Observing Surprisal through the blurry lense of Language Models

Peter Fankhauser

INSTITUT FÜR DEUTSCHE SPRACHE

Goals of this Talk

- Gain a better understanding of „Entropy Rate“
- Influence of the domain of Language Models
- Interaction of Entropy Rate with other variables
  - Register
  - Field
  - Texttype
  - Sentence Length
  - Sentence Position

Entropy Rate: Genzel/Charniak 2002

- Probability of a sentence *S* (2 Gram context):

$$p(S) = p(w_1)p(w_2|w_1) \times \prod_{i=3}^{n} p(w_n|w_{n-1}w_{n-2})$$

- Entropy: $H(S) = -\log(p(S))$
- Average Entropy per word in *S*: $H(S)/|S|$
- Entropy Rate: $H(Y_i)$

  $H(Y_i) = H(X_i|L_i) - I(X_i|C_i, L_i)$

  i … position in text, j … sentence number for X_i

  C_i … context up to sentence S_j, L_i… local context in S_j

  $$H(X_i|L_i) = H(S_j)/|S_j|$$

  $I(X_i|C_i, L_i)$ … mutual information of X_i and C_i, L_i
- Entropy Rate Constancy Principle:

  $H(Y_i)$ is **constant** - for reasons of communicative efficiency

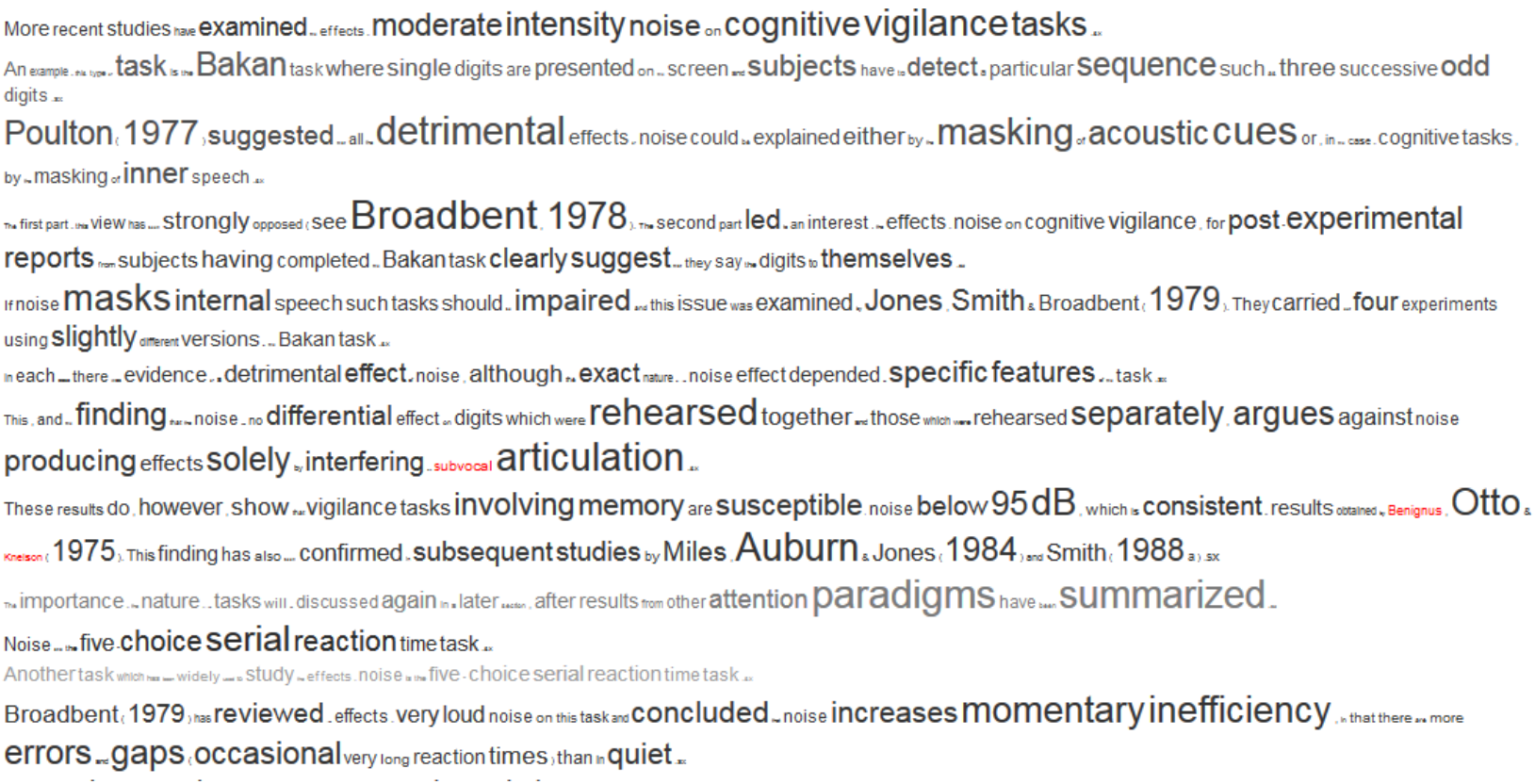
  $I(X_i|C_i, L_i)$ cannot be estimated, but is assumed to increase with *i* – **thus**:

  $H(X_i|L_i)$ also should increase with i.

Language Models

- Cache (unigram only)
  - LM up to current position in text
  - No smoothing; exponential decay (Clarkson/Robinson 1997, e=0.005)
  - „**Best“ bet at MI with Context.**
- Document
  - LM of the Document
  - (Interpolated) Witten-Bell Smoothing
  - Blurry lense at (lexical) **cohesion** (cf. Eisenstein/Barzilay 2008)
- **Corpus**
  - LM of Corpus **excluding** current Document
  - (Interpolated) Witten-Bell Smoothing
  - Domain LM (cf. Genzel/Charniak 2002,2003, Keller 2004, Qian/Jaeger 2010)
- Web
  - Microsoft N-Grams (2013/Body) (Huang et al. 2010)
  - Backoff Absolute Discount Smoothing, Frequency cutoff: 20
  - „General“ LM … with all caveats applying.

