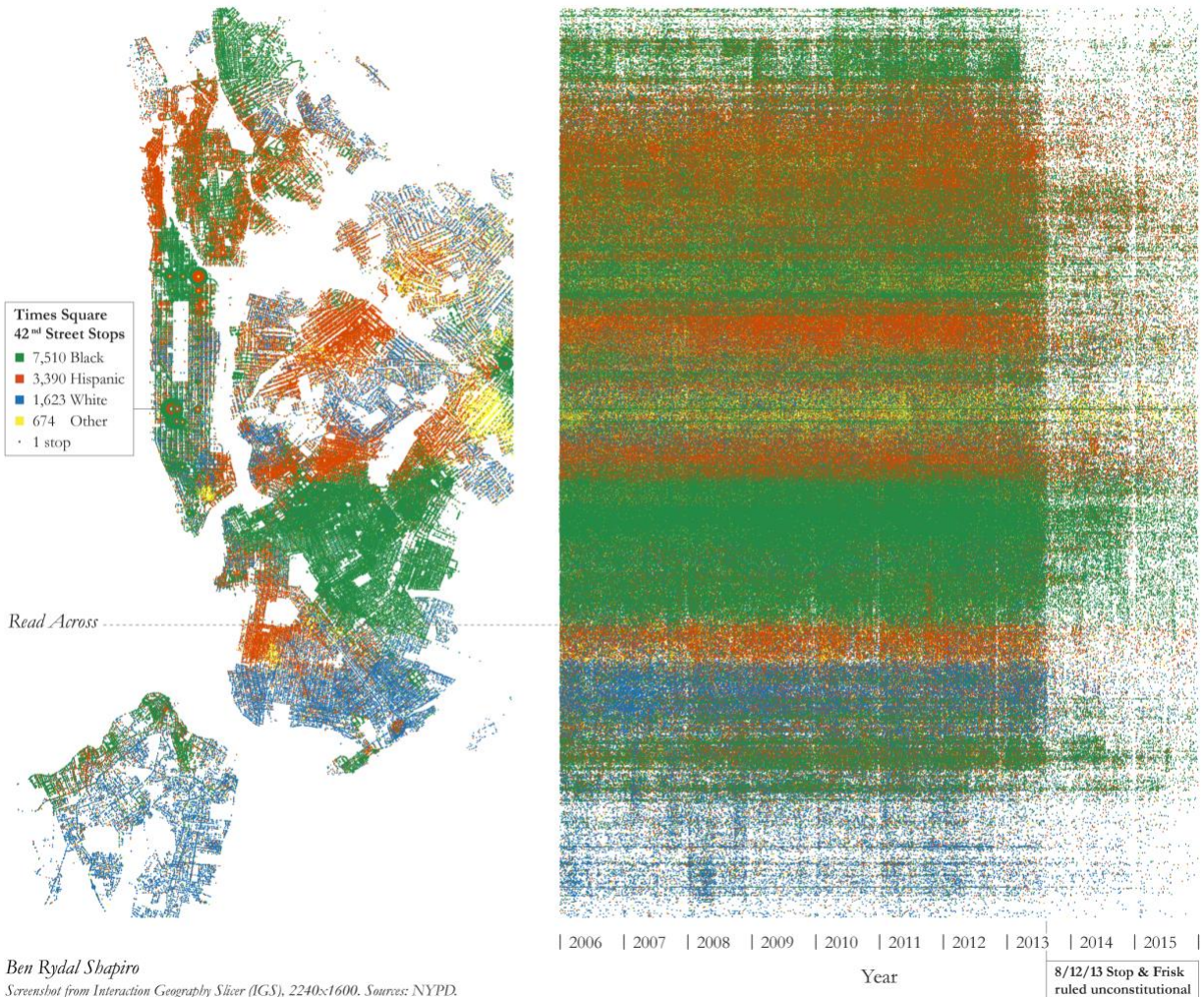
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USING THE INTERACTION GEOGRAPHY SLICER TO VISUALIZE NEW YORK CITY STOP & FRISK

NEW YORK CITY STOP & FRISK, 2006-2015



Ben Rydal Shapiro

Screenshot from Interaction Geography Slicer (IGS), 2240x1600. Sources: NYPD.

Figure 3 - 1: Screenshot from Interaction Geography Slicer (IGS) showing recorded stops in New York City from 2006-2015. The right view extends stops on map horizontally over time. Data from NYPD. Copyright © Ben Rydal Shapiro. Reprinted by Permission

Abstract

This paper adapts and uses a dynamic visualization environment called the Interaction Geography Slicer (IGS) developed by the 1st author to visualize data about New York City's Stop & Frisk Program. Findings and discussion focus on how this environment provides new ways to view, interact with and query large-scale data sets over space and through time to support analyses of and public discussion about New York City's Stop & Frisk Program.

