Visualizing Gaze Information from Multiple Students to Support Remote Instruction

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Abstract
Technologically-mediated learning environments are becoming increasingly popular, however remote learning still lacks many of the important interpersonal features that are leveraged in effective co-located learning. Recent work has started to build in non-verbal cues to support remote collaboration, such as showing pairs where their partner is looking on the screen. This method of displaying gaze visualizations has been shown to support coordination and learning in remote collaborative tasks. However, we have yet to explore how this technique scales to support multiple students with one teacher in a technology-mediated learning environment. In this study, we design and evaluate a system for displaying real time gaze information from multiple students to a single teacher's display during a computer science studio session. Our results suggest that multiple gaze visualizations can improve the teaching experience in remote settings. Further, we provide design recommendations for future systems based on our preliminary results.

Author Keywords
Collaboration; eye-tracking; learning; gaze visualizations

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Figure 1: Gaze Visualization

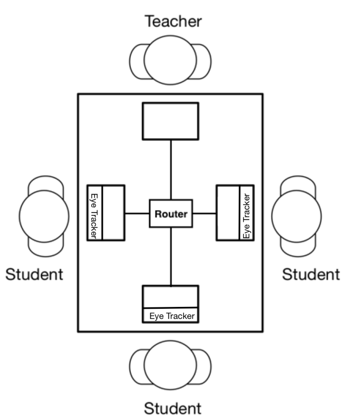

Figure 2: Study Setup

Introduction

Millions of students are enrolled in technologically-mediated learning programs[1] and the ability to learn remotely is increasing information accessibility to a broad and diverse audience. A major drawback of remote learning environments is that the teacher-student relationship becomes impersonal, and teachers are unable to rely on non-verbal cues that normally support communication in a physical classroom [1]. These interpersonal cues, such as gaze patterns, play a key role in facilitating communication and recent evidence suggests they can be integrated in remote settings [6]. For example, students have been shown to use visual representations of the teacher's gaze to help them understand content in MOOC style video lectures [10]. Additionally, gaze information from students can be used to help identify if they are falling behind [11]. However, these studies investigate displaying gaze information in an asynchronous context. Evidence from dual eye tracking studies suggests that displaying gaze information is useful for supporting communication and establishing joint attention in real time remote work [2, 6, 9, 13]. However, these studies only display gaze information from a single user and we have yet to explore displaying gaze information from multiple students in real time.

Displaying where students are looking in a shared visual space can provide interpersonal cues to instructors engaging in distance education. Expanding on traditional dual eye tracking methods, we developed a system to display gaze information from multiple students to a single display for a teacher in real time. This technique has yet to be investigated, therefore we present preliminary results that reveal potential benefits of this system in the context of technologically-mediated learning. For example, when a teacher is communicating to multiple students at the same time, displaying each student's individual gaze position gives teachers the ability to monitor the students attention. In order to design applications that can effectively incorporate real time gaze information from multiple students, we must first understand the impact of multiple gaze visualizations on remote instruction.

[1] http://digitallearningcompass.org/

Related Work

Recent advances in eye tracking and the growth of computer based learning allow for an opportunity to integrate gaze-based interventions into remote environments. Gaze information can provide us with insights into the learner's attention in computer based activities. For example, fixations tell us what information a student is attending to; this can be used to understand if students are following along in distance learning environments [11, 8]. Thus, visualizing this information for teachers could help improve instruction.

In educational contexts there has been a growing interest in using eye tracking technology to improve computer science education [4]. Most of the work in this space has focused on helping novices learn from experts by displaying gaze information from experts to novices [12]. However, gaze information has also been used to understand how novices parse code. For example, an eye-tracking study revealed that novice programmers read code more linearly than expert programmers [3].

In real time studies, displaying gaze information from remote pair programmers helped them communicate about locations in the code more effectively [5]. Additionally, displaying gaze information between remote students helped them understand complex problems [9]. Therefore, displaying real time gaze information from students to teachers could help teachers provide targeted instruction in distance environments.

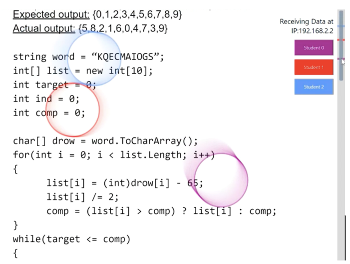

Figure 3: Multiple student visualization.

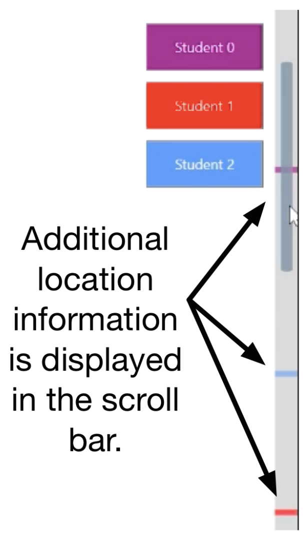

Figure 4: Scroll bar visualization.

