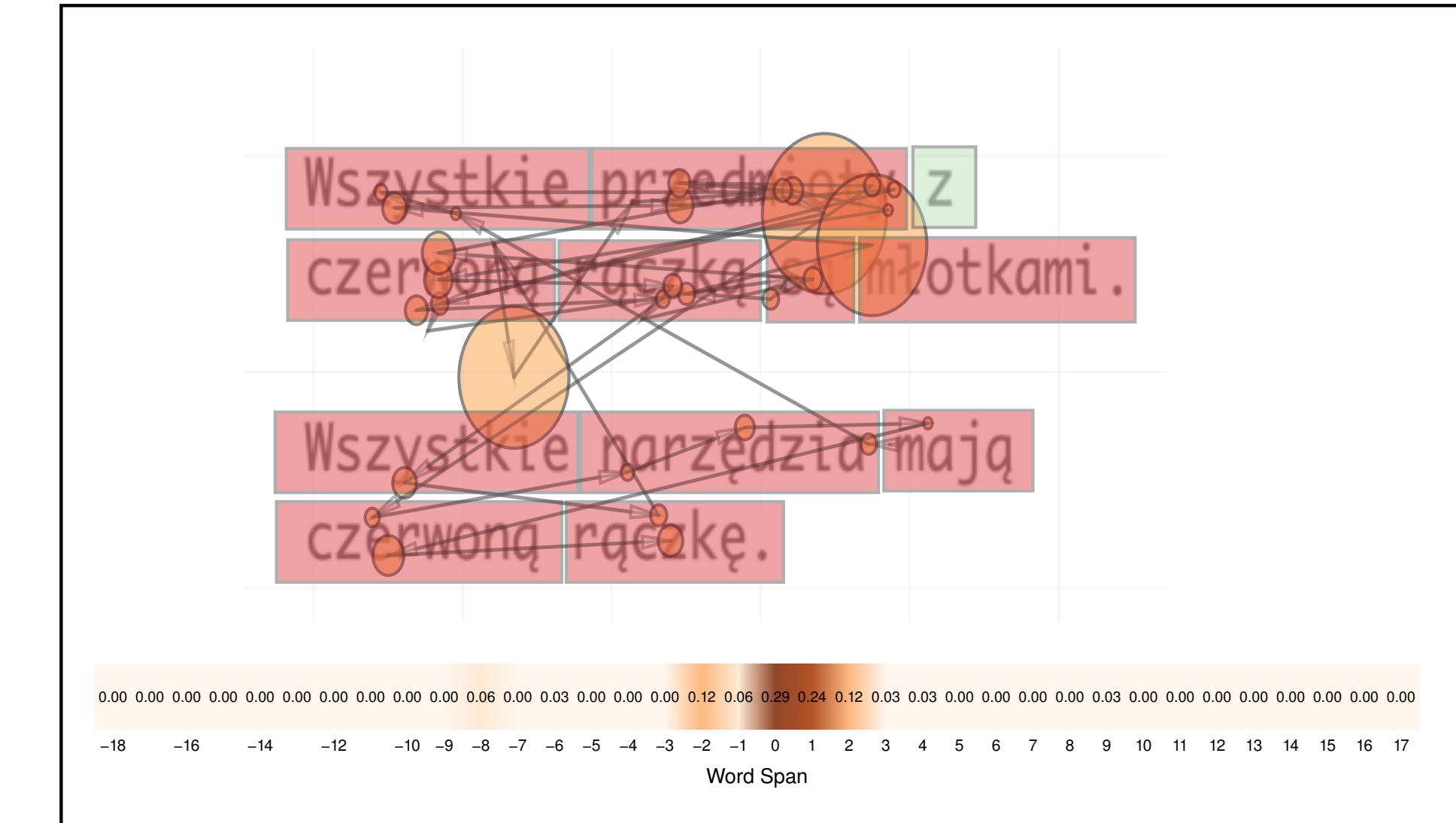
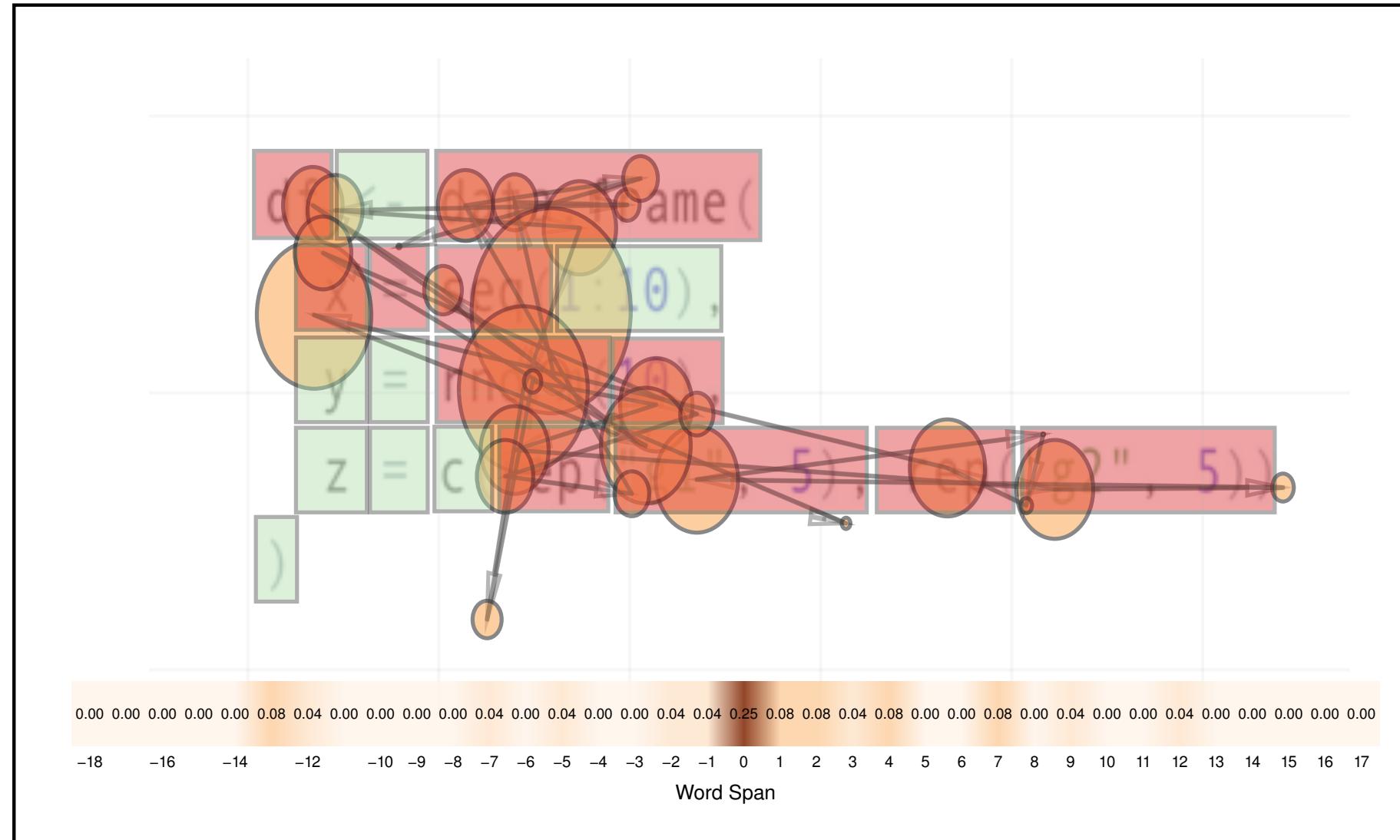