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Introduction

“It worked very well in New York... it brought the crime rate WAY DOWN” – Donald Trump

“It was ineffective” – Hillary Clinton

“The argument is that it is a form of racial profiling” – Lester Holt

The three statements above were made during the inaugural 2016 presidential debate by Donald Trump, Hillary Clinton, and moderator Lester Holt, respectively. These statements reflect different views regarding the effectiveness and future use of “stop, question and frisk” policing tactics that allow police officers to stop civilians whom police officers deem reasonably suspicious and subsequently, frisk, search, or detain them, even through the use of physical force. The central premise of this article is that important (and controversial) political and social issues that occur “in place,” such as stop and frisk, can benefit from new, spatiotemporal ways of viewing, analyzing and discussing them.

This paper adapts and uses a dynamic visualization environment called the Interaction Geography Slicer (IGS) developed by the 1st author to visualize data about New York City’s Stop & Frisk Program. Findings and discussion focus on how this environment provides new ways to view, interact with and query large-scale data sets over space and through time to support analyses of and public discussion about New York City’s Stop and Frisk Program.

We begin by reviewing relevant historical, statistical and visualization research concerning New York City’s Stop & Frisk Program as well as concepts and methods from space-time visualization research that inform this work. Subsequently, we discuss how to read **Figure 3 - 1** that opens this paper and demonstrate what it reveals about stop and frisk that is otherwise concealed, obscured, or overlooked in more conventional representations of the phenomenon. We then use a second figure that visualizes New York City felony data at precisely the same spatial, temporal and symbolic (e.g. dot size) scales to conduct a comparative analysis that we suggest advances stop and frisk research. We continue by discussing a third figure that visualizes data along New York City’s Broadway Street to further define the types of interactive and comparative capabilities of the IGS. We conclude by discussing inherent limitations and next steps in this work.

Relevant work

New York City’s Stop & Frisk Program

Stop, question and frisk or “stop and frisk” policing tactics originated nearly 50 years ago in a Supreme Court case called Terry vs. Ohio (1968) (Meares, 2014). This case laid the groundwork for police officers in many cities to stop and search civilians deemed, however arbitrarily, suspicious (Bostok & Fessenden, 2014). In the 2000s, New York City used stop and frisk policing tactics aggressively and in dramatic fashion. For example, data from the New York Police Department (NYPD) documents the rapid rise in stops from approximately 100,000 stops in 2002 to just over 685,000 stops in 2011. However, this general trend experienced a relatively abrupt

turnaround in 2013 when a federal judge ruled that New York's Stop & Frisk Program utilized indirect racial profiling that violated the constitutional rights of minorities throughout the city (Goldstein, 2017). This ruling did not end New York's Stop and Frisk Program (police officers still stopped roughly 23,000 civilians in 2015) but it did highlight the effectiveness of broad policy-level reform.

Empirical research concerning stop and frisk in New York City has grown considerably primarily due to the release of detailed publicly available data from the NYPD on all individual reported (by police) stops since 2003 (NYPD, 2016). This data describes each reported stop in New York City including characteristics such as the location of each stop (typically precise to the street level), time of the stop (typically precise to the minute) purpose of the stop, information about the person stopped (e.g. race, age, gender) and police actions during a stop such as searching, using physical force, or arresting suspects (Lacoe & Sharkey, 2016; Ridgeway, 2007).

In one strand of research, statisticians utilize this data to document the incidence and distribution of stop and frisk practices. Many statisticians show that police disproportionately stop ethnic minorities and particularly persons of African American and Hispanic descent (Gelman et al., 2007; Goel et al., 2016; Ridgeway, 2007). For example, of the approximately 685,724 reported stops that occurred in New York City in 2011, 53% (350,743) were Black, 34% (223,740) were Latino and 9% (61,805) were white (NYCLU, 2015). Others illustrate how, despite wide acknowledgement that particular geographic areas of New York are targeted due to higher crime rates, (a) there is very little empirical research studying the relation between stop and frisk and crime, (b) the research that has been conducted rarely shows any statistical correlation between stop and frisk and crime, and (c) nearly all of this research uses spatial units at the police precinct or census block level that are too large to adequately conduct comparative analyses between stop and frisk and crime (Goel et al., 2016; Jones-Brown et al., 2010; Lacoe & Sharkey, 2016; Rosenfeld & Fornango, 2014; Rosenfeld, 2014). Still other statisticians demonstrate particular ways stop and frisk tactics influence neighborhood-police relationships. For instance, some study how policing tactics change in certain neighborhoods following homicides (e.g. violent crimes), finding that stops in non-white neighborhoods (particularly majority Black and Hispanic neighborhoods with high crime) increase dramatically after a homicide causing people to experience "the fear and shock that come with extreme violence" (Lacoe & Sharkey, 2016). In contrast, there is no evidence that stops in white neighborhoods increase following a homicide (Lacoe & Sharkey, 2016).

In a separate strand of research, many visualization researchers, designers and artists utilize a variety of techniques to visualize and describe data about New York's Stop & Frisk Program. Some utilize interactive maps to visualize and layer the location of stops and particular stop events such as gun recoveries (Keefe, 2017). Others utilize interactive graphics that include maps and timelines to show the fluctuation and uneven racial distribution of stops (Bostok & Fessenden, 2014; Franke-Ruta, 2017). Still others provide highly interactive and engaging ways for people to visually interact and draw their own conclusions from complex stop and frisk data (Rhiel, 2017).