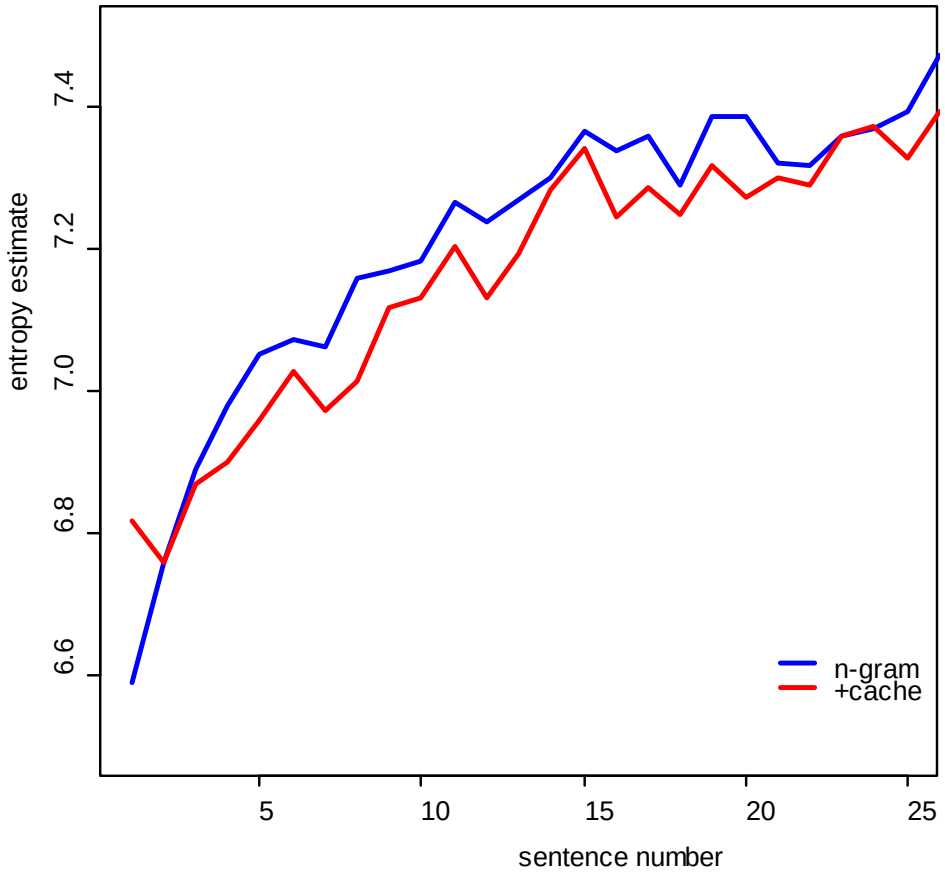
Example: 3gram context, corpus, FLOB-J (learned)

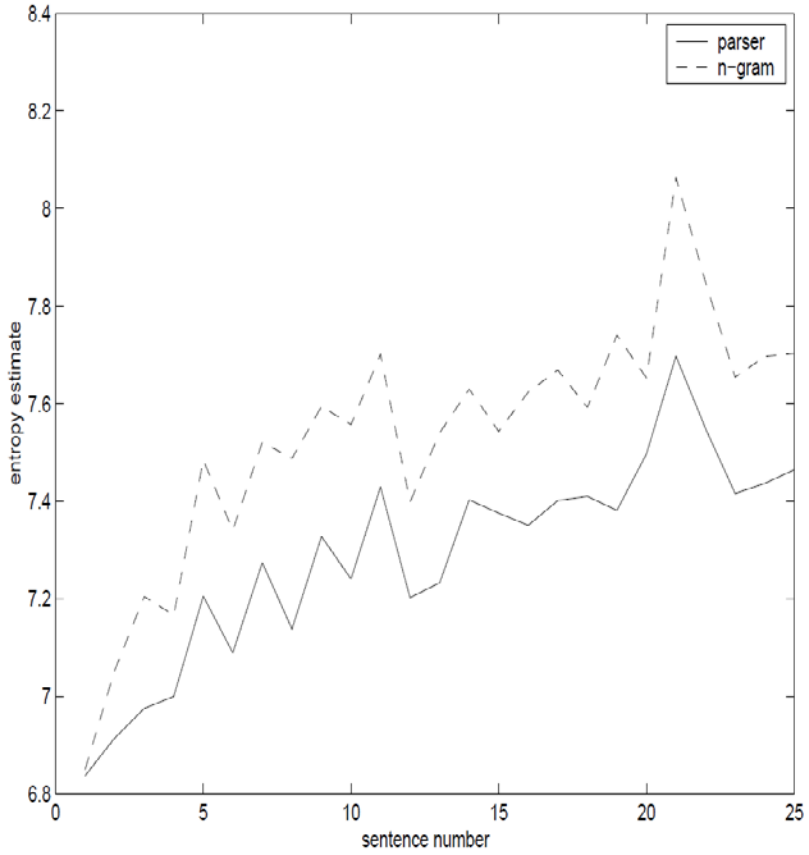


Corpora

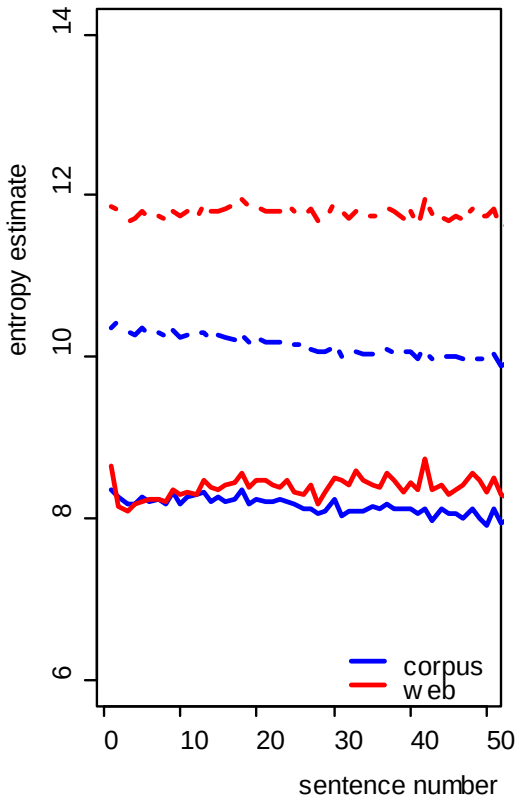
- FLOB: British English, 1991
  - 15 Registers (3 Press, 6 NonFiction, 6 Fiction)
  - 1587 Documents, 56 K Sentences, 1.16 Mio Tokens
- Wall Street Journal Corpus (WSJ)
  American English, 1987 – 1989
  - 2499 Documents, 53 K Sentences, 1.29 Mio Tokens
- Darmstadt Scientific Text (DaSciTex), 1998 - 2007
  - 9 Disciplines
  - Annotated for Head, Abstract, Intro, Main, Conclusion
  - 2111 Documents, 920 K Sentences, 18.8 Mio Tokens

