# Integrative Visualization:<br>Exploring Data Collected in Collaborative Learning Contexts

Ben Rydal Shapiro, Georgia Institute of Technology, ben@benrydal.com

**Abstract:** The development and use of computational approaches to make sense of data collected in collaborative learning contexts is expanding rapidly in the Computer-Supported Collaborative Learning (CSCL) and Learning Sciences (LS) communities. However, developing and using these approaches in ways that maintain a commitment to theory and situational context is a significant challenge. This paper proposes *integrative visualization*, a computationally assisted, human-centered process to visually explore data collected in collaborative learning contexts in a way that maintains a commitment to theory and situational context. To do so, this paper summarizes how integrative visualization supported the development and use of interaction geography, an approach to describing, representing, and interpreting collaborative interaction across the physical environment. This paper concludes by emphasizing the need to further develop integrative visualization in the CSCL and LS communities through stronger connections with the information visualization community.

## Introduction

The development and use of computational approaches to make sense of data collected in collaborative learning contexts is expanding rapidly in in the Computer-Supported Collaborative Learning (CSCL) and Learning Sciences (LS) communities. In particular, computational approaches are providing ways to extend traditional data analysis of phenomena such as language, gesture, or gaze important to studying collaborative learning (Rosé et al., 2008; Schneider & Pea, 2014). Alternatively, these approaches offer resources to reason about larger data sets and data scales including multimodal data collected across classroom settings (Knight et al., 2017). However, developing and using these approaches in ways that maintain a commitment to theory and situational context is a significant challenge (Wise & Schwarz, 2017; also see Law et al., 2018). This challenge also reflects broader efforts in and outside of education to develop "orientations towards and frameworks for data science that are not reducible to mere efficiency" (Zegura, DiSalvo & Meng, 2018; also see Kahn, 2017; Berland et al., 2017).

This paper proposes *integrative visualization*, a computationally assisted, human-centered process to visually explore data collected in collaborative learning contexts in a way that maintains a commitment to theory and situational context. Integrative visualization extends visual methods of exploratory data analysis (Tukey, 1977) to iteratively transcribe data collected in context in order to organize data and develop codes, categories, units of analysis, and questions that support the development of grounded theory (Glaser & Strauss, 1967) and new computational tools. In particular, integrative visualization extends the practice of "integrative diagramming" (Strauss, 1987) through techniques of exploratory data analysis and is summarized as follows:

data context → transcription amplified by visualization → grounded theory & computational tools

This paper illustrates this process of integrative visualization by describing how it supported the development and use of interaction geography, an approach to describing, representing, and interpreting collaborative interaction across the physical environment (Shapiro, Hall & Owens, 2017; Shapiro & Hall, 2018). This paper concludes by emphasizing the need to further develop integrative visualization in the CSCL and LS communities through stronger connections with the information visualization community.

## An example of integrative visualization

### Data context

The example described in this paper draws from data collected during a three-year project in collaboration with a nationally renowned museum located in the mid-South region of the United Sates. This project sought to understand how visitors to this museum cultivated interests in and learned about the diverse historical and cultural heritage of American Roots music during and after their visit. Two initial research questions guided this work. First, this work aimed to understand the organization of visitors' activity not only at single museum exhibits as was typically the case in existing research but also as visitors moved across gallery spaces over their complete museum visit. Second, this work sought to understand how visitors furthered their own interest-driven engagement and learning through their activity across gallery spaces.

 

To answer these questions, a purposive sample of complete museum visits across 22 visitor group cases (2–5 visitors per group) was collected over a period of six weeks. This sample was collected in close collaboration with museum partners, many generous families and visitors participating in this research, and followed institutional review board (IRB) protocols. Data from these 22 cases included continuous, multi-perspective video and audio records (72 hrs total) of each visiting groups' movement, interaction, and social media use collected through small, unobtrusive cameras that each visitor in a group wore as necklaces for the duration of their visit with no researchers present (visits ranged from 30 min to 4 hrs). This data provided detailed records of visitors' interaction (e.g., conversation, movement, use of cell phones and cameras).