Together, we suggest these two strands of research inform a number of important starting points relevant to this paper:

Starting Point 1: Statistical and visualization research and design concerning the use and effectiveness of New York’s Stop & Frisk Program is still in its infancy. Much of the research we have described reflects initial efforts to explore trends in only very recently available data to begin to make sense of an extremely complex and controversial issue.

Starting Point 2: Like many controversial issues, there is a significant need for the production of more powerful “artifacts” to better inform public discussion. For instance, many leading and influential public figures continue to state with complete confidence that stop and frisk tactics inherently reduce crime ignoring empirical research that does not show any correlation between (a) stop and frisk and (b) crime. Put differently, there is a significant need for tools and analytic processes that use information visualization and the arts to make statistical analyses and questioning about this issue more accessible to public figures and the general public (Gelman & Unwin, 2013).

Starting Point 3: There are a number of specific research and design needs. First, there is a significant need to advance existing spatial analysis and visualization of New York City stop and frisk data and to do so not only at the census block or police precinct level but also at the street level (Evans et al., 2014; Lacoë & Sharkey, 2016; Bostok & Fessenden, 2014). Second, there is also a significant need to begin to account for the spatiotemporal dimension of stop and frisk data (Wooditch & Weisburd, 2016). In other words, almost no work currently explores stop and frisk as it occurs in space and through time simultaneously. Third, future research and design must develop ways to analyze and visualize stop and frisk data over more than a single or a few years as is typically the case in most existing work due to technical limitations (e.g. to make data processing “manageable”) (Wooditch & Weisburd, 2016). Finally, future research and design should support more dynamic ways to compare stop and frisk data and crime data.

Space-Time Visualization Research

This paper also draws from an established body of visualization research and design concerning space-time visualization, which seeks to describe and understand phenomena (e.g. movement, information or traffic flows) over space and through time simultaneously (Aigner et al., 2011; Adrienko & Adrienko, 2006, 2013; Andrienko et al., 2011; Bach et al., 2014; Munzner, 2014; Peuquet, 2001; Scheepens, 2016).

In particular, the dynamic visualization environment introduced in this paper, the Interaction Geography Slicer (IGS), is adapted from other work that is developing and using the IGS to study the relation between people’s “interaction geographies” and learning in museums and other built environments (Shapiro & Hall, 2017, Shapiro, 2017). This work and thus this paper also draws from a geographical perspective called “time geography” (Hagerstrand, 1970) and related work concerning the use and advancement of a 3D representational system called the “space-time cube”, which is often used to visualize physical movement (e.g. traffic flows) both over a 2D map and as it extends upwards over time in 3D (Bach et al., 2014; Kraak, 2003). In addition, this paper also draws from research that advances the usability of the space-time cube for expert and non-expert users (Buchin et al., 2014; Chittaro et al., 2006; Elmqvist et al., 2011; Nagel et al., 2016; Pousman et al., 2007; Vande Moere & Purchase, 2011).

Visualizing New York City Stop & Frisk, 2006-2015

How to Read Figure 3 - 1

Figure 3 - 1 that opens this paper is a screenshot from the IGS. It shows recorded stops from 2006-2015 (10 years total) on a map of New York City and also their occurrence over “space-time” (Hagerstrand, 2017) across a timeline. Data is from the New York City Police Department (NYPD, 2016) and records stops precise to the street intersection and minute of occurrence from 2006-2015. Stops without recorded spatial or temporal coordinates are not shown.

The right part of the figure or the “space-time view” extends stops on the map across a timeline, preserving vertical location on the map with the Y-axis. Put differently, the space-time view “stretches” stops shown on the map horizontally to their precise occurrence in time across the timeline while preserving one spatial dimension. Thus, a reader should use the two views (map and space-time) together by looking across horizontally from one view to the other.

Color designates race. Green is Black, red-orange is Hispanic, blue is White, and yellow is Other. These racial categories and color choices reflect particular aesthetic and analytic decisions and can be changed or expanded within the IGS to encompass different colors or more racial categories.

Both map and space-time views use proportional symbol mapping where symbol or dot size represents the number of stops at a location on the map or in space-time (e.g. the larger the dot the more stops). In the figure, symbols are perceptually scaled (e.g. increase in size), which adjusts the area of symbols to account for underestimation that occurs when the area of the symbol proportionally corresponds to increases in the size of the data (e.g. absolute scaling) (Slocum et al., 2009). Furthermore and quite importantly, many symbols/dots only show the racial category that was stopped the most at a location on the map or in space-time (e.g. the other three racial categories are not shown). In cases with an equivalent number of stops of two or more racial categories at a location, dots for each category are plotted adjacent to one another as a single dot. In addition, for locations where the number of stops exceeds 1600, dots for each racial category are plotted on top of one another in descending order (largest on the bottom) so that a dot for each racial category is shown at that location. This technique is most recognizable at locations with many thousands of stops (often subway stations) shown by large, superimposed dots of multiple racial categories. For instance, we have highlighted Times Square 42nd Street Station as one example wherein a large green circle encloses a smaller red-orange circle that encloses even smaller blue and yellow circles. These patterns indicate that the number of stops at Times Square 42nd Street Station exceeded 1600 during the observation period (2006-2015) and that Black civilians were stopped most (green circle), followed by Hispanics, Whites and, finally, Other civilians. This set of algorithms was selected after numerous tests demonstrating that they appropriately balanced aesthetic (dot overcrowding) and functional considerations along with distinct challenges in this data set (e.g. repeated stops at the same street location and heavily skewed data) to communicate the spatial distribution and sequential organization of stops at this spatial and temporal scale.