WSJ: Comparison with Genzel/Charniak 2002

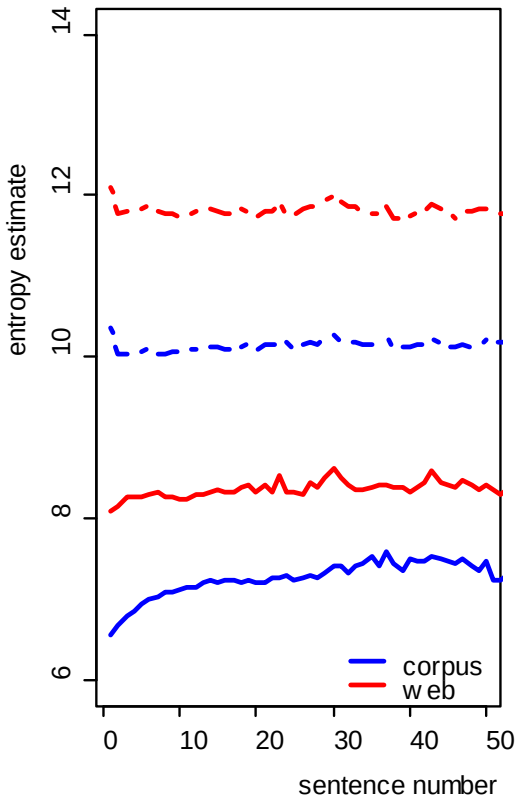




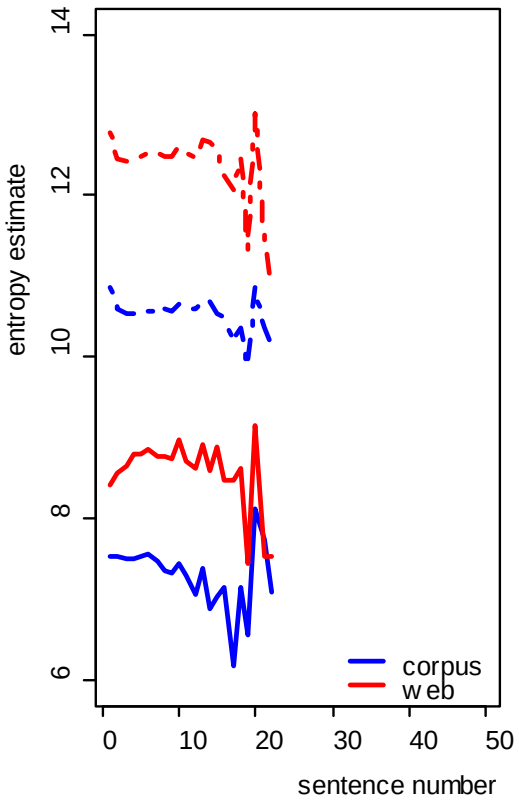
Entropy Rate Comparison



FLOB



WSJ



DaSciTex Abstracts

3 Context

No Context

WSJ: (Near) Duplicates

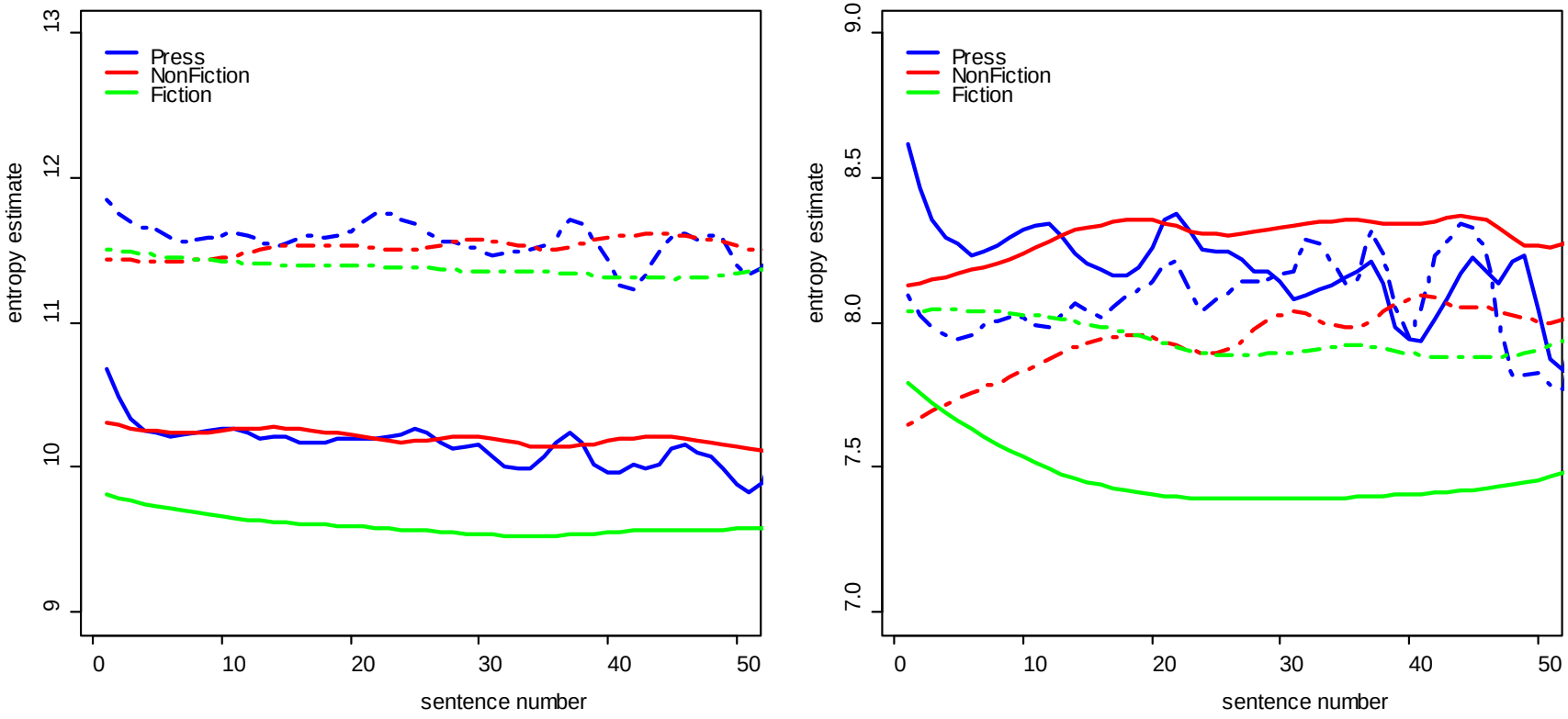
1-5: 217 Occurrences of 44 Duplicates in 10777 Sentences