Entropy of Eye Movements While Reading Code or Text



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Eye Movements in Programming

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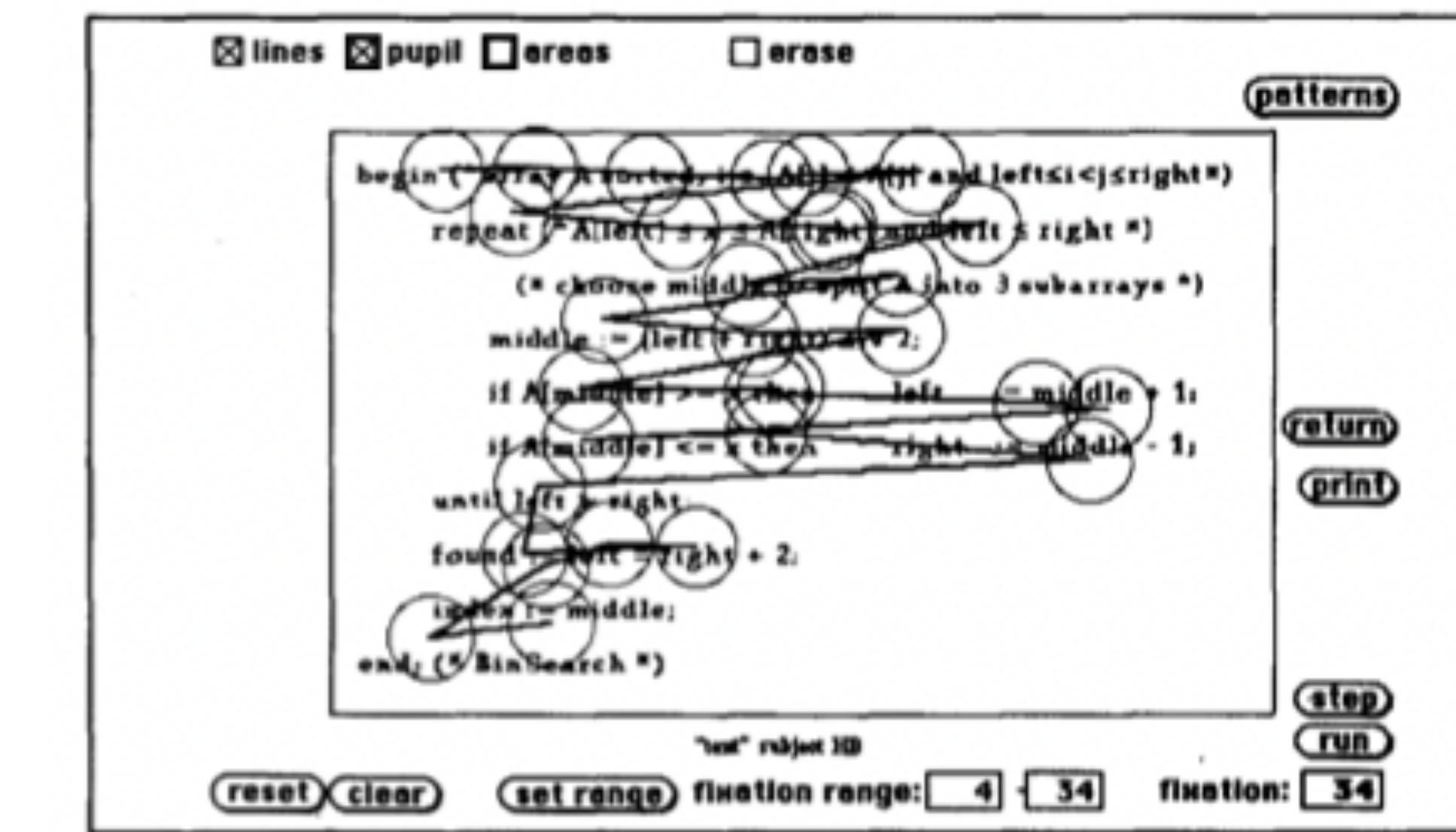
Donations

- NVidia Corp

Introduction

Eye Movements in Programming

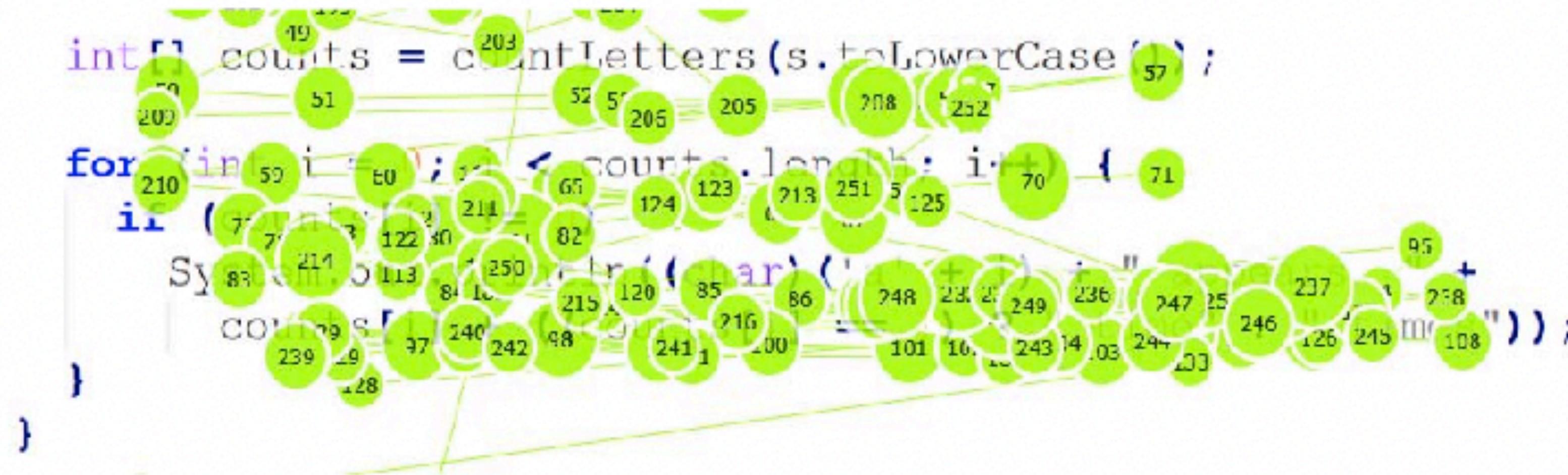
```
begin (*array A sorted, i.e. A[i] ≤ A[j] and left≤i<j≤right*)
    repeat (*A[left] ≤ x ≤ A[right] and left ≤ right *)
        (* choose middle to split A into 3 subarrays *)
        middle := (left + right) div 2;
        if A[middle] >= x then left := middle + 1;
        if A[middle] <= x then right := middle - 1;
    until left > right;
    found := left = right + 2;
    index := middle;
end; (* BinSearch *)
```



- Dates back at least to Crosby and Stelovsky [1990]
 - used Pascal and English description of binary search algorithm
 - found visual scanning differences in code- vs. comment-oriented participants
 - compared expert/novice programmers (former looked more at complex statements)