Like any set of techniques, the conventions depicted in Figure 3 - 1 have limitations and provide only one way to view these data. Later in this paper, we discuss these limitations in more detail as well as ways the IGS addresses these limitations directly by, for example, providing ways to “slice” space and time to provide different views of the data and utilizing algorithms to plot

repeated stops in different types of ways (e.g. utilizing absolute scaling of symbols as opposed to perceptual scaling).

Figure 3 - 1 Discussion & Findings

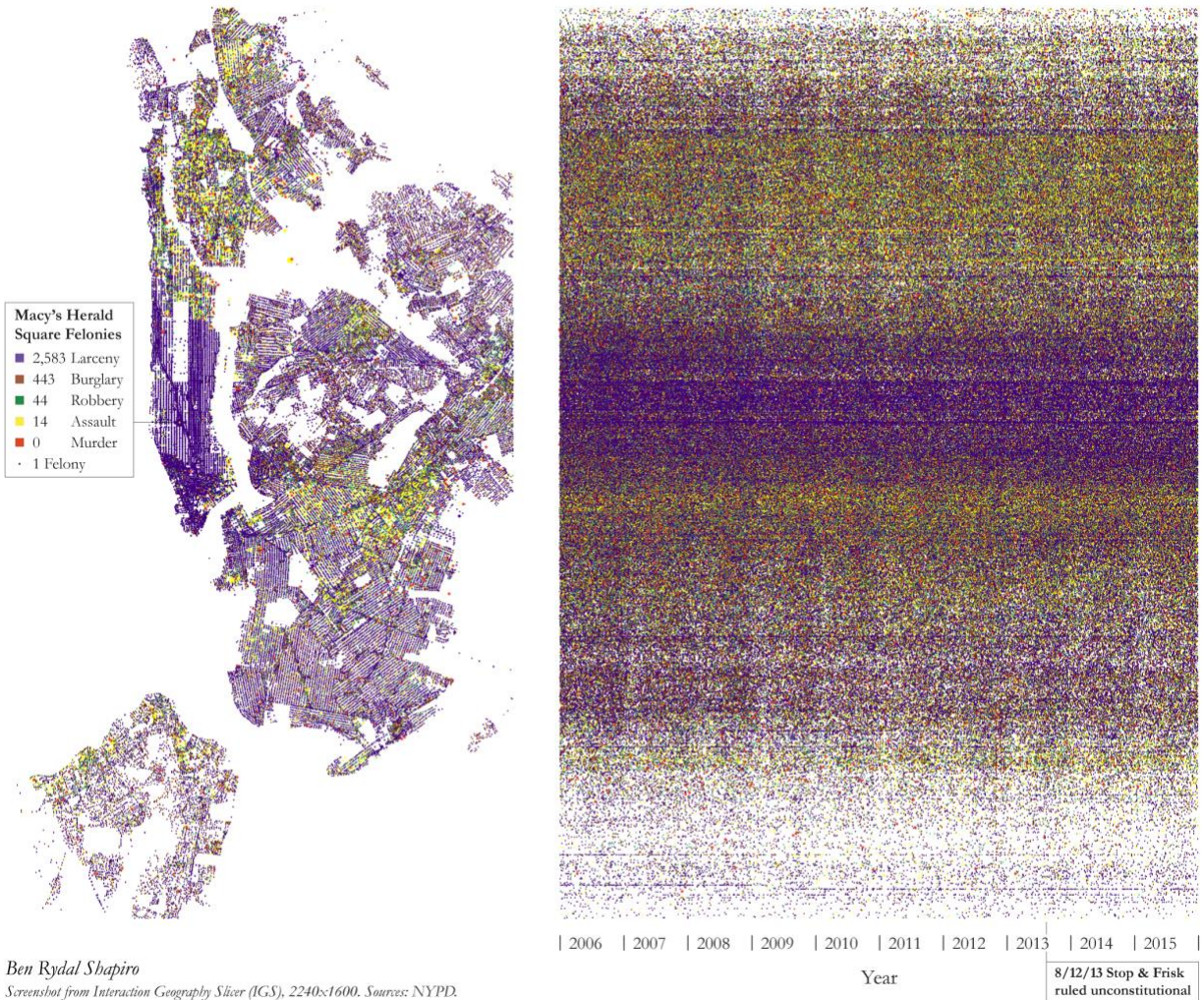
We suggest that an initial overview reading of Figure 3 - 1 (Tufte 1983, 1990) contributes a fundamentally new view of New York City's Stop & Frisk program. The map view depicts a full 10 years of reported stop data, something rarely found in previous research. Likewise, the map view complements and extends existing stop and frisk research by highlighting the uneven racial distribution of stops across the city not just at a neighborhood or police precinct level, but also at particular street level locations and landmarks across New York City. For example, there are an extremely high number of recorded stops at particular subway stations. The space-time view, in contrast, presents a more powerful and fundamentally new view of stops/policing activity across New York City. The space-time view possesses a "graphical weight" that does not and cannot exist in the map view. Put another way, the space-time view has a graphical density, color concentration and color distribution that foregrounds the uneven racial distribution of stops over space and through time.

