The volume and complexity of data generated by modern computing systems are growing exponentially, making visual representations essential for human comprehension and management. However, effective visual analysis for computing data remains a significant challenge, as creating customized, interactive visualizations for this multifaceted system data (e.g., performance logs, computational graphs, network traffic) demands extensive skill and effort. Furthermore, analyzing these complex systems is an inherently collaborative process, bringing together expertise from across an engineering team [6]. My research aims to improve human-data interaction experience for visualizing computing systems from two perspectives: i) enhancing interaction intelligence for data analysis by harnessing Large Language Model (LLM) capabilities to learn and reason with natural input modes—specifically, combinations of natural language, sketches, and gestures; ii) facilitating data collaboration by understanding how humans use visualization to communicate and then implementing support systems for these collaborative workflows. These two perspectives are closely intertwined. The goal is to facilitate collaborative data work by integrating established patterns of human-human visual communication directly into the input modalities of interactive computing systems.

This research summary details a research progression that addresses these two perspectives. I will first present my work (MOVIZ) on visualizing complex computational graphs, which highlights the critical synergy between visual and textual representations of data. Building on this, I will describe two projects that leverage multimodal communication to facilitate collaboration: first, by using LLMs to understand and document on-screen gestures during data discussions over videoconferencing, and second, by developing SlideSAVR, a system that uses live communication as a direct input for collaborative data analysis. Finally, I will discuss my theoretical work on chart definitions and its application to my current research on scaling these collaborative visualization tech--niques for massive time-series data produced by high performance computing systems.

My first doctoral project involved developing a system to help developers understand the computational graphs (networks) constructed as part of their automated workflow. During a one year period, I worked with a group of ML scientists (the developers) to develop a system called MOVIZ to support their reasoning around and debugging of constructed graphs. For this system, I created a new compound graph layout algorithm inspired by the interface design schemes of overview+detail vs. focus+context. This algorithm achieves high quality visual results by clearly displaying graph hierarchy and maintaining stability during user interaction. The layout algorithm was published at IEEE VIS 2024 [1]. MOVIZ combines the layout algorithm with many other features drawing from close collaboration with the developers. One key observation was that even a high-quality visualization often cannot stand on its own for data analysis. The developers needed to quickly relate the graph with its generating code. To address this, MOVIZ provides visual-data correspondence. It features two juxtaposed windows showing the data and the visualization side by side, with linked highlighting enabling developers to simultaneously inspect the structured JSON data and its corresponding graph structure. This project advances the visualization of network data, its application to computing systems, and also hints on how the visual and textual format of data synergically work together for the sense-making tasks in data analysis.

My next project focused on effectively using natural language and gestures together for collaborative data work. While powerful, visual data representations alone are insufficient for collaboration. Analysts must also use natural language to refer to, describe, and anchor visual elements in the space. Such references often cannot be expressed solely with natural language, requiring the supplemental use of gestures and sketches as the "visual language." This project explores the use and documentation of this visual language during remote data communication via visualization, focusing specifically on the documentation of deictic gestures. These gestures are accompanied by locational deixis—the use of referential words such as "look here," "these nodes," or "connecting these two." The system captures deictic gestures made by mouse movements, pairs them with a recorded transcript, and generates interactive documentation that summarizes discussion points while reproducing these gestures directly on the discussed data visualization. A significant challenge in this process is matching these multimodal signals. Gestures and words often lack temporal co-occurrence (e.g., one may precede the other) and are subject to flexible, individual expression, making accurate pairing difficult [2]. The advanced capabilities of Large Language Models (LLMs) in understanding natural inputs offer a promising solution to these long-standing problems. Acting on the premise that an LLM can learn to understand what humans intuitively understand, we used an LLM to refine the matching of words and gestures beyond simple timestamp alignment. The LLM achieved near-human capability in matching these deictic references. This work was published at IEEE TVCG[3]. This work suggests a future where computing systems could be seamlessly embedded within human-human communication for collaborative visualization, allowing the natural signals generated during this interaction to be used as direct system inputs.

SlideSAVR, my next project, further extends the use of multimodal signals in human-human communication around data analysis, employing them as direct inputs to define and trigger analysis operations within computational systems during collaborative data work. The system addresses the challenge that while interpersonal communication in data science yields valuable insights, presentation environments, such as those used in weekly meetings by data science and engineering teams, are often not conducive to live analysis, forcing questions and leads from these meetings to be handled after the fact, where they may be misinterpreted or forgotten. SlideSAVR incorporates a built-in Multimodal LLM module to interpret and act upon multimodal communication from both the presenter and the audience. This approach enables the system to perform live actions such as creating or editing visualization charts, generating annotations, or initiating online searches in real-time. SlideSAVR is powered by an agentic framework that flexibly defines augmentation rules, dynamically updates slide content to match the live context, and automates backend computations. This framework enables fluid audience-presenter interaction, reducing the need for subsequent offline reanalysis and follow-up communication. A technical evaluation was conducted to evaluate the efficacy of the system, showing the engine powered by LLM can properly interpret and process human communication signals. This work was performed in collaboration with Adobe Research and is currently under submission.

Additionally I am also interested in advancing visualization theories, especially on how we use natural language to communicate visualization charts. Another project of mine explores how visualization charts are named and communicated, particularly within visualization research where new chart types are invented and studied. For my primary use case, I focused on the Gantt chart, a visualization commonly employed in project planning and computing systems analysis. For example, it is used to support performance analysis for distributed databases [5]. To build a comprehensive understanding of its application, I conducted a systematic analysis of 89 Gantt chart examples sourced from research papers and practitioner websites. This analysis enabled me to derive a full-scale design space, capturing how these charts are designed and used across various domains.

My current project focuses on improving how people interact with and communicate large-scale time series data of computational traces, with the aim to help developers to develop, debug, and tune their systems. Building on ESeMan [4]—a system that employs hierarchical data structures and intelligent caching for scalable, interactive Gantt charts—I am now exploring methods to efficiently communicate and operate on massive (terabyte-scale) datasets. This new research confronts a combined scalability challenge. While ESeMan addresses the visual scalability (rendering the data) on gigabyte-scale, this project will further extend it and tackle the interactional and communicational scalability. It will investigate how the natural, multimodal interaction approaches from deixis documentation and SlideSAVR can provide the flexibility needed for teams to collaboratively explore, construct, and discuss these complex Gantt charts. This work offers strong synergy with research in computing systems, particularly in areas like HPC and database management. While these fields provide the foundation for storing and processing massive data, my research provides the **complementary, human-centric frameworks** that make this data actionable for collaborative teams.

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