Introduction

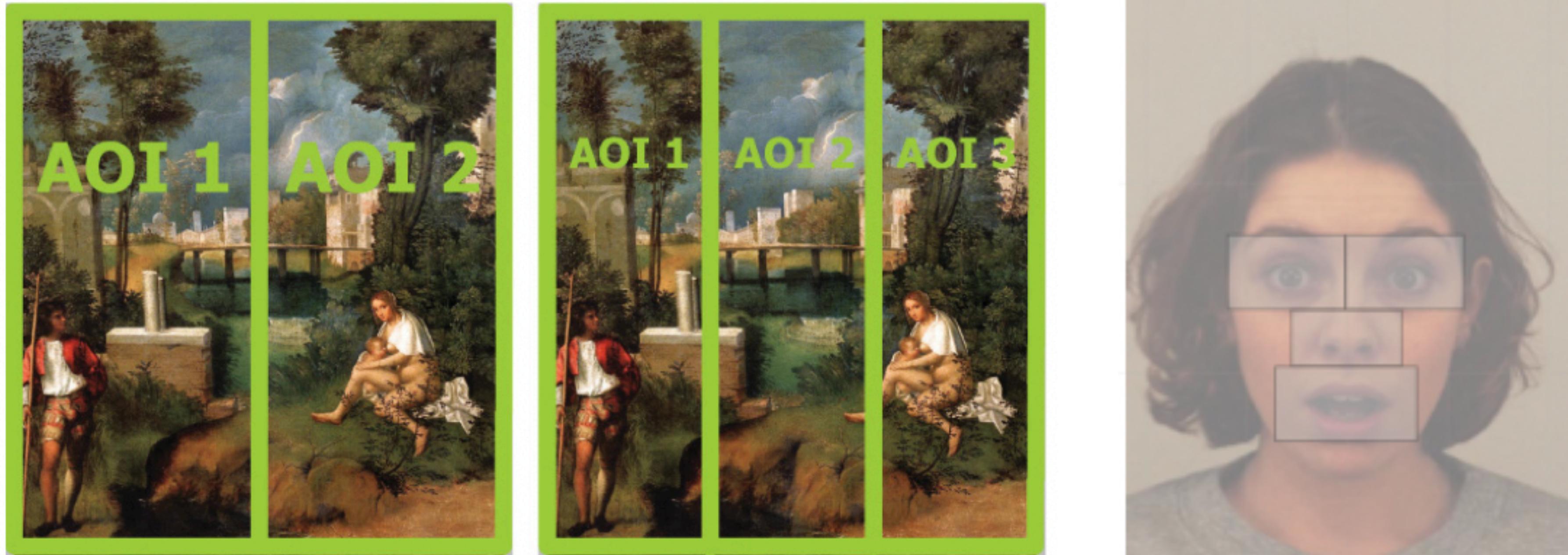
Eye Movements in Programming



- More recently Sharafi et al. [2015] review various metrics
 - traditional metrics include fixations, fixation durations, pupil size, blink rate
 - scanpath comparison including Levenshtein distance also available
 - collectively, except for Levenshtein similarity, these are *first-order analyses*

Background

Gaze-transition Entropy

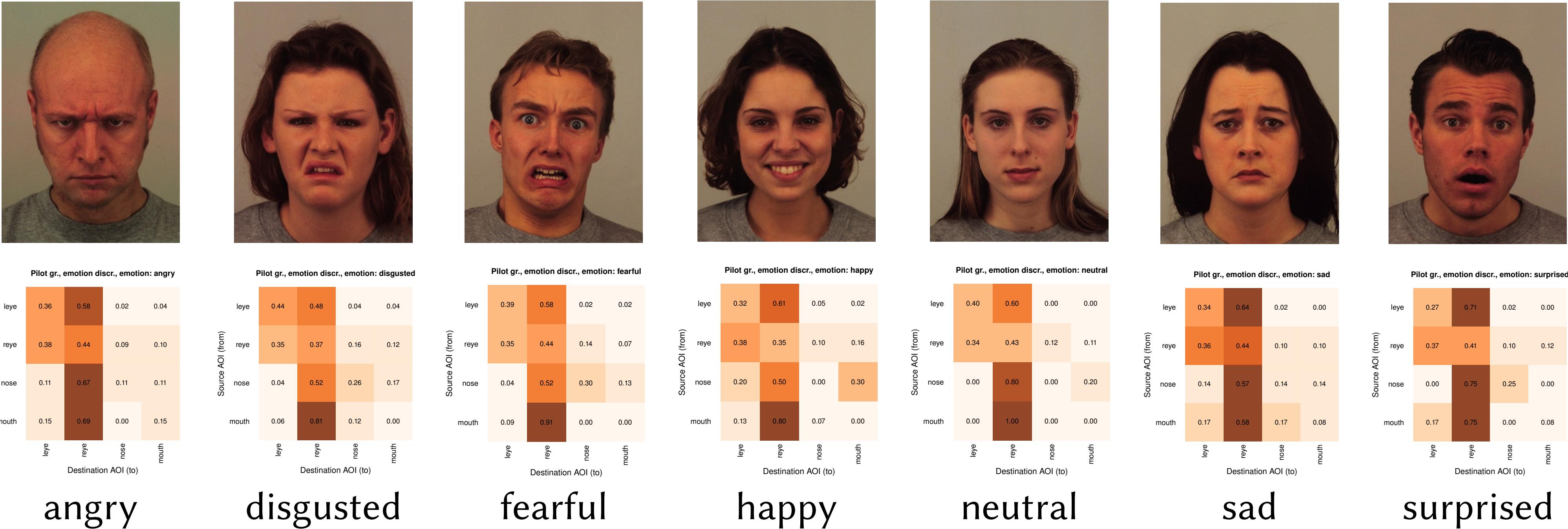


- Gaze-transition entropy [Krejtz et al. 2015]

- typically used to represent 2D gaze transitions between source i and destination j AOIs
- uniform grids or other sensibly defined AOIs suffice
- gaze transition probabilities p_{ij} yield transition matrices from which entropy is computed

Background

Gaze-transition Entropy

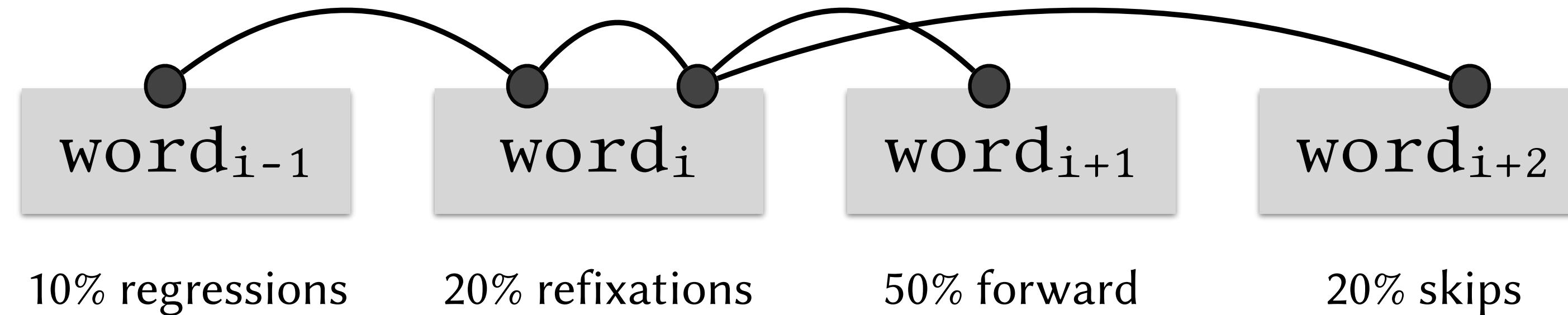


• Gaze-transition entropy

- transition matrices are intuitively easy to understand
- they are also useful for gaze synthesis [Duchowski et al. 2019]
- $H_t = -\frac{1}{\log_2 s} \sum_{i \in \mathcal{S}} \sum_{j \in \mathcal{S}} p_{ij} \log_2 p_{ij}$ defines normalized entropy for set of AOIs $\mathcal{S} = \{1, \dots, s\}$