Once the space-time view is digested and understood, the figure offers deeper levels of reading. Most notably, the space-time view reveals the dramatic fall or "decay" of stops after years of aggressive stop and frisk policing tactics in New York, following the ruling by a federal judge on 8/12/13 that New York's Stop & Frisk Program violated the constitutional rights of minorities. This dramatic fall is not visible in the map view, but is clearly evident as it unfolds after 8/12/13 on the timeline.

Furthermore, the space-time view provides more detail as to how stops are potentially distributed across different neighbourhoods and geographic areas. Since the racial distribution of stops in this data is so uneven and concentrated in particular geographic areas, the space-time view creates dense strips or bands of stops of the same color/racial category. For example, the density and concentration of Blacks stopped in Brooklyn (the geographic region that appears in green above the horizontal line drawn on Figure 3 - 1) is apparent in the map view. However, the space-time view makes the magnitude of these stops more apparent by revealing an incredibly thick and dense strip of green. Likewise, the space-time view highlights many dense strips of Hispanic stops occurring in predominantly Hispanic neighborhoods.

In addition, the space-time review reveals phenomena that are not visible using the map view. These phenomena include: 1) vertical "white lines" or blank spaces many of which indicate a cyclical cessation of stops during the holiday season (e.g. December/Christmas/the New Year), 2) "blotches" of stops that appear or bleed through dense bands of stops indicating potential times of intense policing activity often of Blacks and Hispanics, 3) the uneven "fall" of stops after the court ruling with some areas of the city even experiencing a subsequent and brief increase in stops after the dramatic fall, and 4) extremely straight, "horizontal lines" indicating a high density and even or uneven sequential organization of stops at particular locations. We encourage readers to draw their own findings from Figure 3 - 1.

NEW YORK CITY FELONIES, 2006-2015



Ben Rydal Shapiro
 Screenshot from Interaction Geography Slicer (IGS), 2240x1600. Sources: NYPD.

Figure 3 - 2: Screenshot with title, legend and keys from Interaction Geography Slicer (IGS) showing recorded felonies in New York City at the same scales and dot conventions as stops shown in Figure 3 - 1. Data from NYPD. Copyright © Ben Rydal Shapiro. Reprinted by Permission

In summary, Figure 3 - 1 introduces one way in which the IGS visualizes data from New York City's Stop & Frisk Program at one spatial and temporal scale. We suggest the figure shows stops in a new and provocative way and identifies segments of space and time of potential interest for stop and frisk research. Equally important, like any visualization, Figure 3 - 1 has limitations that necessitate other ways to view, interact with and query this data.

Comparing New York City felonies, 2006-2015

How to Read Figure 3 - 2

Figure 3 - 2 shows a screenshot from the IGS that maps New York City felonies over space and time using exactly the same scales and dot conventions as Figure 3 - 1. Rape is not included because it is not coded at the street level and grand larceny/grand larceny with a motor vehicle is combined into a single felony category of larceny. Additionally, murders are enlarged slightly.

Figure 3 - 2 Discussion & Findings

We suggest that an overview reading of Figure 3 - 2 in comparison to Figure 3 - 1 leads to two striking and important realizations. First, there are far fewer and less concentrated felonies at particular places in comparison to stops shown in Figure 3 - 1. This finding is documented in existing literature but these figures make it visible in new ways (Bostok & Fessenden, 2014, Gelman et al., 2007; Joens-Brown et al., 2010; Weisburd et al., 2016). Second, the space-time view reveals what appears to be very little change in the consistency of felonies over 10 years. Most importantly, this visual “wall” of felonies persists through the dramatic rise and fall of New York Stop and Frisk and its unconstitutional ruling. This does not mean that stop and frisk is having no effect on reported felonies—as numerous reports show, the number of felonies has decreased slightly over these 10 years (Ridgeway, 2007; Rosenfeld & Fornango, 2014; Rosenfeld et al., 2014). However, the figures provide a stark and vivid contrast to statements from those who predicted (and still claim) that felonies would rise dramatically and immediately following the reduction of stop and frisk policing tactics in New York City. Thus, Figure 3 - 2 contributes to stop and frisk research by further challenging statements that claim stop and frisk policing tactics influence crime in a direct or cause-and-effect way.

Figure 3 - 2 also supports deeper levels of reading. First, the figure reveals the distribution of felonies in a particular manner. For example, the figure shows a large amount of grand larceny occurring in Manhattan. This is striking in both the map and space-time views. Second, cyclical patterns of reported felony activity are visible in the space-time view as white spaces or “waves” that indicate cessations in reported felony activity at particular times each year. This is documented in existing research but is shown in a new way. As with Figure 3 - 1, we encourage readers to draw their own findings and questions from Figure 3 - 2.