n	corpus	web	sentnum	std	sentence
27	2.22	11.87	1 8/27	0.82	Terms were n't disclosed .
14	0.96	6.28	2	0.00	The base rate on corporate loans at large U.S. money center commercial banks .
14	0.98	4.82	4	0.00	Reserves traded among commercial banks for overnight use in amounts of $ 1 million or more .
14	1.74	13.54	5	0.00	Source : Fulton Prebon (U.S.A .
14	1.86	9.61	1	0.00	PRIME RATE : 10 1\ % .
13	0.84	8.40	3	0.00	The percent difference compares actual profit with the 30-day estimate where at least three ….
13	0.85	7.37	1	0.00	The companies are followed by at least three analysts , and had a minimum five-cent change in …
13	1.38	10.06	2	0.00	Estimated and actual results involving losses are omitted .
13	1.40	9.42	4	0.00	Otherwise , actual profit is compared with the 300-day estimate .
4	2.53	9.27	1 1/2	0.58	The price was n't disclosed .

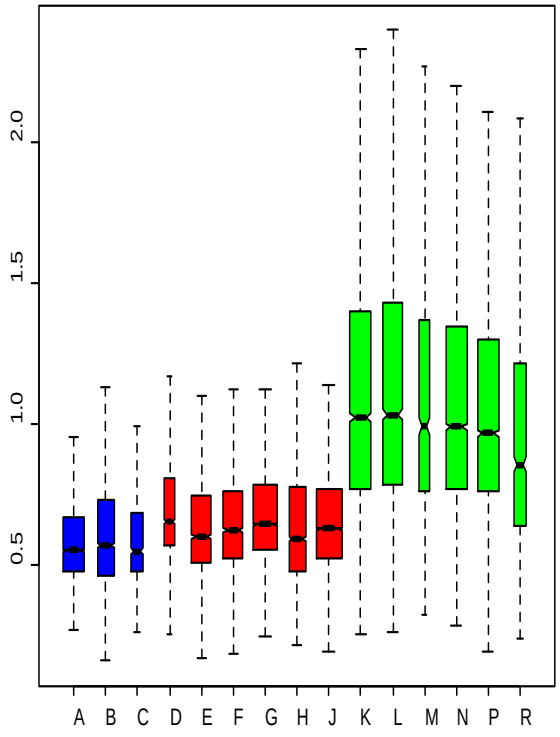
21-25: 73 Occurrences of 12 Duplicates in 4200 Sentences

n	corpus	web	sentnum	std	sentence
14	0.83	4.65	21	0.00	The average of interbank offered rates for dollar deposits in the London market based on …
14	0.87	7.15	23	0.00	These rate indications are n't directly comparable ; lending practices vary widely by location .
13	2.17	5.32	25	0.00	FEDERAL HOME LOAN MORTGAGE CORP .
8	0.64	12.56	22	0.00	FOREIGN PRIME RATES : Canada 13.50 % ; Germany 9 % ; Japan 4.875 % ; Switzerland 8.50 % ; …
6	0.71	13.26	22	0.00	FOREIGN PRIME RATES : Canada 13.50 % ; Germany 8.50 % ; Japan 4.875 % ; Switzerland 8.50 % ; …
4	0.66	7.96	24	0.00	TREASURY BILLS : Results of the Monday , October 16 , 1989 , auction of short-term U.S. …
4	0.69	7.89	24	0.00	TREASURY BILLS : Results of the Monday , October 23 , 1989 , auction of short-term U.S …
2	0.78	7.94	24	0.00	TREASURY BILLS : Results of the Monday , October 30 , 1989 , auction of short-term U.S. …
2	1.85	8.11	24 1/2	0.71	San Antonio , Texas -- $ 640 million of gas and electric revenue refunding bonds , …
2	2.58	10.76	24	0.00	Estimated volume was three million ounces .

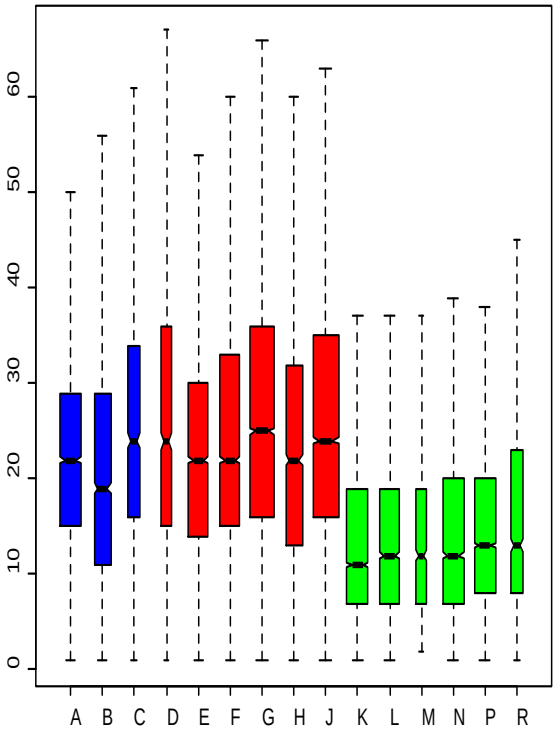
FLOB: Entropy by Sentence Number/Register



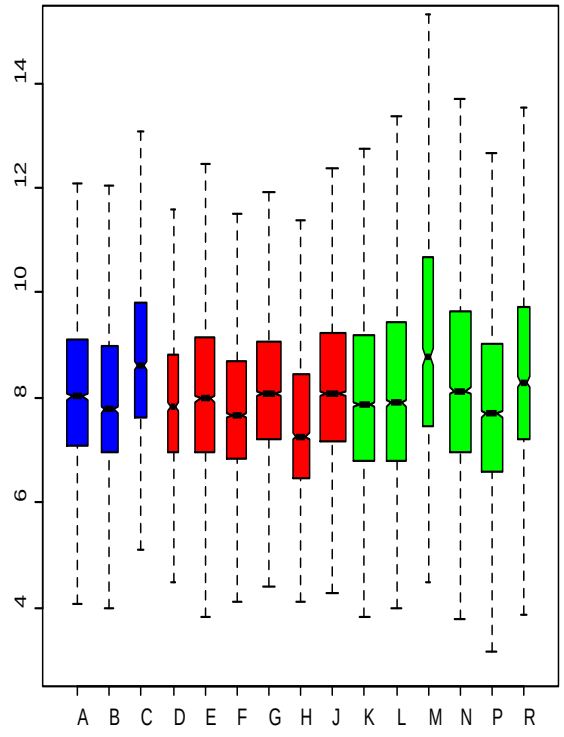
FLOB: Entropy by Register (3 Ctx)