Current Study

In this study we designed a system for visualizing gaze information from multiple users to a single display and conducted a pilot study to understand its potential applications for technology-mediated learning. We evaluated the system in the context of a remote learning task where a teacher guides multiple students through a coding exercise (see Figure 3) while receiving gaze information from the students, visualized using circles illustrating each student's fixation location in a unique color. We evaluated our design based on interviews with teachers and feedback from students. Our results suggest that displaying gaze information from multiple students helps teachers confirm that students are following along and monitor the entire class without distracting from instruction. We discuss implications for the design of future systems.

Design of Gaze Visualizations

Each student's gaze is visualized by a circle with a 70 pixel radius (see Figure 1) and is assigned a unique color. The colors and student ID are displayed in a key for the teacher. The radius was chosen to compensate for the accuracy of the eye trackers while still displaying meaningful location information. Additionally, we reduce shakiness from small shifts in gaze or microsaccades by only moving the visualization when students look to a new location outside of the 70px radius. The gaze design also includes a drop shadow visible when the student's gaze moves, which is a subtle indicator of the direction of gaze movement (see Figure 1).

Additionally, because the coding exercise extends beyond a single screen, participants must scroll to see all of it. To enable teachers to easily locate where the students are looking when the object takes up more than just the current screen, the scroll bar along the side of the screen has colored indicators indicating the real-time position of each student, similar to visualization techniques explored by Hill et al. [7] and by D'Angelo and Begel [5]. This provides a global view of where all students are looking and allows teachers to easily click to jump to the location of each student to see more detailed information (see Figure 4).

Methods

Participants

12 students at a Midwestern university participated in the study (2 teachers, 10 students). A "teacher" is a participant with prior knowledge of the material and the solutions to the exercise. Each teacher was paired with two groups of two to three students each. A "student" is a participant who has no prior knowledge of the task but is currently enrolled in an introductory computer science course. Consent was obtained prior to the study; students received $20 and teachers received $50 compensation.

Apparatus

The study setup includes four laptops and three Tobii Eye Tracker 4C devices (see Figure 2). The three "student" computers are set up with the eye trackers, and the "teacher" computer displays the gaze coordinates received from all eye trackers. The computers are locally networked to reduce delay in displaying gaze coordinates.

Procedure

Prior to the study, the teachers were given the coding exercise and solution key. The teacher was instructed to answer students' questions and provide guidance without revealing the answers. Students were participants with some prior knowledge related to the material (enrolled in an introductory C++ course), but no knowledge of the specific task. Groups consisting of one teacher and two to three students engaged in a remote learning task in a pseudo-remote setup. All participants were in the same room, al-

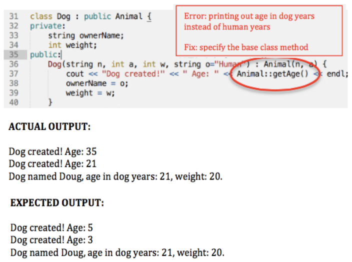

Figure 5: Example task problem with solution.

Figure 6: Example of a student looking in a different section from the group.

lowing them to communicate verbally. However, to simulate a remote setting they were not allowed to move and were seated at different sides of the table to prevent participants from seeing each others' screens (see Figure 2). All screens showed the same task, a code debugging exercise.

The coding exercise is divided into two parts. The first is 10 minutes of instruction, where the teacher explains the code and related concepts. The concepts, including class inheritance, virtual functions, and inherited member access, are covered in an introductory C++ class that was a pre-requisite for the study. The second part is the 15 minute exercise, in which students find five bugs in the code. Once a student locates a bug, they notify the teacher and discuss their answers with the class before moving on to the next bug as a group.

One teacher led three sessions. For a baseline, the teacher conducted one session without the gaze visualizations. In the second and third sessions, the gaze visualizations were visible. The second teacher led one session and the gaze visualizations were visible. Note that in all setups, students could communicate freely with the teacher and ask questions about the task. Following the session, teachers and students participated in a semi-structured interview with the research team about their experience.

Learning Exercise
The exercise consists of C++ code including class definitions for the base class "Animal" and its derived classes, a main function, and expected and actual output (see Figure 5). The goal is for the student to find the errors in the code that would cause the code to produce the actual (incorrect) output when run, rather than the expected. During the exercise, students may ask questions to the teacher, who has been given the solutions in advance.

Analysis
All sessions were recorded and analyzed by the research team to identify common themes. Our analysis focused on how teachers used the gaze visualization to support instruction, how students felt about having gaze visualized, and feedback on the design on the gaze visualizations.