In summary, Figure 3 - 2 provides a valuable and striking comparison to Figure 3 - 1. We suggest this comparison supports public discussion about the complex relationship between stop and frisk policing tactics and felony activity in New York City. However, as with Figure 3 - 1 there are many limitations that specifically highlight the need for additional ways to interact with, view or query these data (e.g. most dots only show felonies that occur the most at a location, yellow emphasizes assaults, and small yearly decreases in felonies are not adequately shown).

Broadway stops & murders, 2006-2015

The prior two visualizations highlight patterns of stops and felonies across the entire New York City area between 2006 and 2015. However, the IGS can also be used to visualize spatiotemporal patterns of stop and felony data at scales and in ways that, to our knowledge, do not exist in current research. As one such example, consider **Figure 3 - 3**, which arrays stop and frisk as well as felony data along Broadway Street, one of the oldest North-South thoroughfares in New York City. Although Broadway Street is perhaps best known as the epicenter of America’s theater industry, the street itself stretches the length of Manhattan and intersects, across its 13-mile pathway through Manhattan, a wide range of neighbourhoods that vary in racial and socioeconomic composition. As described next, Figure 3 - 3 reveals some of the novel dynamic and comparative possibilities of the IGS that we use to, for example, show how Broadway Street varies considerably with respect to the use of stop and frisk tactics and with regard to incidents of murder.

BROADWAY STOPS & MURDERS, 2006-2015

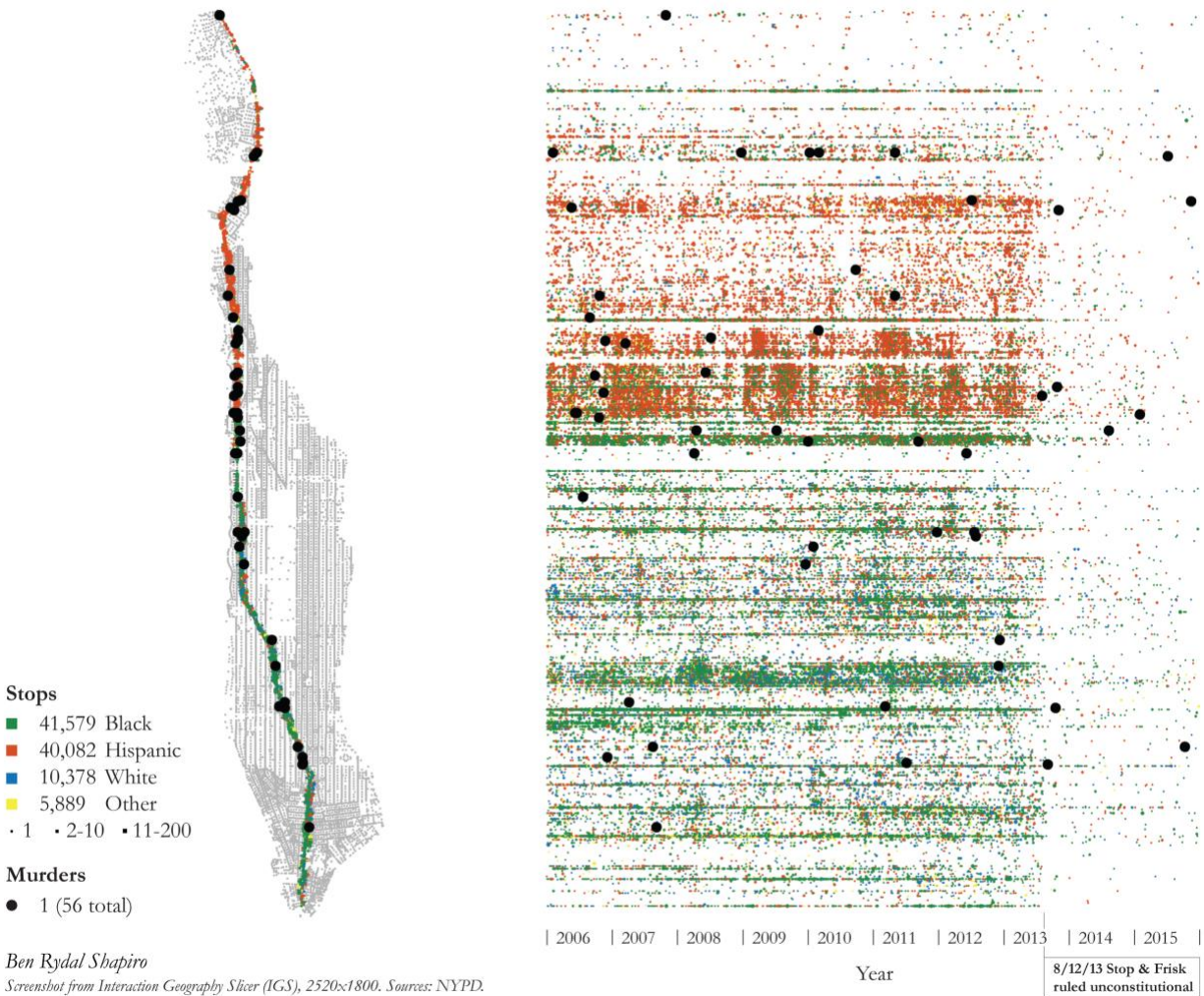


Figure 3 - 3: Screenshot with title, legend and keys from Interaction Geography Slicer (IGS) showing stops and murders along Broadway Street in Manhattan, New York. Data from NYPD. Copyright © Ben Rydal Shapiro. Reprinted by Permission