Document

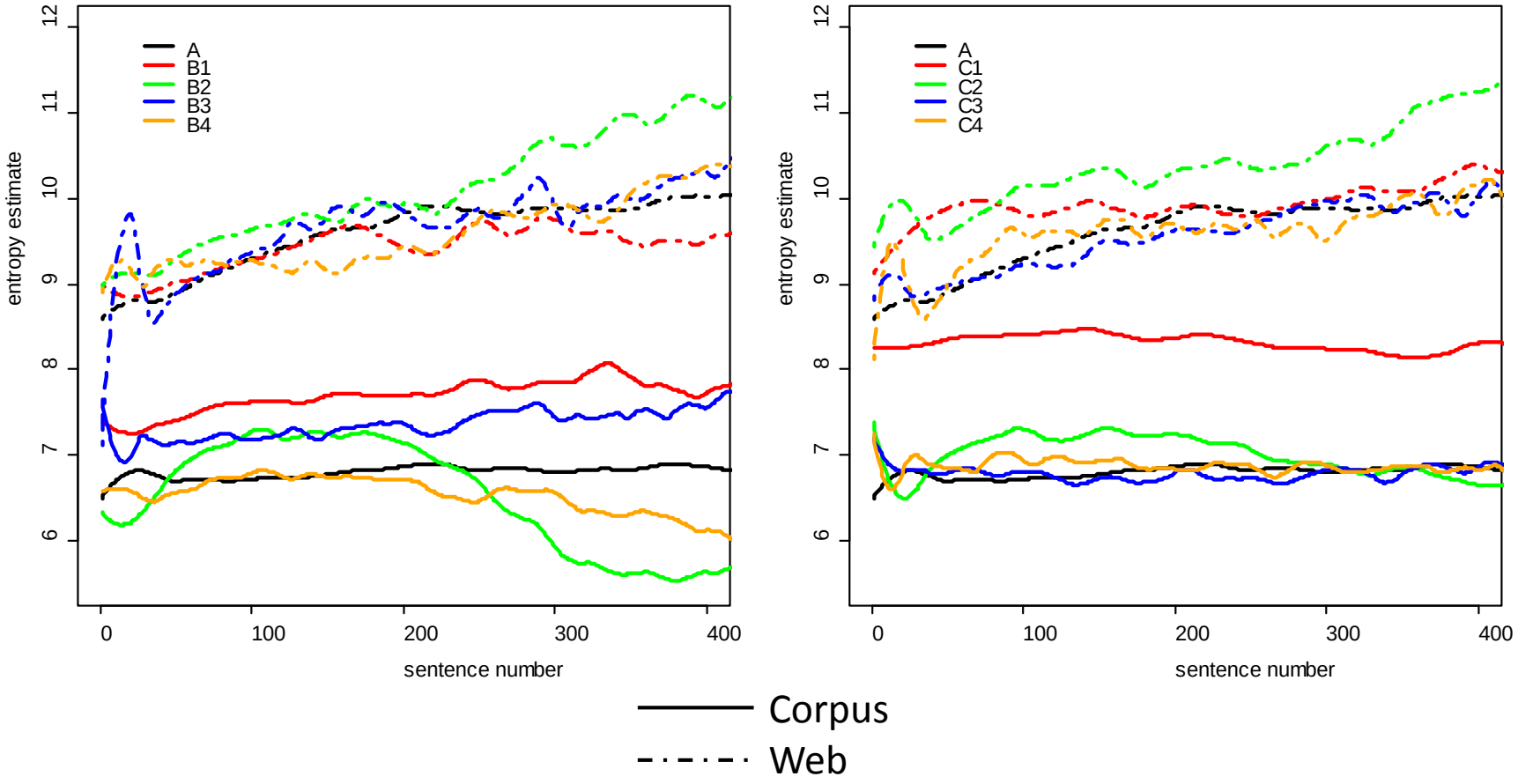


Sentence Length

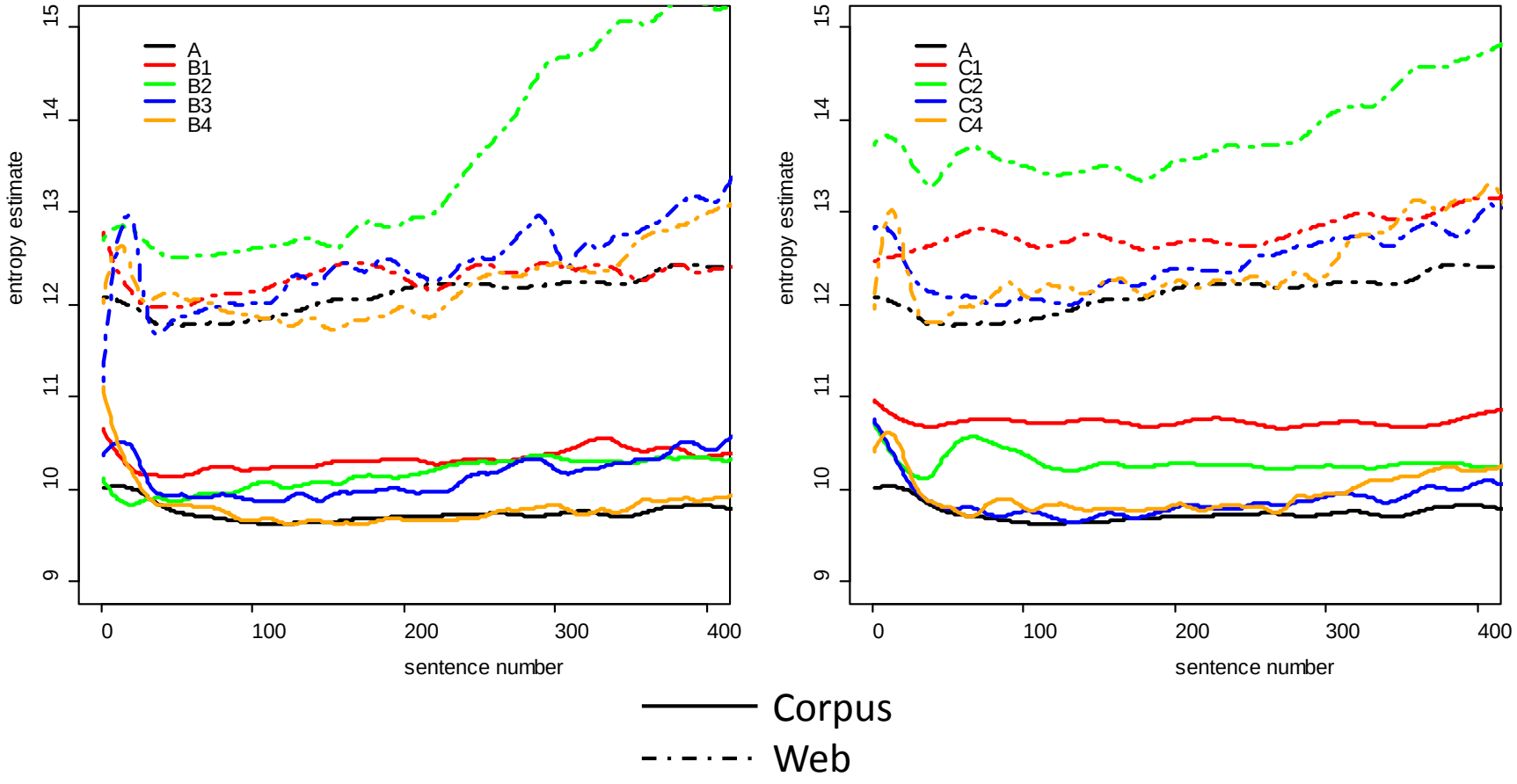


Web

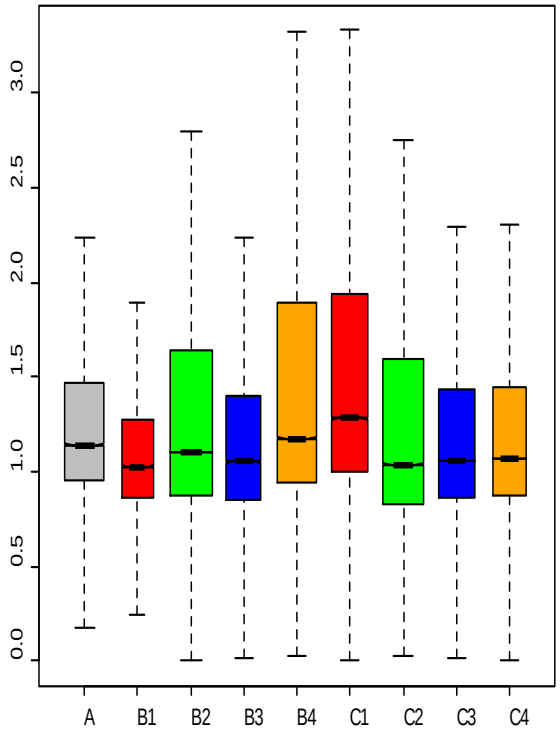
DaSciTex: Entropy by Sentence Number/Discipline (3 Ctx)