This data presented two novel research challenges. First, existing research was only beginning to make sense of complex, multi-perspective audio and video data in ways necessary to answer the questions informing this work (see Marin, 2013; Steier, 2014; Taylor & Hall, 2013 for early work). Second, apart from a few novel and inspirational examples (see Fouse et al., 2011), computational tools to support this work did not exist. For example, contemporary transcription software (e.g., InqScribe, NVivo) and video editors (e.g., Final Cut Pro, Adobe Premier) were not designed to account for the spatial dimension of collaborative interaction as people moved. Likewise, information visualization and visual analytics software used to study visitor activity in settings such as museums did not operate at a fine enough grain size to answer the research questions informing this work and also typically focused exclusively on visitors' movement ignoring their conversation.

In summary, this particular cultural heritage museum along with these initial questions, goals, types of data collected, and unique challenges framed the data context of this work. This data context included a theoretical commitment to studying visitors' interest-driven engagement and learning as they moved across gallery spaces through continuous, multi-perspective video records of visitor activity. The following section uses a set of figures and analysis to illustrate an iterative process of transcribing this data amplified by visualization in a way that maintains this theoretical commitment and is driven by this data context.

## Transcription amplified by visualization

Figure 1 is a hand drawn sketch that represents a first attempt to make sense of this data and specifically, a five-member family's activity within a particular museum gallery space. Namely, the sketch tries to make sense of the family's experiences across a gallery space from watching five separate video records.

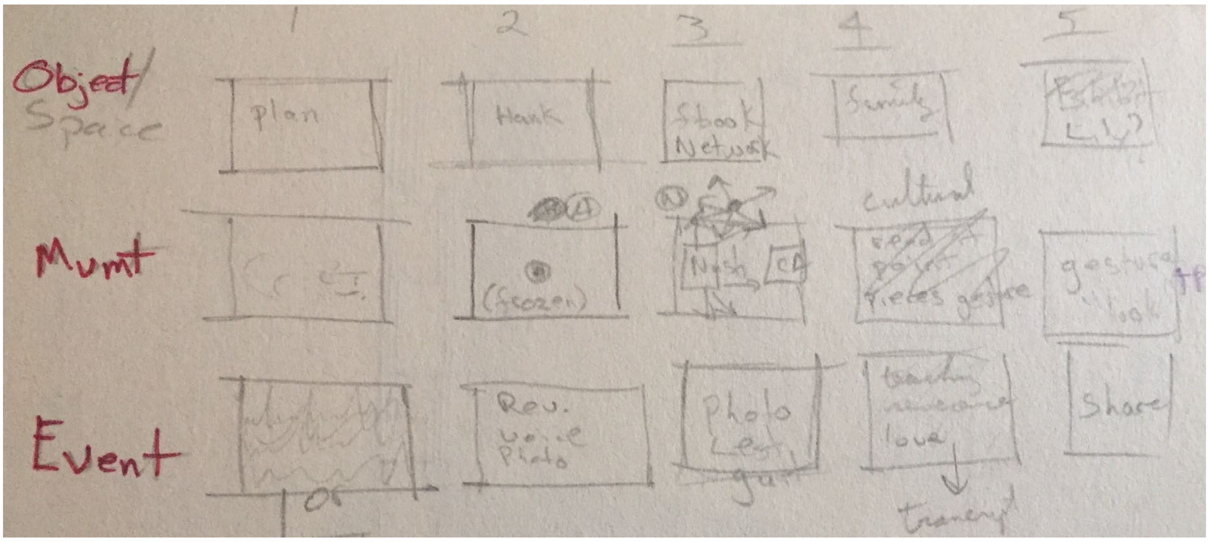


Figure 1. Manual sketch of a family's activity in a museum gallery transcribed from multi-perspective video.

