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Exploring Lag Times in a Pair Tracing and Debugging Eye-Tracking Experiment

Maureen VILLAMOR[a,b*] & Ma. Mercedes RODRIGO[a]
[a]*Ateneo de Manila University, Philippines*
[b]*University of Southeastern Philippines, Davao City, Philippines*
*maui@usep.edu.ph, mrodrigo@ateneo.edu

Abstract: This paper investigated the leader/follower patterns that possibly occurred in a remote pair programming eye-tracking experiment. We intended to build the profile of the initiator and the follower and explore the lag times inherent to pairs categorized based on prior knowledge using the diagonal recurrence profile. Findings revealed that in a pair programming setup, the initiator was the low prior knowledge participant. We defined the "initiator" as the one who encountered a problem in the code first and hence initiated the contact to ask for help, and the "follower" was the one who responded to help. The characteristic lag times based on prior knowledge were 2.33 seconds for both high prior knowledge pairs, 1.96 seconds for both low prior knowledge pairs, and 1.51 seconds for mixed prior knowledge pairs.

Keywords: Leader/follower, lags, eye-tracking, pair programming, diagonal recurrence profile

1. Introduction

Schilbach (2015) defined joint attention as "attending to something together with someone and being aware that 'we both' are attending." It establishes a form of cooperative behavior that relies on shared intentions (Pfeiffer et al., 2014) and denotes following the direction of another person's gaze (Bayliss, Pellegrino and Tipper, 2005). For joint attention to occur there must be an initiator directing someone else's gaze toward a particular target and a follower who will go along with the gaze cue provided.

Cross-recurrence quantification analysis (Marwan and Kurths, 2002) is used to quantify how frequently two systems exhibit similar patterns of change in time. It produces a cross-recurrence plot (CRP), which has been used to analyze the coordination of gaze patterns between individuals and determine how closely two collaborators' gaze follow each other. One important measure that can be derived from the CRP is the diagonal recurrence profile (DiagProf), which can be interpreted as a lag profile that reflects co-occurrence patterns between utterances of varying relative lags (Warlaumont et al., 2010). This measure was used in the analysis of linguistic and eye-movement coordination in the studies conducted by (Richardson and Dale, 2005; Richardson, Dale and Kirkham, 2007).

This paper used the diagonal recurrence profile to answer the following research questions: (1) What is the profile of an initiator and a follower in a pair tracing and debugging eye-tracking experiment? and (2) What is the characteristic lag time between pairs of participants categorized according to prior knowledge? In a prior study we conducted (Villamor et al., 2017), we speculated that the mixed-prior knowledge pairs may have a presence of leader/follower patterns where we hypothesized that the high prior knowledge participant was the one taking the lead in debugging and telling the low prior knowledge participant what to do. We wanted to validate in this study if this hypothesis is true.

2. Methods

The study was conducted in four private universities in the Philippines. Thirty two (32) pairs of participants aged 18-23 years old who were in their 2nd year to 4th year level in college and had taken the college-level fundamental programming course were recruited to participate in this study. For a detailed explanation on the structure of the study, see Villamor and Rodrigo (2017).

A diagonal recurrence profile was constructed for each pair for every program by implementing the function *drpdformats* from the crqa package of Coco and Dale (2013) for R. Each sampling unit is 33 milliseconds. For this data, the radius was set to 5% of the maximal phase space diameter (Schinkel, Dimigen and Marwan, 2008). More information about the diagonal recurrence profile can be found in Fusaroli, Konvalinka and Wallot (2014).

3. Results and Discussion

To determine the initiator and the follower between the participants with a low- and high-prior knowledge, only the mixed prior knowledge pairs (LH) were considered. For consistency, the pairs were ordered starting with the low prior knowledge (LPK) participant followed by the high prior knowledge (HPK) participant. The function *drpdfromts* was used to compute the diagonal recurrence profile of the two fixations sequences per program for each pair under different categories. This function returns a recurrence profile with the length equal to the number of lags considered, the maximal recurrence observed between the two fixation sequences, and the lag at which it occurred. However, for this study we focused only on the lag at which the maximum recurrence was observed.