DaSciTex: Entropy by Sentence Number/Discipline (0 Ctx)



DaSciTex: Entropy by Discipline (3 Context)



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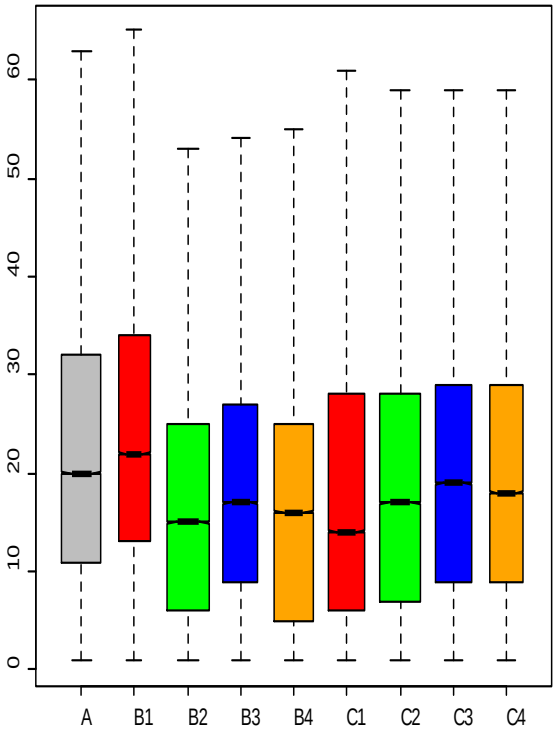
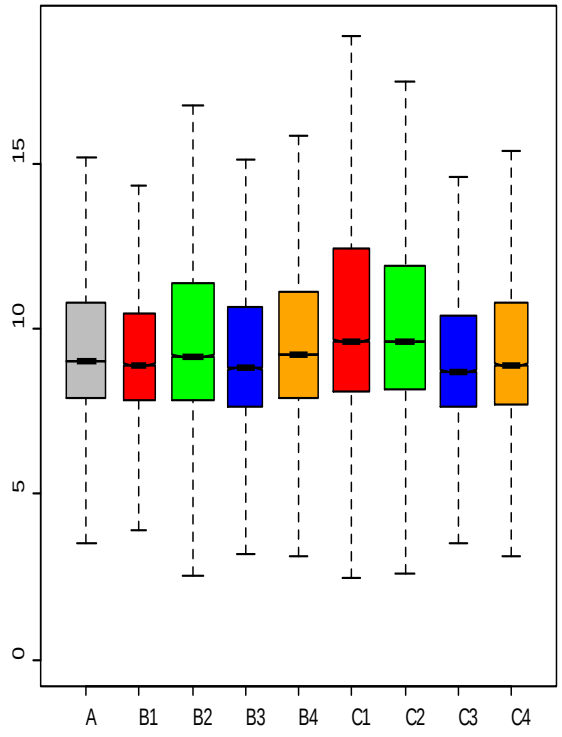