Importantly, the sketch draws from a set of famous architectural drawings known as the "Manhattan Transcripts" developed by architect Bernard Tschumi: The Manhattan Transcripts aimed to expand the theorization and design of architecture beyond space and form to also include the relations between space, movement, and event or what happens in space (Tschumi, 1994). The sketch uses the Manhattan Transcripts to organize aspects of this family's activity in this gallery space across dimensions of object/space, movement, and event. For example, the 2nd column describes one family member's (named Adhir) activity at an exhibit. The first row of this column describes the exhibit/object of focus (a musician named Hank Williams); the second row characterizes Adhir's movement as frozen or not moving; the third row characterizes events/things Adhir does at the exhibit (stands in reverence, talks, takes a photograph). Altogether, the figure shows a commitment to understanding visitor groups as a mobile unit (e.g., multiple participants are placed in columns across different times of their visit) and questions concerning how and what happens as each family member moves.

Figure 2 is a computationally generated sketch produced 4 months after the previous sketch. It illustrates an early attempt to transcribe the same five-member family's conversation as they move across part of the museum gallery space described previously. Put differently, this sketch illustrates an initial attempt to address a fundamental problem regarding how to make sense of people's conversation as they move.

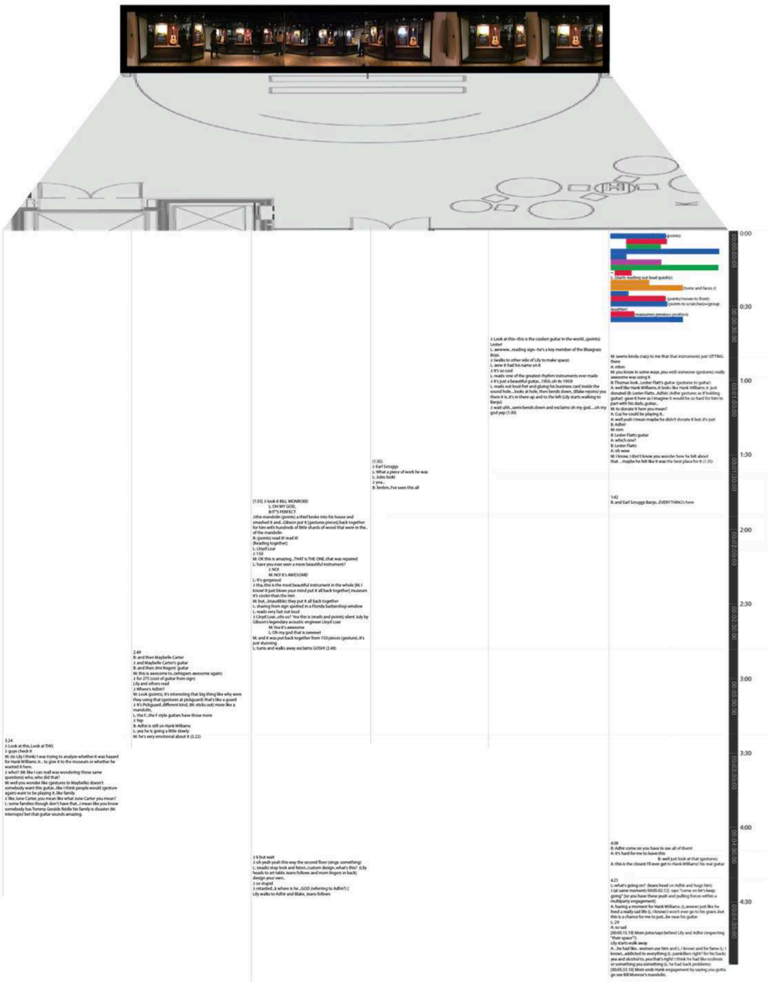


Figure 2. Extending the space-time cube to transcribe a family's conversation across a museum gallery space.

The sketch shows a floor plan of part of the gallery space (i.e., looking down on the space). This floor plan is tilted in 3D isometric perspective. A set of images is shown on top of the floor plan. These images correspond to six museum exhibits that line a semicircle drawn on the floor plan. A timeline in minutes and seconds along with grid lines that separate 6 regions of the floor plan (corresponding with the 6 exhibits along the semicircle) extend downward/below the floor plan. Turns of transcribed talk from each family member are placed along this timeline and in regions of this gridded space (i.e., placed in time and space). Turns of talk are also grouped into topically related conversations (typically spatially related conversations about exhibit content). Thus, the position of turns of talk/conversations vertically on the timeline and horizontally across the floor plan indicate when (over approximately 5 minutes) and where (along the semicircle of six exhibits) each turn of talk/conversation occurs. In addition, turns of talk in the first conversation (top of the timeline) are overlaid by colored lines that indicate speaker (i.e., color indicates which family member speaks that conversation turn).