Findings and Discussion

Interviews with teachers revealed that displaying gaze information presents advantages for assisting teachers during both the instruction and individual work phases.

Confirmation/Feedback: Teachers used the gaze visualizations when giving instructions to confirm that students were following along. This was a form of immediate feedback that allowed teachers to confirm that students were responding to their instructions. For example, when a teacher directed the students' attention to a specific portion of the code, the aggregation of visualizations to that area confirmed that students were looking in the correct location and the teacher could begin discussing it, while a wandering visualization could signal a misunderstanding in real time and allow the teacher to clarify immediately.

Monitoring: While students were working independently, teachers used the gaze visualizations to monitor the class. Displaying multiple visualizations allowed them to easily understand the status of the classroom (see Figure 6). Since teachers knew the structure of the task they could infer what students were working on and pick up on their thought processes, as well as confusion or misunderstanding. For example, if students were looking in the wrong spot or their gaze was wandering back and forth or incoherently, the teachers knew to speak up and nudge them in the right direction. Teachers also commented that it was easier to

Figure 7: Example of gaze clustering.

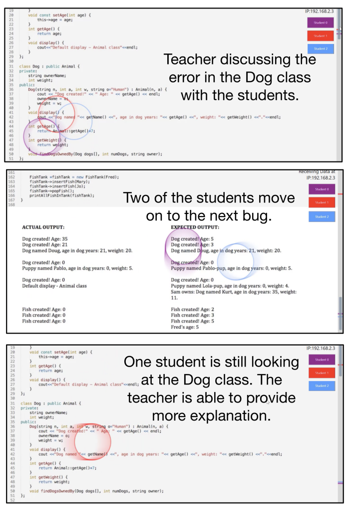

Figure 8: Example of teacher using gaze visualizations to give targeted instruction.

monitor the group of students with the visualizations compared to walking around to check on each individual.

Not Distracting: In contrast to prior work that suggests displaying real time gaze visualizations is distracting [6], teachers did not find this to be the case, despite receiving visual feedback from multiple students at once. This may be because of the nature of the teachers' role; being already familiar with the task, the teachers only needed to keep track of students' progress. They were not engaged in completing or understanding the task, or coordinating with students, especially given that their own gaze was not displayed. Instead, they devoted their attention to using the visualizations to confirm and monitor class status, so the visualizations became a useful tool rather than something they needed to ignore. Thus, teachers found it relatively easy to acclimate to the gaze visualizations and were able to use them effectively to support their teaching role.

Implications for Design

Based on our preliminary results, there appears to be potential for visualizing students' gaze information. There are several important implications for designing systems that display multiple gaze points from students.

Gaze Clustering: Having students work together allowed for natural clustering of gaze to relevant areas of code. This behavior was especially prevalent when teachers explained a piece of code to the group. The clustering made the multiple visualizations manageable and provided a cue if a student deviated from the group, either lagging behind or ready to move on (see Figure 7). If students were working individually or on separate problems, it would likely be difficult for teachers to attend to each student. It could also become difficult to keep up with students as their number increases.

Privacy: Students reported that they did not feel uncomfortable with teachers being able to see where they were looking. This is promising for similar situations where students are solving a problem or working through a dense set of code in a group. However, in contexts where students aren't actively working, such as lectures, if students are looking at personal content they may be less comfortable with teachers having access to their gaze information.

Scroll Bar Visualization: Teachers reported that the scroll bar visualization was useful when students were attending to different locations in the code because the full assignment spanned much farther than the height of the display screens. It provided a global view of all students and a cue for teachers to monitor the entire class while focusing on individuals. In particular, teachers noted this as a benefit when compared to monitoring a physical classroom, because they could oversee all students' activities without having to move around to observe them separately, and based on the path of each students' gaze, they could infer their progress on the assignment.

Conclusion & Future Work

Eye tracking technology is becoming more affordable, allowing for opportunities to collect gaze information from many users. Understanding how to visualize that information in meaningful ways is vital. This work presents preliminary findings that suggest that visualizing the gaze of multiple students in a technology-mediated learning scenario helps teachers effectively guide students through instruction and discussion of relevant tasks. For example, teachers can easily monitor students and detect when extra help is needed (see Figure 8), despite not having access to the nuanced physical cues of a real classroom, such as facial expression and body language. Gaze information provides useful feedback to the teacher without disrupting students.

These encouraging preliminary results should motivate further research in visualizing gaze information from multiple users. There are interesting unanswered questions regarding how gaze visualizations impact instruction and understanding of the perspective of the students. Finally, we suspect there is a limit to the number of gaze visualizations that can be used effectively, after which they become distracting; however, the scroll bar visualization is promising for scaling this method up to support many students.

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