Sentence Length



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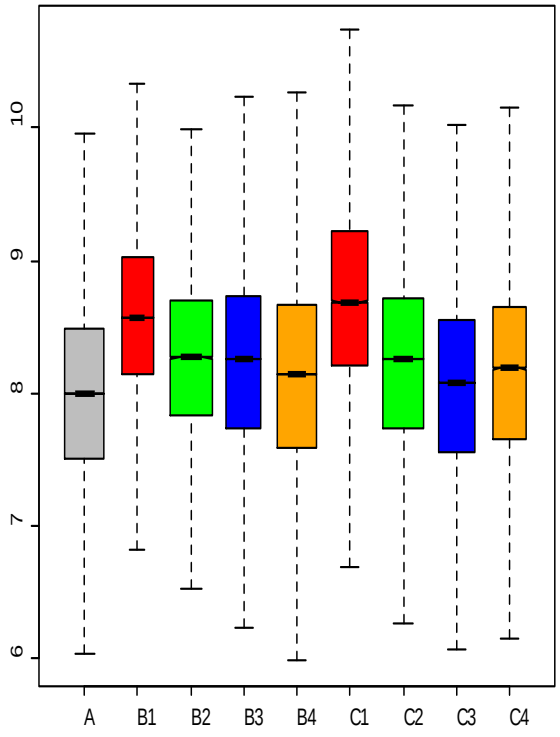
DaSciTex: Entropy by Discipline (No Context)



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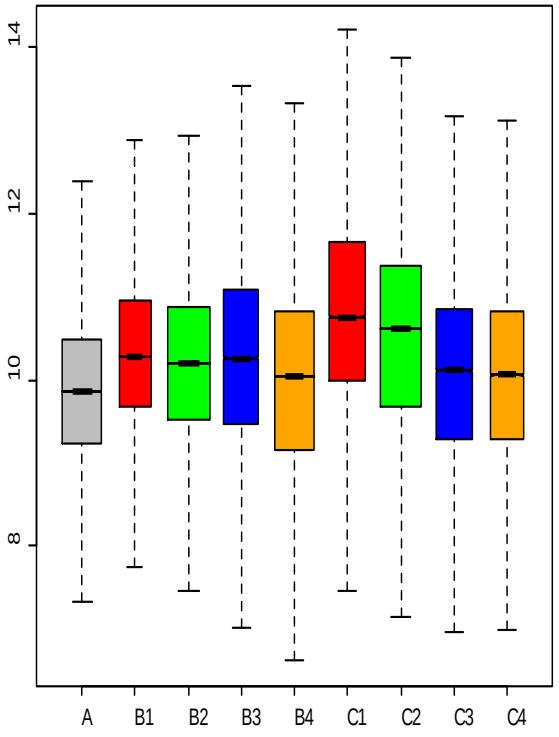
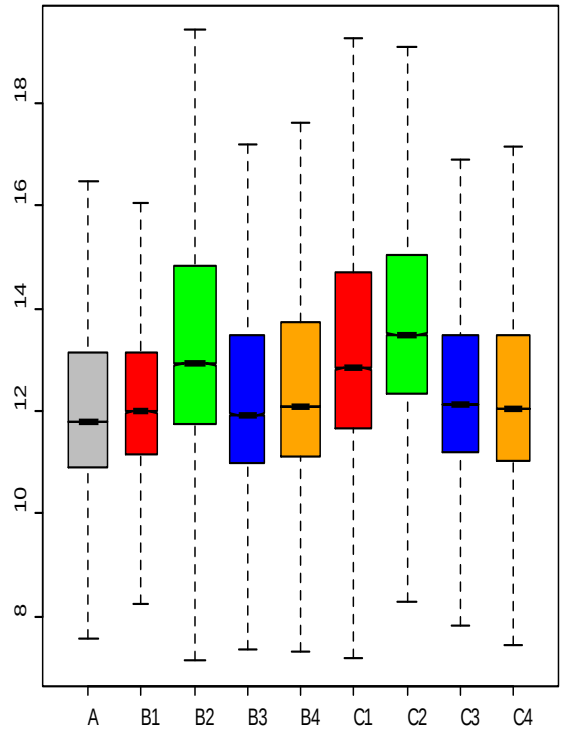


Corpus



Web

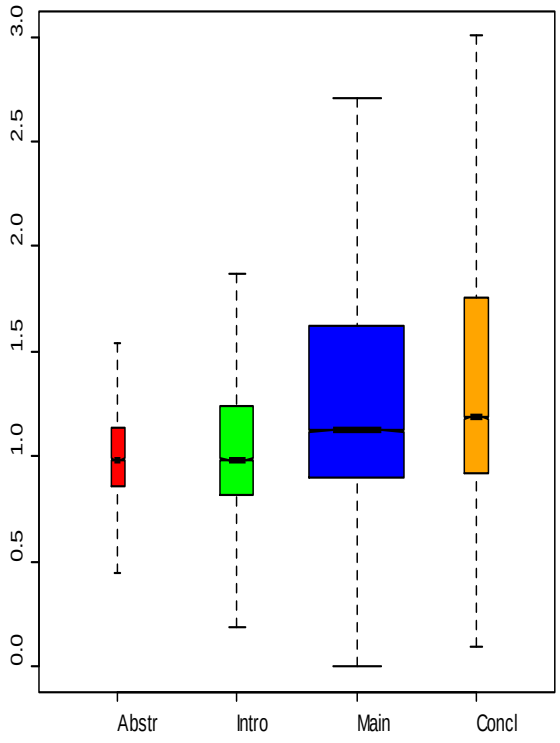
Reasons for low Corpus Entropy

- Abbreviations: „Fig .“ (12950), „2 .“ (4086)
- Boilerplate: Freq 63, Ent 0.364
  „Users are entitled to use , reproduce , disseminate , or display ….”
- References: Freq 16, Ent 1.203
  „(1999) Molecular classification of cancer : class discovery and class …“
  also prominent reason for **low** Web Entropy
- Duplicate(s): Holzer2006, Rocher 2006 (B4)
- Formulaic Expressions: Freq 46, Ent 2.222
  „This paper is organized as follows .”
  „The organization of the rest of this paper is as follows .”

Reasons for high Corpus Entropy

- **Out of Vocabulary terms**
- Long lists of numbers
- Tokenization Issues
- Foreign Language (Ent 15.7)
  „Je schneller Hans rennt , umso schneller wird er müde .“
  “Pero es sabida la periodicidad de los terremotos de magnitud e intensidad superiores en esos territorios....”
- “Dense” Constructions (Ent 13.4)
  ”Leishmania donovani , possesses unusual heterodimeric type IB topoisomerase .”
  “Signatures spanning consecutive exons confirmed 142 predicted introns . “

DaSciTex: Entropy by Section (3 Context)