Altogether, this sketch illustrates an initial effort to extend a geographical perspective called time geography and a visualization system known as the space-time cube (Hagerstrand, 1970) to begin to develop codes and categories to explore this family's conversation over space and time in new ways. Doing so necessitated categorizing and grouping conversation in ways that foregrounded the spatial and mobile dimensions of visitors' conversation (i.e., reflective of the theoretical commitments and data context of this work).

 

Figure 3, produced approximately three months after the previous figure visualizes different aspects of the same family's interaction over the total time they spent in the same part of the gallery space (approximately 8 minutes) in a small multiple format (Tufte, 1990). The top left visualization in the figure titled "overlayed talk" shows the turns of talk from the family colored by speaker. The visualization below this titled "conversation structures" isolates visual boxes that group turns of talk into topically related conversations while the visualization adjacent titled "transcribed talk" shows all transcribed talk for the family. In comparison to Figure 2, this includes about 3 more minutes of talk. The visualization above titled "mobility paths" shows the family's movement across this space and over time as lines or paths (color again indicates family member). The four visualizations to the right isolate each family member's individual movement and turns of talk: the mother named Mae is shown in purple, her son and daughter named Jeans and Lily are shown together in green and yellow respectively as their movement is nearly identical, their 6-year old brother named Blake is shown in blue, and Lily's fiancé Adhir is shown in orange. By visualizing each family member's movement and conversation as layers over space and time comparisons can be drawn across family members to simultaneously study who speaks, what is said, and where each family member goes in this gallery space. For example, the figure supports asking new questions such as how parents' conversation across gallery spaces structures and responds to children's movement and conversation.