Background

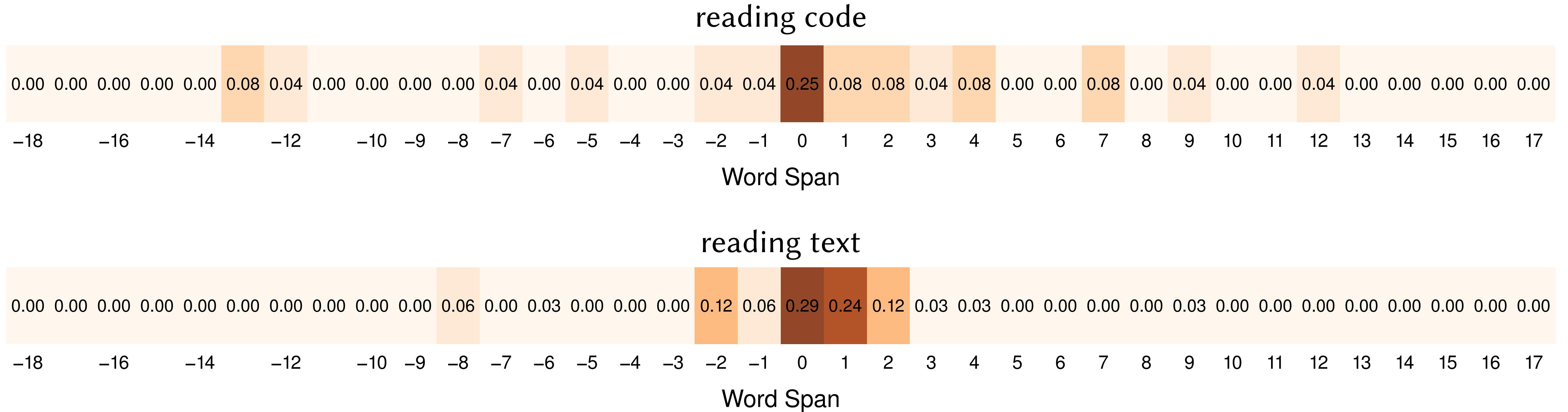
Second-order Metrics



- We introduce *word span entropy* based on Rayner's [1998] model
 - reading consists of *refixations*, *skips* forward, or *regressions* backwards
 - most reading models are expressed in similar terms of span distribution [Thibadeau et al. 1982]
 - reading models can include lexical analysis (e.g., SWIFT or EZ-READER)

Background

Second-order Metrics



- Word span entropy
 - codifies *re-fixations*, *skips*, or *regressions* numerically as probability of jumping j words
 - $j < 0$ regressions, $j = 0$ re-fixations, $j > 0$ skips
 - p_j observed probability, is used to compute entropy

Method

Experimental Design, Stimuli & AOI definitions

Code (R language for statistical analysis) reading task exemplary stimuli with AOIs

```
fit <- aov(y ~ sex, data = d)
summary(fit)
require(emmeans)
emmeans(fit, ~sex,
        contr = "pairwise")
```

Text (logical proposition) reading task exemplary stimuli with AOIs

Niektórzy Francuzi są członkami klubu muzycznego.

Wszyscy członkowie Klubu muzycznego są koneserami wina.

- 2×2 mixed experimental design with within-subjects reading task (code vs. text) and between-subjects prior experience with R (yes vs. no)
- Experimental sample $N = 22$ (17 F) social science students
- Reading tasks (code vs text syllogism) assumed logical reasoning processes involved

Method

Procedure and experimental settings

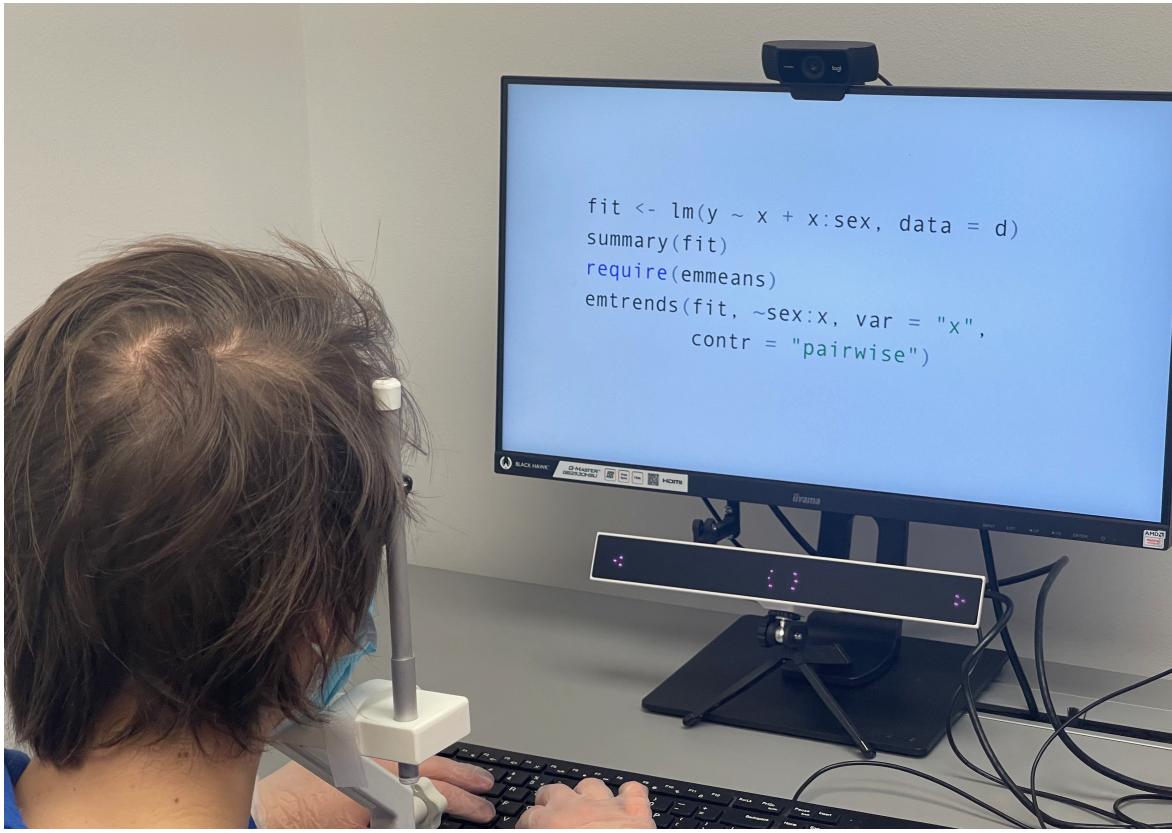


Table-mounted Gazepoint HD eye tracker (150 Hz)
1980 x 1080 screen

Experimental settings

Study participant is completing a code reading trial

self-pace

15 s.

self-pace

Numer uczestnika badania

Rok urodzenia

Płeć

Mężczyzna

Kobieca

Inna

Nie chcę podawać

Min: 0.0123

Za chwilę, rozpocznesz główne zadania w tym badaniu.

Przeczytaj dokładnie instrukcję do każdego zadania.

