Science of reading behavior: how and what do you read?

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Introduction

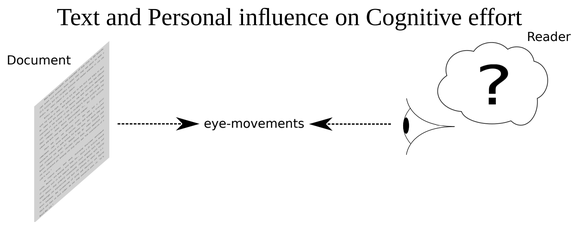
Word consumption

- 100.500 words for avg. person on avg. day.
- 35K words per day from text.

Challenges:

- Combine linguistic and eye data.
- Quantitative analysis for inference.

Text and Personal influence on Cognitive effort



- Technicality
- Layout
- Syntactic complexity
- Semantic consistency, etc.

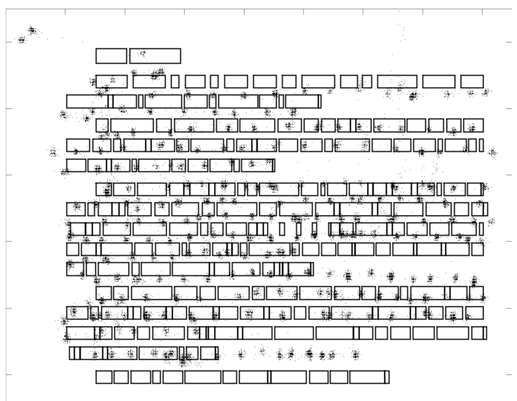
- Background knowledge
- Native language
- Emotional state
- Working memory, etc.

Image registration for text-gaze alignment

Motivation

- Increase recognition accuracy beyond sensor capabilities.
- Variable and **systematic** errors.
- No assumption on reading behavior.

Raw gaze data when reading



Formalization

- Define a linear transformation as:

$$g_{a,b} : (x, y) \rightarrow (x, y \cdot b + a)$$

where a is a translation and b is a scaling.

- Objective function:

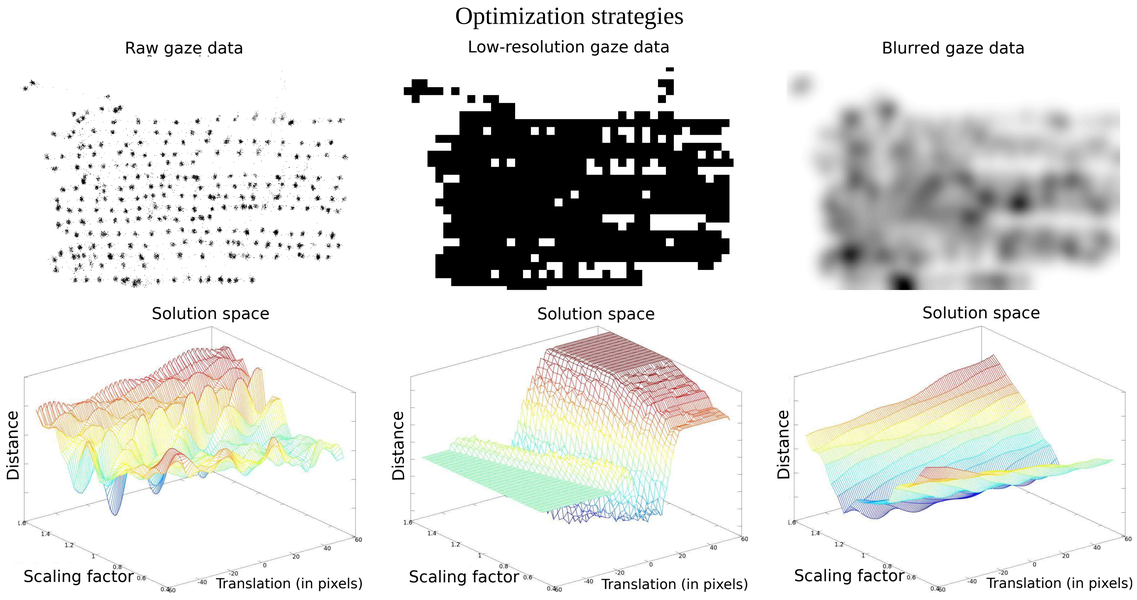
$$f(\mathbf{G}_{a,b}, \mathbf{W}) = \sum_i \sum_j |\mathbf{G}_{a,b}(i,j) - \mathbf{W}(i,j)|$$

- Optimization problem:

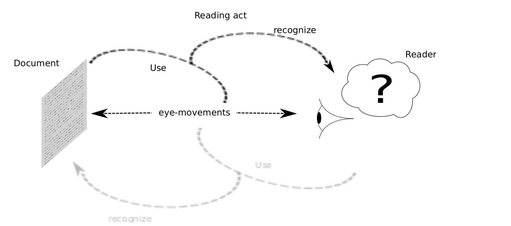
$$\begin{aligned}(\hat{a}, \hat{b}) &= \underset{a,b}{\operatorname{argmin}}\, f(\mathbf{G}_{a,b}, \mathbf{W}) \\ &= \underset{a,b}{\operatorname{argmin}} \sum_i \sum_j |\mathbf{G}_{a,b}(i,j) - \mathbf{W}(i,j)|\end{aligned}$$

- Solution space is not convex.

Optimization strategies

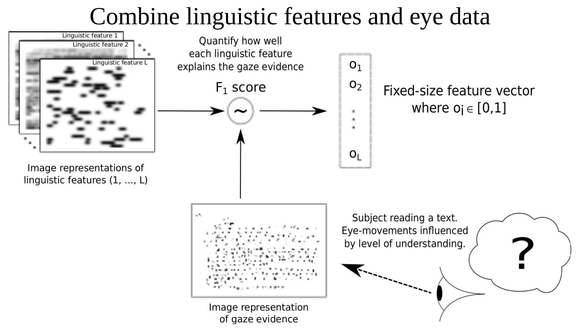


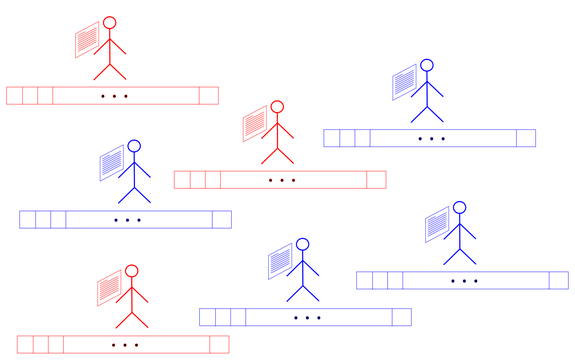
Recognizing Personal Attributes



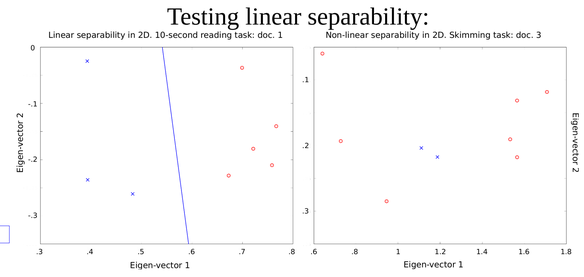
"Subjects with high understanding can be distinguished from subjects with low understanding."

Combine linguistic features and eye data





Testing linear separability:

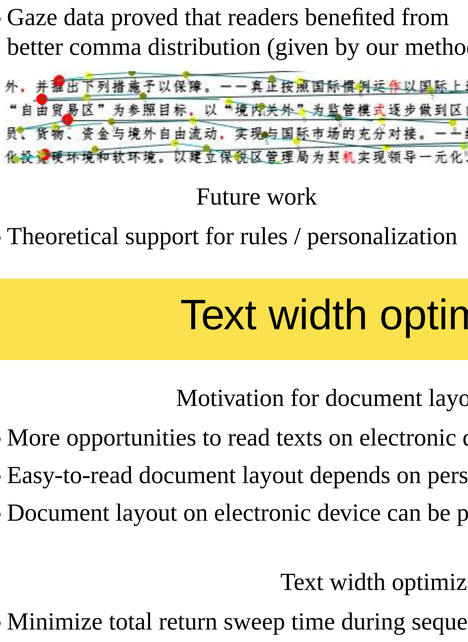


Readability Diagnosis

Currently, discriminative models for readability prediction:

$$\hat{r} = \underset{r}{\operatorname{argmax}}\, \Pr(r \mid l_1, \ldots, l_m)$$

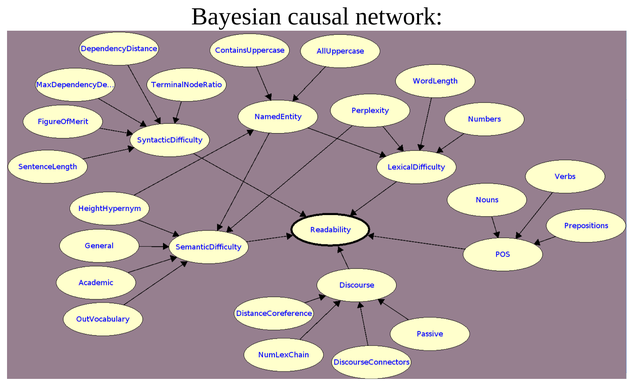
Generative models necessary for cause diagnosis:



Generative models allow to:

- Marginal MAP (e.g. $\mathrm{MAP}(\hat{\ell} \mid \mathbf{Lex}^{\mathrm{high}}, r^{\mathrm{good}})$)
- Sensitivity analysis
- Hypothesis testing

Bayesian causal network:



Optimizing Comma Placement for Chinese Readability

Motivation

- Massive informal writing with *wrong* punctuations
- Segmentation cues influence reading Chinese

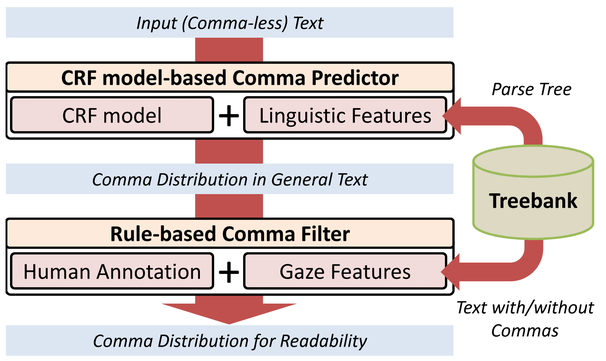
Experimental Results

- Gaze data proved that readers benefited from better comma distribution (given by our method →)

Future work

- Theoretical support for rules / personalization

Methodology



Text width optimization based on gaze data

Motivation for document layout optimization

- More opportunities to read texts on electronic devices.
- Easy-to-read document layout depends on person.
- Document layout on electronic device can be personalized.

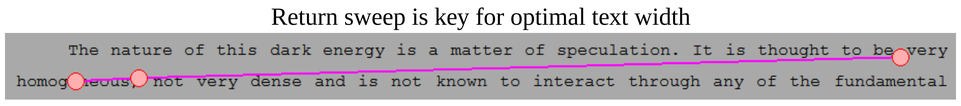
Text width optimization

- Minimize total return sweep time during sequential reading.
- $\bar{t}_{\mathrm{RS}}(w)$: average return sweep time when reading text of width w.
- $\bar{t}_{\mathrm{RS}}(w)$ can be computed from gaze data on text of width w.
- Estimate $\bar{t}_{\mathrm{RS}}(w_i)$ for different w_i and minimize objective function.

Objective function:

$$\begin{aligned}\sum_{k=1}^{N} t_k &= N \cdot \frac{\sum_{k=1}^{N} t_k}{N} \\ &\propto h \cdot \frac{\sum_{k=1}^{N} t_k}{N} \\ &\propto \frac{1}{w} \cdot \frac{\sum_{k=1}^{N} t_k}{N} \\ &\propto \frac{1}{w} \cdot \bar{t}_{\mathrm{RS}}(w)\end{aligned}$$

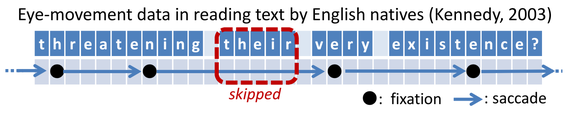
Return sweep is key for optimal text width

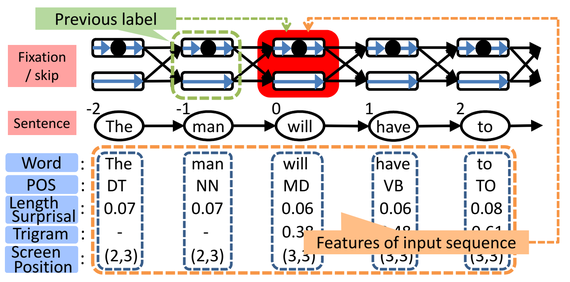


Prediction of word fixations/skips by readers

- Clues: surface, POS, length, frequency, etc.
- Prediction with 0.95 similarity to observed data (for distribution across readers)
- Regardless of individuality / unstableness → general reading strategy

Eye-movement data in reading text by English natives (Kennedy, 2003)





Future Work and Challenges

Future Work

- Real-time text-gaze alignment.
- (Semi-)automatic readability optimization.
- Diagnose causes of understanding.
- Layout optimization.
- Eye data for adaptive interfaces.

Challenges

- Text-gaze alignment with low-quality sensors.
- Formal framework to estimate cognitive effort using:
  - Fixation time and locations,
  - Saccades,
  - Regressions,
  - Pupil diameter size changes.

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