An ACT-R framework for modeling the interaction of syntactic processing and eye movement control

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Previous work (Boston et al., 2011) has shown that surprisal (Hale, 2001) and retrieval difficulty (Lewis & Vasishth, 2005) are significant predictors of reading time in the Potsdam Sentence Corpus (PSC). It remains an open question how such measures of parsing difficulty interact with eye movement control processes (Reichle et al., 2009). We investigate this interaction using the eye movement control model EMMA (Salvucci, 2001), a serial attention shift model similar to E-Z Reader, which is integrated in the cognitive architecture ACT-R. Several simulation studies are presented that explore the possibilities of incorporating surprisal and retrieval in an ACT-R/EMMA model. The ACT-R model interacts with EMMA by shifting attention from word to word. The model includes a post-lexical integration stage inspired by Reichle et al. (2009), that triggers short regressions on high difficulty. A baseline study evaluates the performance of the latest EMMA implementation in ACT-R 6.0 on the sentences of the English Schilling Corpus, thereby replicating the original study by Salvucci (2001) in the latest version of the ACT-R architectural environment. The model reproduces effects of word frequency for gaze duration, first fixation duration, single fixation duration, and the probabilities of skipping, one fixation, and two+ fixations (mean correlation r = 0.96, RMSD = 0.220). In a second simulation the same model is applied to the German Potsdam Sentence Corpus (r = 0.89, RMSD = 0.285). Further simulations include surprisal, retrieval, and both, respectively, and are qualitatively evaluated on data of the PSC. Retrieval values (calculated by Boston, 2011, under independently motivated assumptions of ACT-R theory) are used to define the duration of the integration stage. Surprisal was tested in different configurations: (a) modulating integration time and (b) directly integrated in EMMA's equation of word encoding time. Configuration (b) is motivated by experimental and corpus work (e.g., Boston, 2011; Vasishth & Drenhaus, 2011) suggesting that surprisal may show early effects in the eye movement record more reliably than retrieval does. Our implementation of surprisal and retrieval, although resting on simplified assumptions, enables the model to reproduce general effects of both measures on reading time as observed in the PSC data (retrieval: r = 0.67, RMSD = 0.156; surprisal[b]: r = 0.81, RMSD = 0.309). The model predictions for frequency effects improve with the incorporation of surprisal[a] (RMSD = 0.232), retrieval (RMSD = 0.200) and in a model containing both predictors (RMSD = 0.199). The overall goodness of fit for word-by-word gaze duration improves only when surprisal is included (r = 0.45, RMSD = 0.983, vs. for the baseline: r = 0.39, RMSD 0.991). This work provides a first qualitative demonstration of an integrated, flexible framework incorporating two complementary measures of parsing difficulty interacting with eye movement control on different levels. It serves as a foundational step for future work on a precise investigation of the interactions between high-level language processing and eye movements.

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