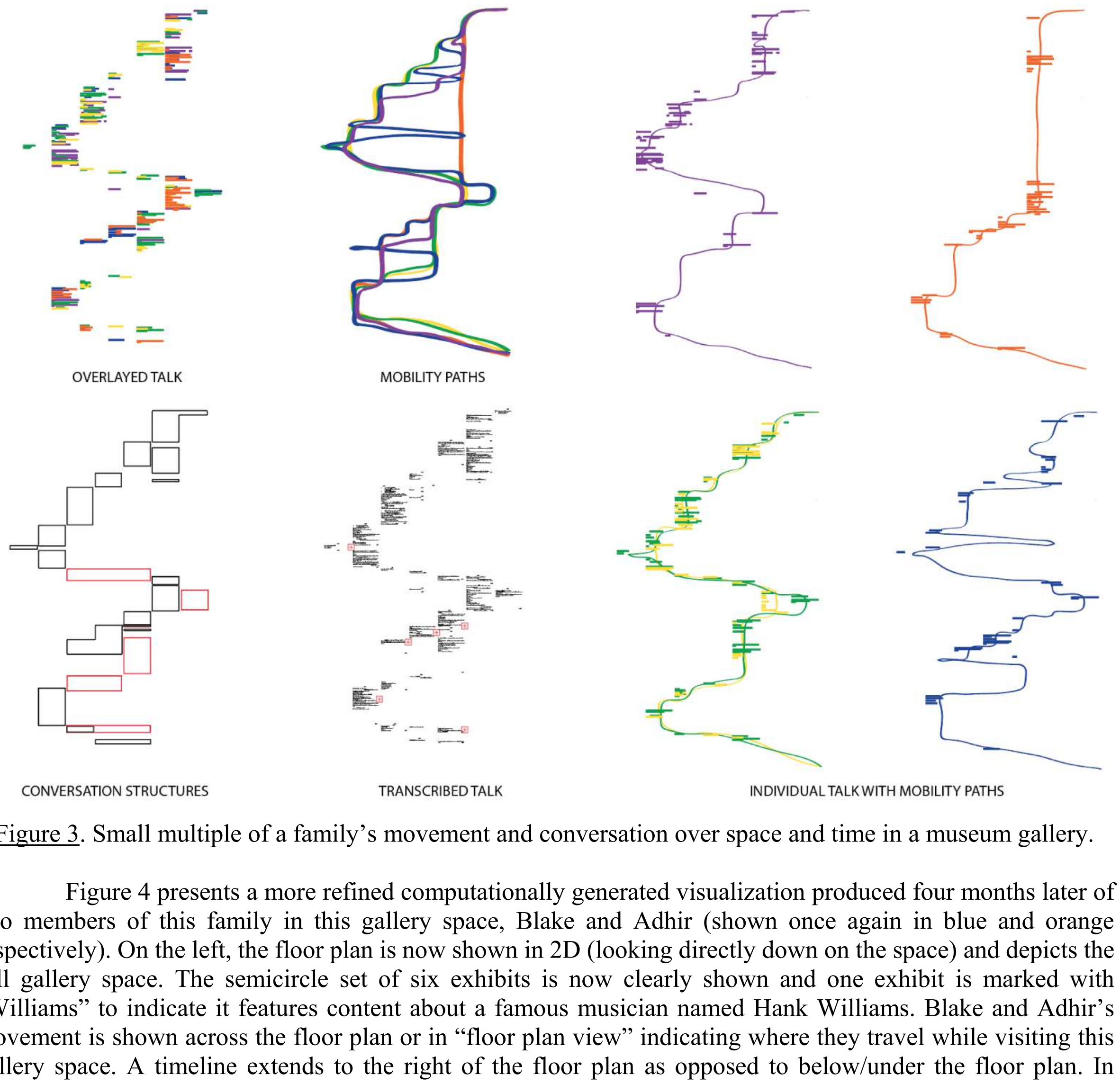


Figure 3. Small multiple of a family's movement and conversation over space and time in a museum gallery.

Figure 4 presents a more refined computationally generated visualization produced four months later of two members of this family in this gallery space, Blake and Adhir (shown once again in blue and orange respectively). On the left, the floor plan is now shown in 2D (looking directly down on the space) and depicts the full gallery space. The semicircle set of six exhibits is now clearly shown and one exhibit is marked with "Williams" to indicate it features content about a famous musician named Hank Williams. Blake and Adhir's movement is shown across the floor plan or in "floor plan view" indicating where they travel while visiting this gallery space. A timeline extends to the right of the floor plan as opposed to below/under the floor plan. In comparison to Figures 2 and 3, this subtle rotation of the timeline (suggested by a collaborator, Lara Heiberger, in the context where this data was collected) aids in interpreting complex space-time visualizations. In this case, similar to the previous figures but more clearly illustrated here, the "space-time view" (Hagerstrand, 1970) extends

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, the space-time view shows that after entering the gallery space (top left of the floor plan view and beginning of the space-time view), Adhir and Blake walk together toward the Hank Williams exhibit. 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 floor plan view. 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 multiple attempts to draw Adhir away from the Hank Williams exhibit. After four failed attempts, Blake finally succeeds 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. The change in line pattern in Blake's path distinguishes between three different horizontal areas of space on the floor plan providing some description of horizontal movement on the floor plan in the space-time view.

In comparison to previous figures, this figure begins to provide more detailed ways to interpret collaborative interaction across a physical environment (i.e., reflective of the original commitments of this work). For instance, the figure characterizes new, path-based units of collaborative interaction such as Blake's tour that support asking and answering new types of questions including how young children use their movement to manage their families as resources for their own interest-driven engagement and learning.