How to Read Figure 3 - 3

Figure 3 - 3, titled “*Broadway Stops & Murders, 2006-2015*”, is a screenshot from the IGS that shows all recorded stops and murders that occurred along Broadway Street in Manhattan from 2006-2015. Each black dot indicates a murder. Colored dots indicate stops using the same color choices but different dot/symbol scaling as Figure 3 - 1. The map view shows felonies occurring across Manhattan in grey and highlights in color all stops and murders that occurred along Broadway Street. The space-time view shows only stops and murders that occurred along Broadway Street (e.g. it does not show all felonies across Manhattan in grey).

Figure 3 - 3 Discussion & Findings

Several conclusions can be drawn about the dynamic visualization and analytic possibilities of the IGS by considering Figure 3 - 3: *Broadway Stops & Murders, 2006-2015*. First, the figure shows how one can use the IGS to dynamically “slice” regions of space to highlight phenomena by, in this case, drawing (with one’s cursor/mouse) over the map. Put differently, the figure shows how

we have highlighted phenomena along Broadway Street by “drawing the street” to reveal phenomena in both the map and space-time views that occur along/near Broadway Street. Thus, this example shows how the IGS provides not only a way to perform the types of street level spatiotemporal analysis that many stop and frisk researchers call for, but how it also provides new ways to interact with and determine the boundaries of spatial regions in ways that draw from and extend existing space-time visualization research. Moreover, one can also draw shapes in the space-time view to define and highlight phenomena across different types of temporal regions (not shown in the figure). In addition, the IGS supports many more conventional and computationally less expensive (e.g. faster) ways of slicing regions of space and data through the use of circular and rectangular shapes (e.g. one can select circular and square regions on the map and in space-time to highlight phenomena). Likewise, future development aims to support the import of standard geographic shapefiles and census tracts to highlight data.

Second, the figure illustrates (in comparison to previous figures) how one can use the IGS to dynamically “zoom” to select and reveal phenomena in both the map and space-time views (e.g. both views adapt to one another). In this case, we have zoomed on to Manhattan in the map view to reveal phenomena across the Manhattan region (e.g. as opposed to all of New York City as shown in Figures 3 - 1 and 3 - 2). Though the figure maintains a temporal scale of 10 years to allow comparisons to be made to Figures 3 - 1 and 3 - 2, temporal zooming down to the minute for this data set is possible within the IGS.

Third, the figure also shows one way to “layer” stop and felony data in the IGS. In this case, recorded murders are layered on top of recorded stops. However, the IGS supports a variety of interactive ways to layer and toggle between different types of stop and felony data.

Broadway Stops & Murders, 2006-2015 contributes to stop and frisk research in a variety of ways. First, the figure continues to reveal and emphasize that ethnic minorities and particularly persons of African American and Hispanic descent are stopped at an extremely high rate. In this case, over 80% of recorded stops along Broadway Street are of Blacks and Hispanics.

Second, the figure aims to make visible and support public discussion about an important question in stop and frisk research. Namely, how does police activity respond to violent crime in particular geographic areas for different races (Lacoe & Sharkey, 2016)? Put simply, the figure aims to provide an artifact to support broader public discussion and consideration about this research question.

Third, the figure affords observations that on one hand further public discussion about stop and frisk but on the other hand indicate the need for more comparative forms of visual analysis (e.g. of other streets in New York City) as well as more powerful forms of statistical analysis.

For example, some observations the figure makes visible include: (a) continuous and discontinuous lines of stops in the space-time view, primarily of Blacks and Hispanics, that correspond with particular locations along Broadway Street, (b) variation in the distribution of murders along Broadway Street across both space and space-time (e.g. only a single murder occurs in 2014) and (c) locations and regions of space and time for further analysis and comparison to other streets in New York City.

To review, Figure 3 - 3 demonstrates some of the dynamic visualization and analytic possibilities of the IGS that provide new ways to view, interact with and query stop and felony data. In doing so, the figure (a) provides an artifact to support public discussion about New York

City's Stop and Frisk Program, (b) makes visible and supports public discussion about stop and frisk research and (c) raises new questions relevant to stop and frisk and criminal research such as what are productive spatiotemporal units of analysis to study "micro-geographic hot spots" of policing or felony activity (Lacoe & Sharkey, 2016; Wooditch & Weisburd, 2016)?

Contributions

In summary, this paper makes three primary contributions. First, it adapts and uses the IGS to illustrate new, spatiotemporal ways to view, interact with and query large-scale data sets to support public discussion about New York City's Stop & Frisk Program. In doing so, this paper shows how with further development the IGS may be applied to other types of large-scale data sets and particularly ones concerning important political and social issues that occur "in place."