Będziesz odpowiać używając przycisków 'A', 'B' i 'C' na klawiaturze.

Sprawdź, gdzie są te przyciski.

Main Instruction

==== SPACJA ====

Eye Tracker calibration

Press SPACE to continue.

Demographic questionnaire

Implemented in Qualtrics (online questionnaire software)

Blocks of trials in random order

Block of syllogisms

reading trials (x5)

in random order

self-pace

INSTRUKCJA

W tej części badania, na kolejnych ekranach zobaczysz zdania logiczne. Uważnie przeczytaj każde z nich i zastanów się, jaką jest konkluzja z przedstawionych zdań.

Jeżeli będziesz już to wiedział/a, naciśnij spację.

Between blocks instruction

Blank Screen

Fixation Point

Text read

Response (Answer choice)

NASA-TLX

presented at the end of the block of trials

Response (Answer choice)

self-pace

										self-pace	
:: WYMAGANIA CZASOWE ::											
Czy tempo zadania było wymagające?											
 nie tak											
NASA-TLX											

presented at the end
of the block of trials

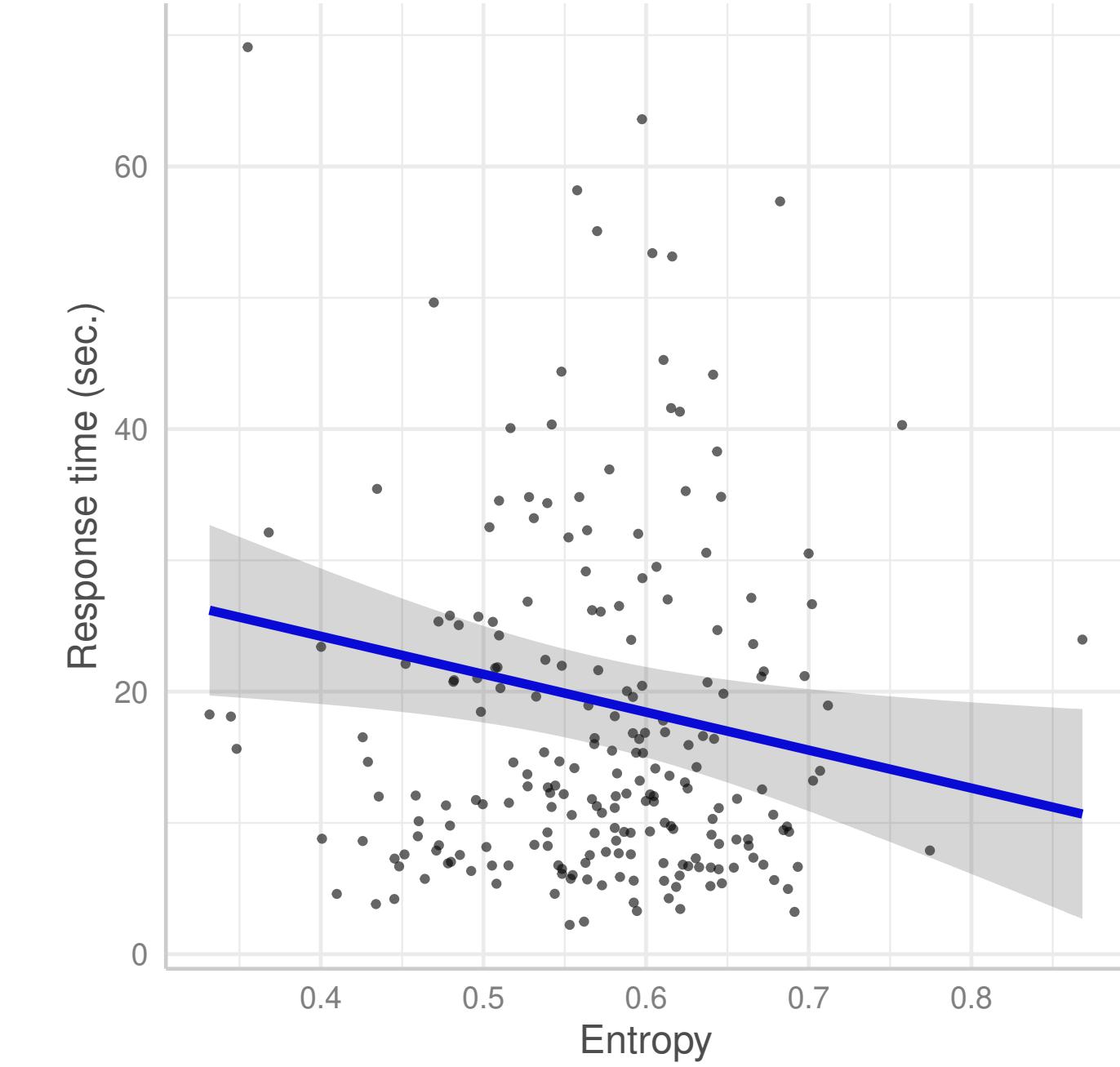
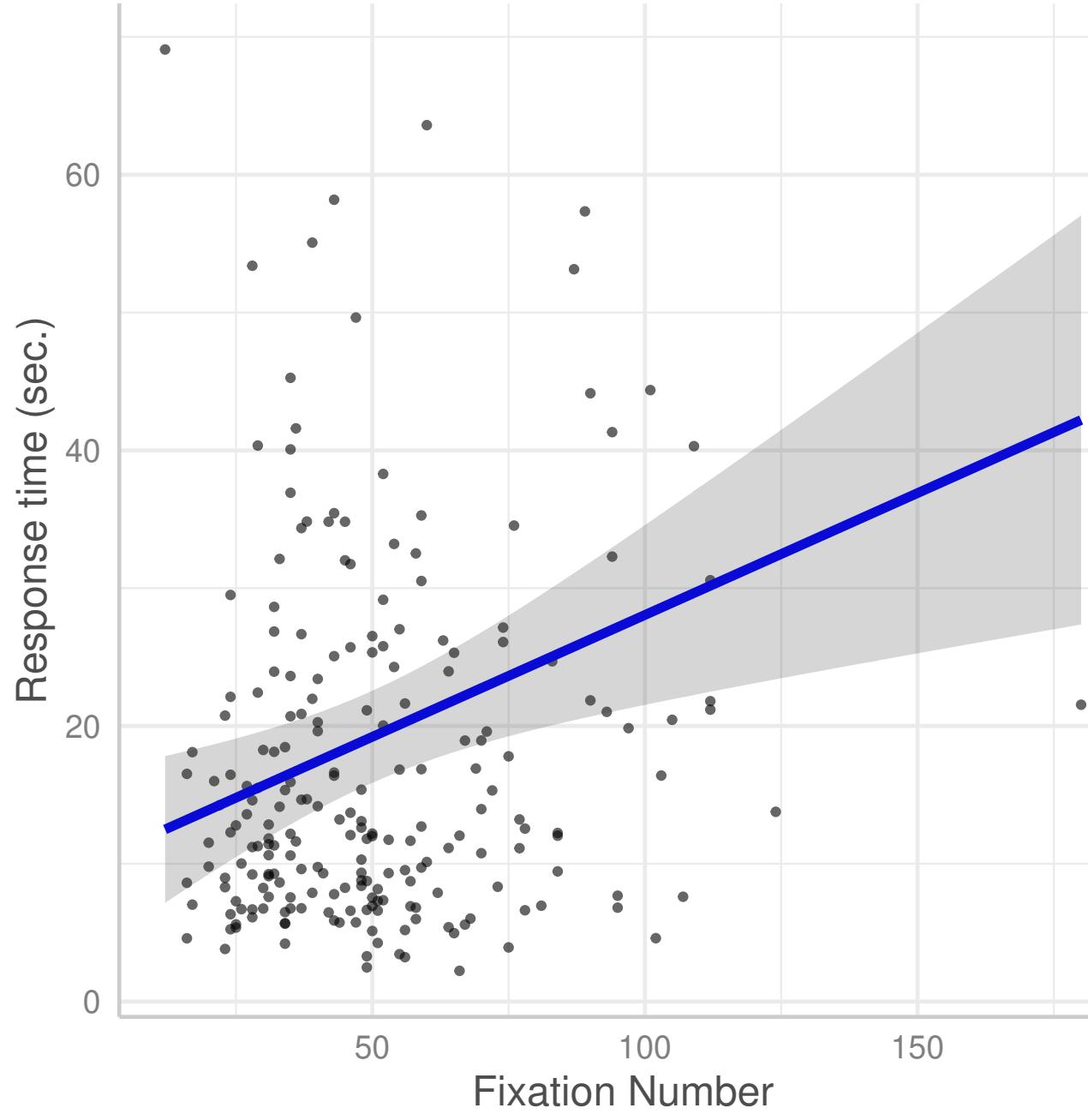
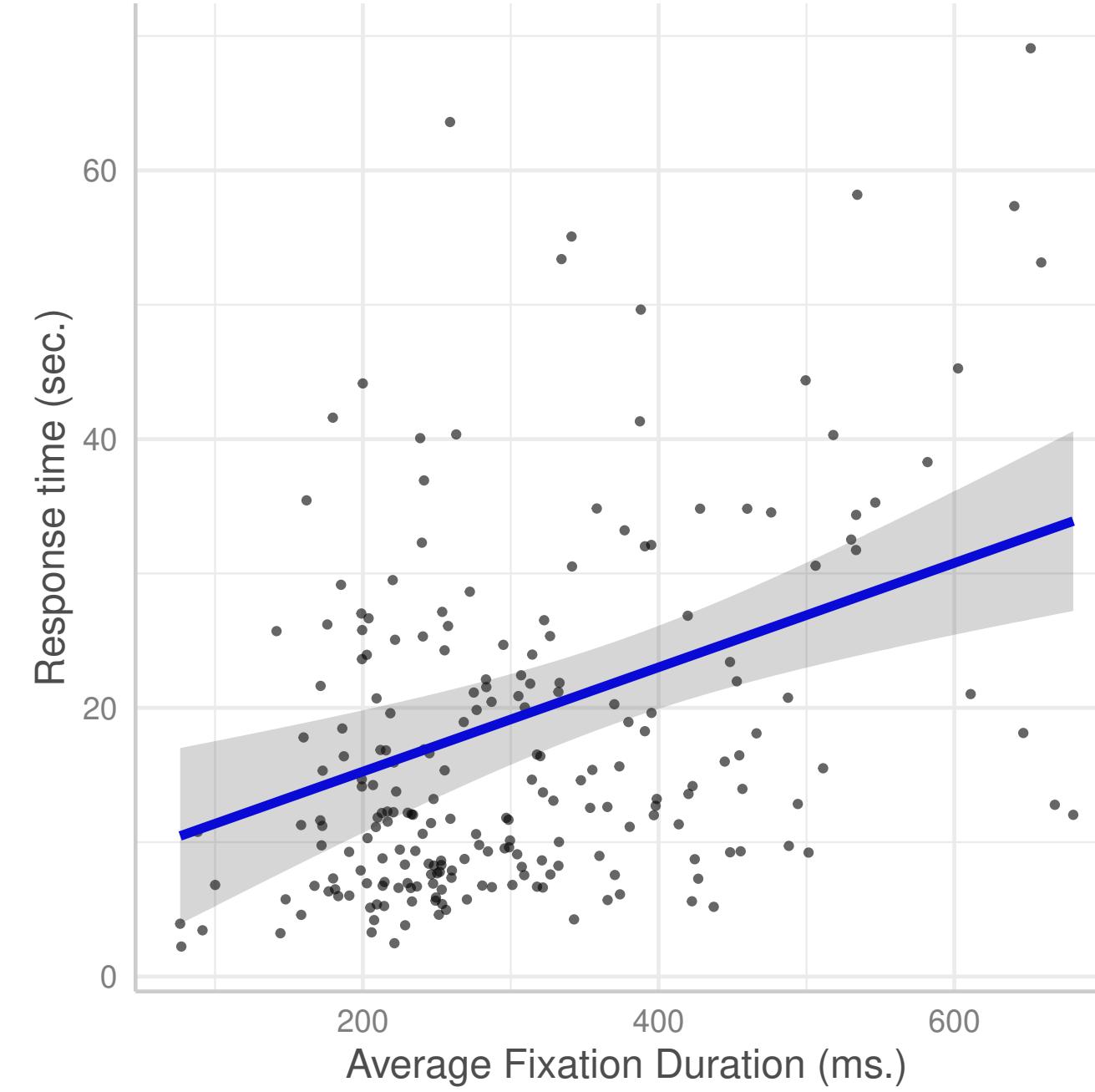
NASA-TLX