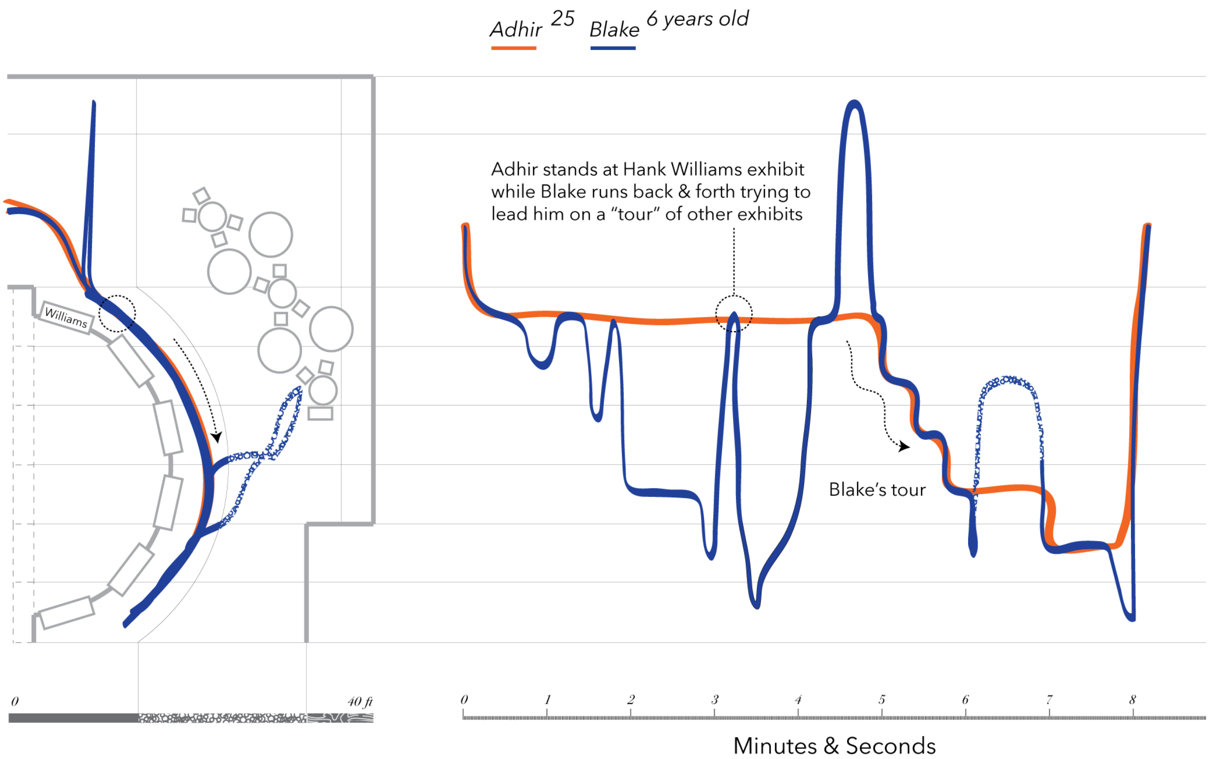


Figure 4. Adhir (orange) and Blake's (blue) movement over space and space-time in a museum gallery.

## Grounded theory and computational tools

Figure 5 was produced over a year after Figure 4 and represents a significant amount of theoretical and computational development. The figure is a screenshot from a dynamic visualization tool called the Interaction Geography Slicer (IGS), which allows for new forms of interaction and multimodal analysis. The figure also illustrates a refined method to transcribe movement and conversation, in this case, of all five members of the previous family (including Blake and Adhir) in the previously described gallery space. This method called Mondrian Transcription draws inspiration from the Manhattan Transcripts and the Modernist artist, Piet Mondrian (1872–1944), particularly his use of lines in relation to forms, which resemble how movement and conversation are represented, coded, and categorized in Mondrian Transcription. 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 ways introduced previously. 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). In the space-time view, each box marks the start, duration, and end of a sequence. 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 (resembling a "heat map" of talk in place). For example, the region of space around the Hank Williams exhibit has the largest number of conversation turns (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.