Results revealed that the initiator and follower were the LPK participant and the HPK participant, respectively. The LPK participant's gaze was on the average ahead of the HPK participant's gaze by 1.51 seconds 53.16% of the time. The baseline delay is 1.89 seconds. This lag time is still within the range reported in Richardson and Dale (2005) where the follower needs a lag of two (2) seconds to be maximally aligned with the speaker's eye movements.

One possible interpretation for this finding is that in programming tasks, it is usually the low performing students who ask help from their more experienced peers. This is a common scenario observable in class laboratory exercises. The gaze direction in this study was initiated by the LPK participant, possibly in an attempt to seek help from the HPK participant. It could be that in most cases the LPK participant encountered problems in the code and pointed them out to the HPK participant who followed the direction of the LPK participant's gaze. Hence, in this case, the "initiator" was the participant who encountered a problem in the code first and instigated contact with the other to ask for help, and the "follower" was the one who responded to help and followed the gaze of the initiator.

Of the 31 pairs (one pair was discarded), 11 had both high prior knowledge, 6 had both low prior knowledge, and 14 were mixed pairs. We will refer to these categories as HH, LL, and LH. The lag time at which the maximum recurrence occurred for every program based on prior knowledge were averaged. The aggregated results were examined to find differences among the categories, which entailed looking at incidences of long and short lags. A lag was long if it was equal to or greater than the mean plus one standard deviation; and short, otherwise.

The HH, LL, and LH pairs exhibited coupled gaze patterns lagged at about 2.33 seconds, 1.96 seconds, and 1.51 seconds, respectively. Further results showed that HH pairs had average to long lags, the LL pairs had short to average lags, and LH pairs had a variation of lags but majority of the lags were below the mean. HH pairs had the longest lag while the LH pairs had the shortest.

Results showed that the HH pairs took longer for their gazes to focus on the same target, whereas it took faster for the LH pairs for gaze coupling to take place. One possible explanation for the longest lag for HH pairs is that the HH pairs may not have collaborated as much compared to other relationships. Findings from our previous study confirmed this speculation. HH pairs had the lowest average recurrence rate (Marwan and Kurths, 2002). It could be that the HH pairs did not feel the need to collaborate more often because they were already confident with their work. It is also possible that they were engaging in more divergent episodes (Sharma et al., 2012). For the LL pairs, two persons who are both inexperienced in debugging and who are struggling with program comprehension frequently may have difficulties trying to understand and locate in the code what the other one is trying to point out. Students who are low performers or have low prior knowledge do not even know correct programming terminologies, which is probably one of the reasons why the LL pairs took longer for their gazes to overlap. Lastly for the LH pairs, since it was the LPK participant who initiated the gaze direction, as revealed in the previous section, it was easy for the HPK participant to follow suit since the HPK participant has more experience in debugging and thus can easily understand and find in the code what the LPK participant was referring to.

4. Summary and Conclusion

The goal of this paper was to build the initiator/follower profiles between pairs of novice programmers and investigate the lags between pairs categorized according to prior knowledge to find out the delay that maximally aligns their gazes. Results showed that the initiator majority of the time was the low prior knowledge participant. This result was counterintuitive to our hypothesis from our previous study. It turned out that the gaze initiation was possibly a result of the low prior knowledge participant asking for help from the high prior knowledge participant. The lag times of the pairs categorized according to prior knowledge varied, which was within the range of the lags recorded in the study conducted by Richardson and Dale (2005).

These preliminary findings are significant because it paves the way for us to determine if the similarity between participants' gazes can result in similar cognitive states particularly in programming. The lags can inform us how students with different prior knowledge interact and collaborate through their gazes. Future work will look into the impact of the gaze coupling with respect to how the follower understood the initiator to reflect the follower's attentiveness and the success of their communication by exploring both the eye-movement and discourse data.

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