presented at the end
of the block of trials

Experimental procedure implemented in PsychPy with ioHub software

Results

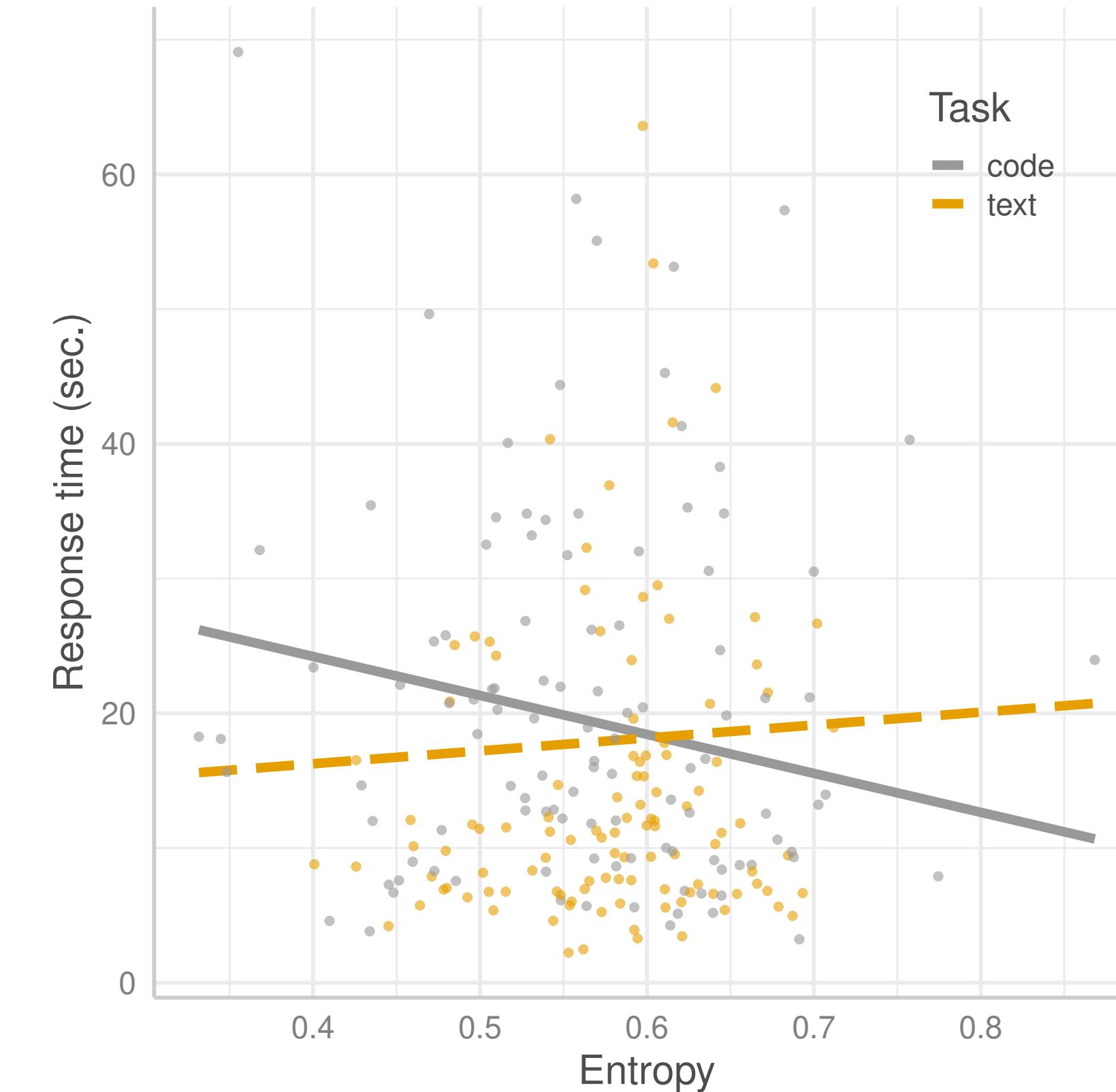
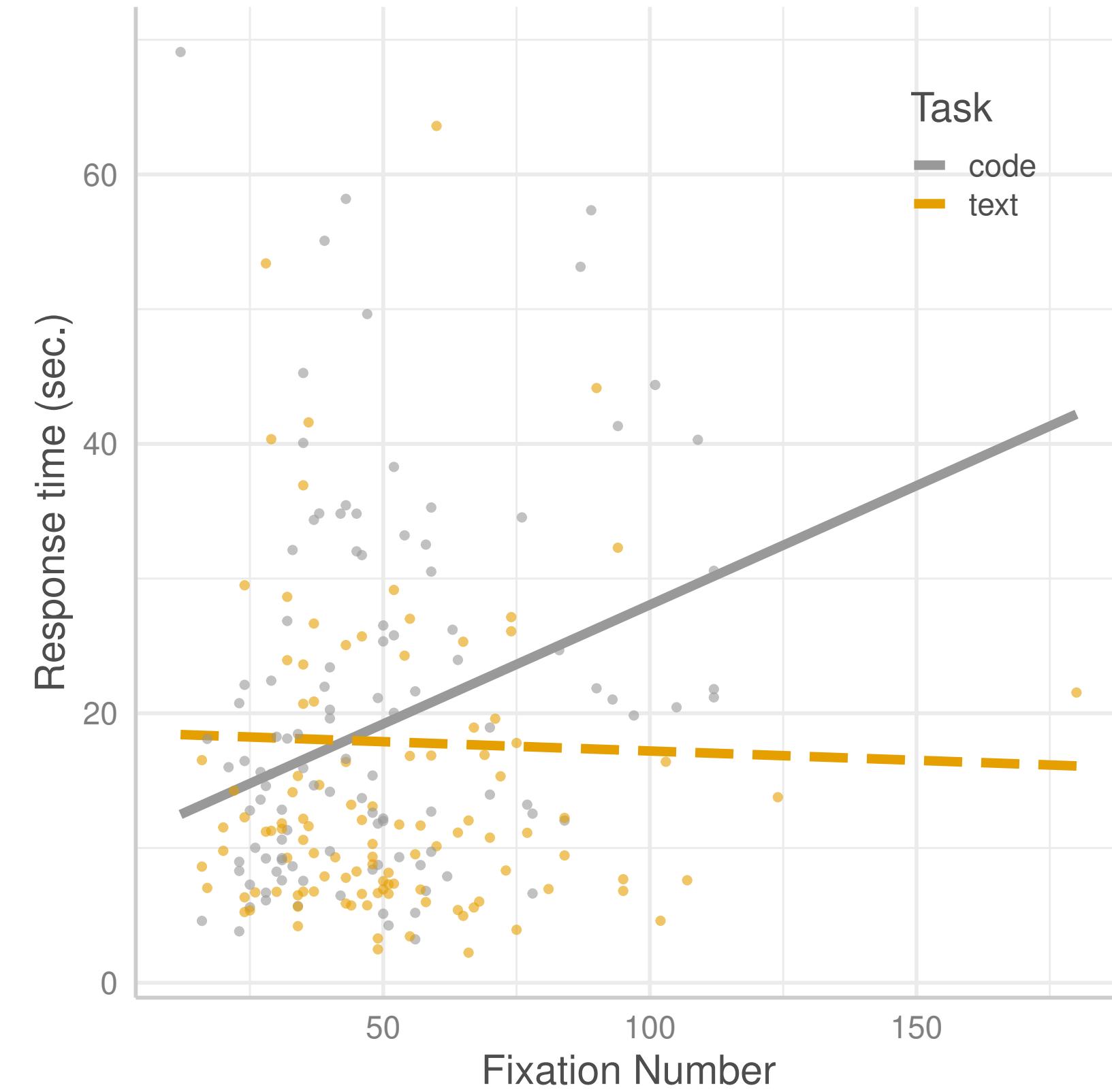
Response accuracy & time (main effects)



- Response accuracy:
 - significantly higher in text reading than in code reading
- Response time:
 - significantly lower when the response was accurate than when it was not.
- Increase in average fixation duration and number of fixations predicts longer response time.
- Entropy is inversely related to response time (greater entropy reduces response time).

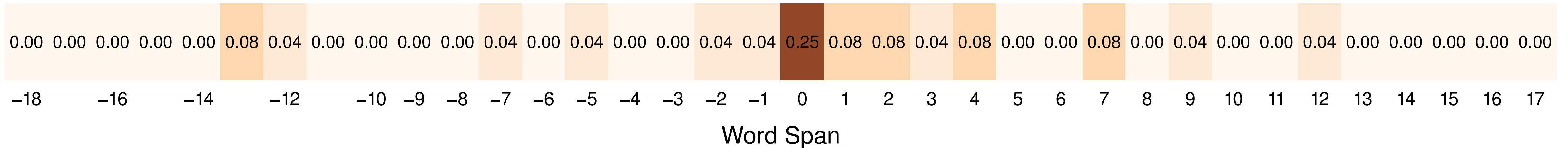
Results

Predicting response time in text and code reading tasks



- Increase in fixations predicts longer code reading (but not text)
- Decrease in entropy predicts shorter code reading
- Increase entropy reduces response time but only for code reading