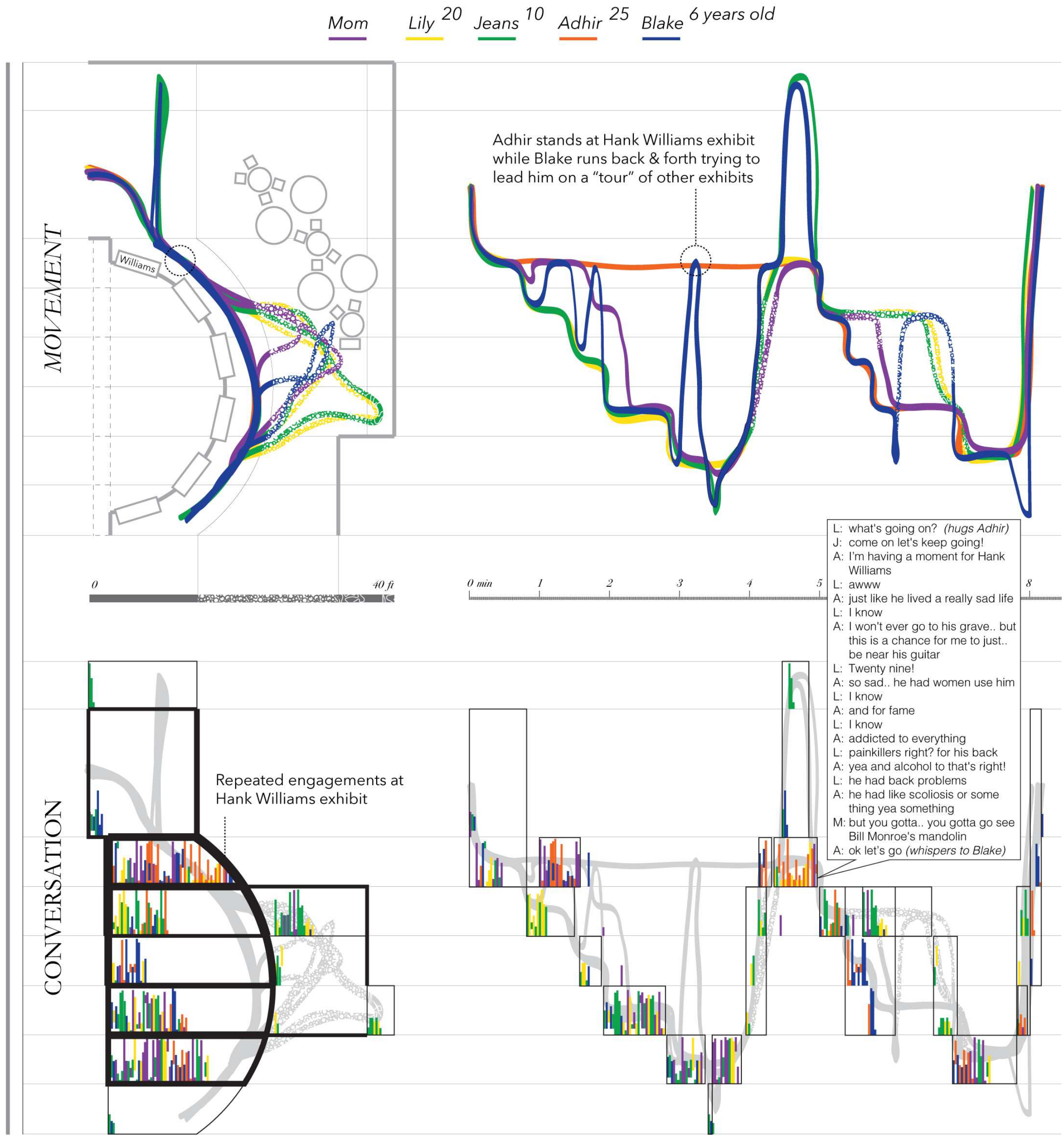


Figure 5. Screenshot from the Interaction Geography Slicer (IGS) of family's movement and conversation.

In the figure, the highlighted sequence (i.e., readable conversation) in the space-time view expands the conversation turns of one particular sequence. In other words, the highlighted sequence illustrates an analytic "operation" possible within the IGS on data collected in this work. As the figure shows, one can use the IGS to select, magnify, visualize, and read conversation turns. Not shown is the additional ability to use the IGS to watch and listen to video/audio from the perspective of each family member gathered as part of this work. The IGS syncs multi-perspective audio and video to visualizations such as Figure 5. As a result, anywhere a user clicks on the visualization activates audio or video from the perspective of an individual.