Second, this paper contributes to collaborations across the disciplines of information visualization, art and statistics. The authors of this paper are from each of these fields and such collaborations are necessary to this work. Likewise, the figures in this paper are informed by and integrate each of these disciplines. For example, the figures synthesize (a) techniques of space and time flattening from information visualization, (b) compositional and color choices inspired by artists including Mark Rothko and Piet Mondrian (e.g. Hispanic stops in Figure 3 - 1 are shown in red-orange as opposed to orange to suggest that New York City is "bleeding") and (c) specific questions and findings raised by statisticians concerning policing activity and crime.

Finally, this work exemplifies the value of many open-source programming languages and libraries designed by/for visual artists and designers. The version of the IGS used in this paper is written in Java and draws from the Processing Programming Language (Reas & Fry, 2007) created by Ben Fry, Casey Reas and a vibrant community of many other generous and hard working contributors, as well as the Unfolding Maps Library (Nagel et al., 2013) created by Till Nagel and a team of similarly generous and hard working contributors.

Limitations

There are several limitations of this work. First, each figure described in this paper embodies particular computational and aesthetic choices that show selected phenomena in certain ways while hiding others (Monmonier, 2014). Figures 3 - 1 and 3 - 2 in particular, utilize algorithms that often show the highest number of stops or felonies of a racial or felony category at each space and space-time location. As a result, for example, Figure 3 - 1 does not adequately communicate that police do stop White citizens in Brooklyn and does not compare stops to neighborhood demographics. Instead, it shows that police stop far more Black citizens in Brooklyn than other races. Likewise, felony assaults in Figure 3 - 2 appear more numerous than they actually are due to the color choice of yellow. Moreover, all figures in this paper show "fixed" views from the IGS that are intentionally oriented in a particular manner. In other words, rotating the map view (an operation possible within the IGS) would change the types of patterns visible in the space-time view. Throughout this paper, we have discussed how these limitations necessitate the need for multiple views of the same data and how the IGS can provide such views by utilizing different algorithms to scale symbols, slice space, time and data, layer or toggle data, change colors and

expand data categories and zoom space and time. Nevertheless, it is important to understand the inherent limitations and particular goals of the static figures shown in this paper.

Second, there are a number of limitations with respect to the original data sets from the NYPD. For example, numerous researchers have demonstrated the issues and limitations with police reporting of stops (e.g. many stops go unreported). Likewise, both data sets aggregate phenomena to the street intersection and sometimes aggregate phenomena from a larger geographic region to particular street intersections. For example, as the NYPD describes (NYPD, 2016), felony offenses occurring within the jurisdiction of the Department of Correction are located at Riker's Island (e.g. this creates a line of felony assaults (yellow) in the upper right part of the space-time view in Figure 3 - 2). Thus, the figures in this paper make the structure of the original data sets quite visible—this is on one hand a strength of the IGS but on the other hand, a limitation and caution against interpretation or explanation that makes conjectures about human action at scales below the spatial resolution of the original data.

Third, our processing of the original data sets (retrieved from the NYPD in September, 2016) resulted in certain limitations. For instance, we eliminated all data points without a space or time coordinate. Moreover, we defined what constituted Broadway Street as a geographic region (e.g. no shapefile currently existed) by testing (via drawing) whether all points in the original data set were located within a certain number of pixels from Broadway Street (e.g. at a particular map scale) and as a result, intentionally included points/phenomena that were near to Broadway Street. These decisions served the purposes of this paper and could be easily adjusted in future research.

Fourth, the figures in this paper are limited by the resolution of the screens and prints through which they are shown. Higher resolution screens or prints afford more precise readings (e.g. the IGS adapts to resolution).

Finally, interpretation of the figures in this paper is limited by prior knowledge of the geography and social and political landscape of New York City. Readers who live in or know New York City are able to read and interpret the figures included in this paper in more nuanced and informed ways than those persons without this prior knowledge.

Next steps

With further development and support, this work will be made publicly available to support further public discussion and analysis of New York City's Stop & Frisk Program. Current and future development aims to refine the ways of reading, using and performing analyses with these data using the IGS. For example, additional user group test cases are necessary to better understand how people read and make sense of the complex, spatiotemporal visualizations depicted in this paper and to build supports that aid in interpretation and reduction of misinterpretations. Likewise, current and future work includes optimizing the IGS to, for instance, advance the speed, fluidity and precision of spatial "slicing" of stop and felony data.

Conclusions

We began this paper with three statements from the inaugural 2016 presidential debate that illustrated different views regarding the effectiveness and future use of “stop, question and frisk” policing tactics. Subsequently, we adapted and used the Interaction Geography Slicer (IGS) to visualize data about New York City’s Stop & Frisk Program. In doing so, this paper demonstrated how the IGS provides new ways to view, interact with and query large-scale data sets over space and through time to support analyses of and public discussion about New York City’s Stop and Frisk Program. Throughout this paper, we have highlighted particular contributions of this work and equally important, particular limitations of this work. We hope to have demonstrated that important (and controversial) political and social issues that occur “in place,” such as stop and frisk, can benefit from new, spatiotemporal ways of viewing, analyzing and discussing them. Finally, it is our hope that the previous pages make evident the value of and new possibilities for collaborations across the disciplines of information visualization, the arts and statistics.

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