Discussion & Conclusions



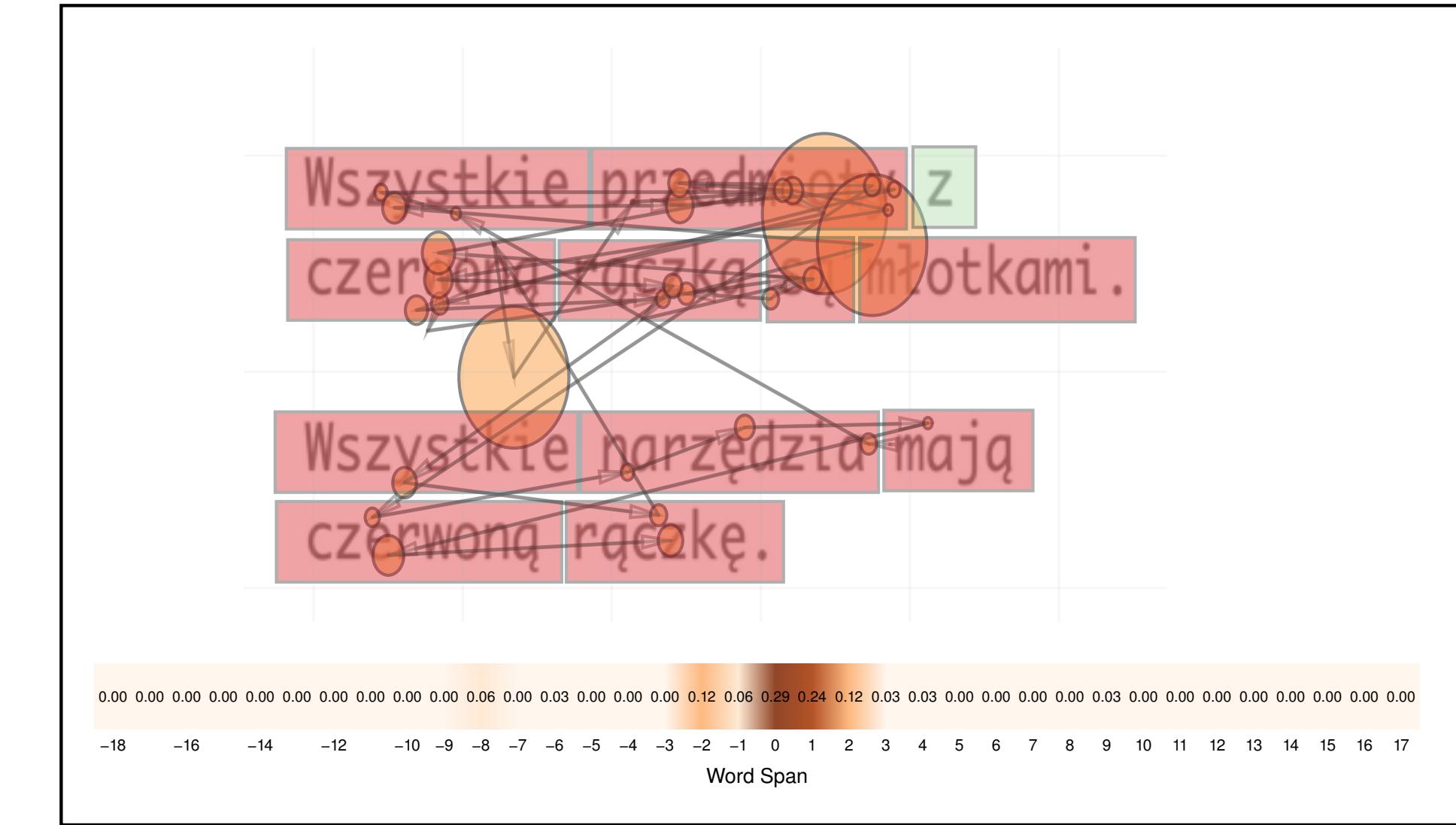
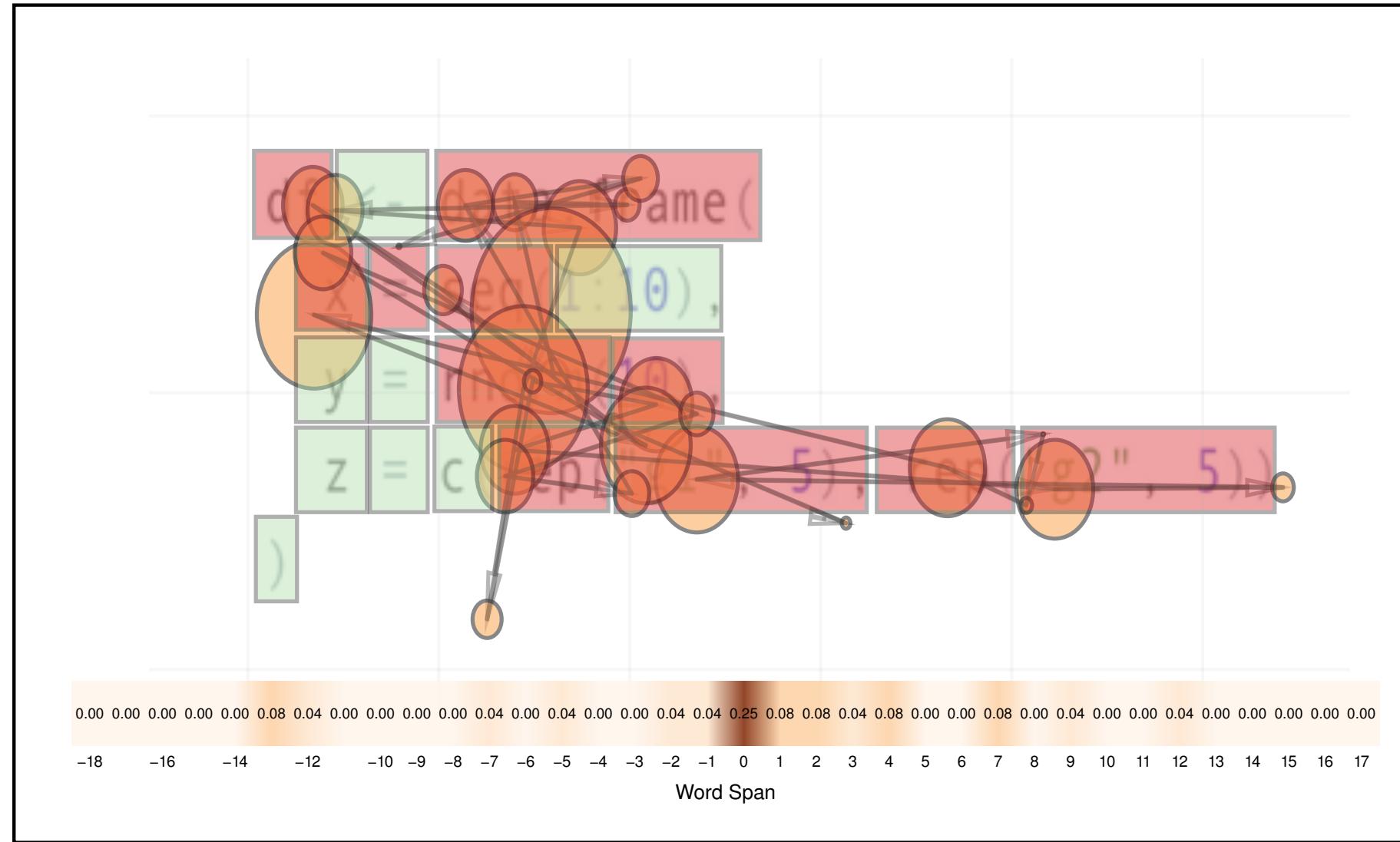
- Implications of word span entropy for code reading

- greater word span entropy can possibly lead to better comprehension of code
- greater gaze switching strategy seems applicable to reading code, which differs from text
- gaze switching over code could give reader better sense of structure (of the code)

- Word span entropy

- promising measure of the reading process
- second-order metric that is easy to implement
- future studies should consider differences between experts and novices

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