The figure shows how these refined tools/methods provide ways to engage in exploratory data analysis (Tukey, 1977) that pays careful, contextual attention to how people engage and learn across museum gallery spaces. For example, the highlighted conversation or sequence in the figure from approximately minutes 4–5 in the space-time view encompasses a complex mesh of activity around the Hank Williams exhibit. Reading this sequence of activity in relation to the rest of the figure shows how: 1) Lily (yellow) 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 (green) 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 in purple), 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); and 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 exhibit along the semicircle of exhibits (at the end of the highlighted conversation; see Shapiro, Hall & Owens, 2017).

Altogether, the ability to read this sequence of activity in relation to the rest of the figure by exploring data within the IGS reveal phenomena and relations between phenomena such as Blake's tour, Adhir's persistent engagement with the Hank Williams exhibit, a mother's efforts to support her children's engagement, and particularly important units of engagement or "peak engagement contours" such as the previously described sequence of activity during this family's visit to this gallery space. In other words, the figure communicates concepts and methods of interaction geography, a new approach to describing, representing, and interpreting people's collaborative interaction as they move across the physical environment, and how to use interaction geography to study visitors' interest-driven engagement and learning across a museum gallery space.

## Discussion and conclusion

In summary, the development and use of interaction geography was interleaved with and furthered a line of exploratory data analysis that led to new questions, units of analysis, and computational tools to describe how visitors pursued their own interest-driven engagement and learning in a museum. Put differently, the example characterizes integrative visualization, a computationally assisted, human-centered process to visually explore data in a way that maintains a commitment to theory and situational context.

Though illustrated through a single example in this paper, integrative visualization is proposed as a generalizable process researchers or practitioners can leverage to make sense of data collected in collaborative learning contexts. Integrative visualization begins with a data context, understood as an initial set of questions, goals, challenges, and particular types of data collected in a specific context. In the example, this data context included continuous, multi-perspective audio/video data collected in a cultural heritage museum and a theoretical commitment to understanding visitors' interest-driven engagement and learning as they moved across gallery spaces. Subsequently, integrative visualization extends visual methods of exploratory data analysis to iteratively transcribe data. Like any process of transcription, transcription of data amplified by visualization is theory laden and selective because it aims to organize data and develop codes, categories, questions, and units of analysis central to the data context (see Ochs, 1979; Hall, 2000). For instance, the example illustrated the use of the space-time cube to categorize conversation over space and time in ways that foregrounded mobility. Finally, integrative visualization supports the development of grounded theory and new computational tools. On one hand, the example characterized concepts and methods of interaction geography, units of analysis, and questions about visitors' interest driven engagement and learning as potentially generalizable to other types of settings where people move to engage and learn (e.g., other museums, natural or urban environments). On the other hand, the example demonstrated how integrative visualization produced computational tools that support new forms of interaction and multimodal analysis. Importantly, developing these tools required (and requires) shifting from using traditional transcription tools (e.g., ranging from Microsoft Word to InqScribe to NVivo) to composing in more dynamic graphical layout tools (e.g., Adobe products) to developing visualizations and software in programming languages used in exploratory data analysis such as Processing and p5.js (see Fry, 2004). Though fully describing this shift is beyond the scope of this paper, it is critical to integrative visualization.

Integrative visualization may be particularly well suited to addressing some of the unique challenges of making sense of unstructured data (e.g., audio and video) about people's interaction collected in and important to studying collaborative learning contexts. However, such work entails stronger connections between the CSCL and LS communities and the information visualization community. These connections are challenging to develop but essential to integrating technical skills of parsing, mining, representing, and interacting with data (see Stasko et al., 2008; Fry, 2004) with non-technical ways of working with data that foreground theoretical and contextual dimensions (see Wise & Schwarz, 2017; Kahn, 2017; Zegura, DiSalvo & Meng, 2018; DiSalvo, 2016).

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