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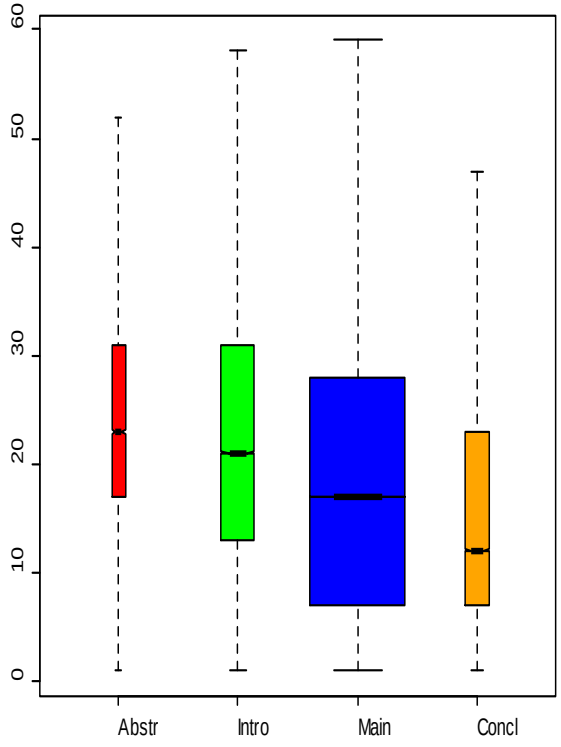
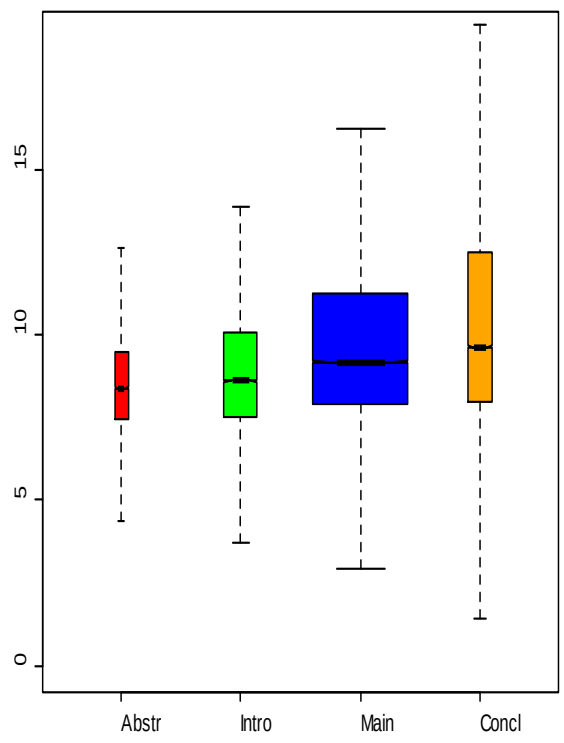
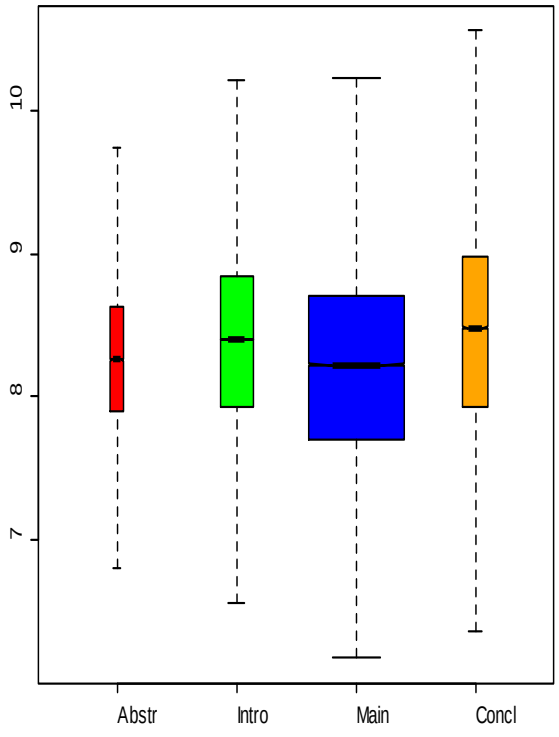


Sentence Length



Web

DaSciTex: Entropy by Section (No Context)



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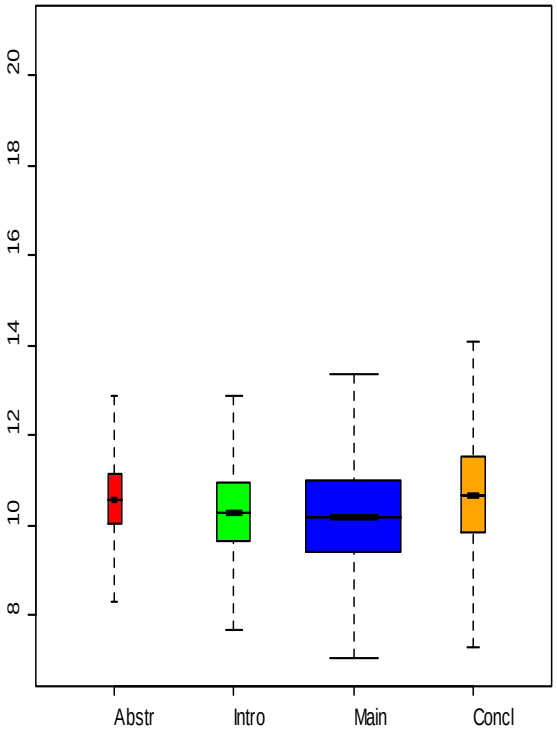
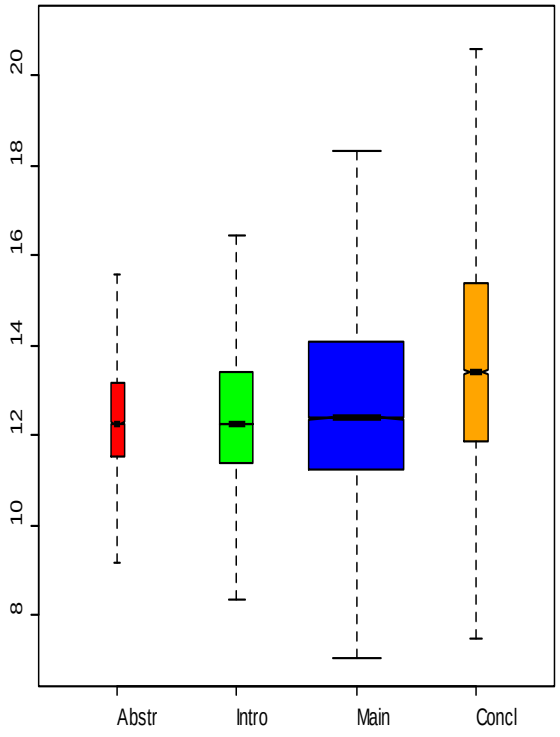
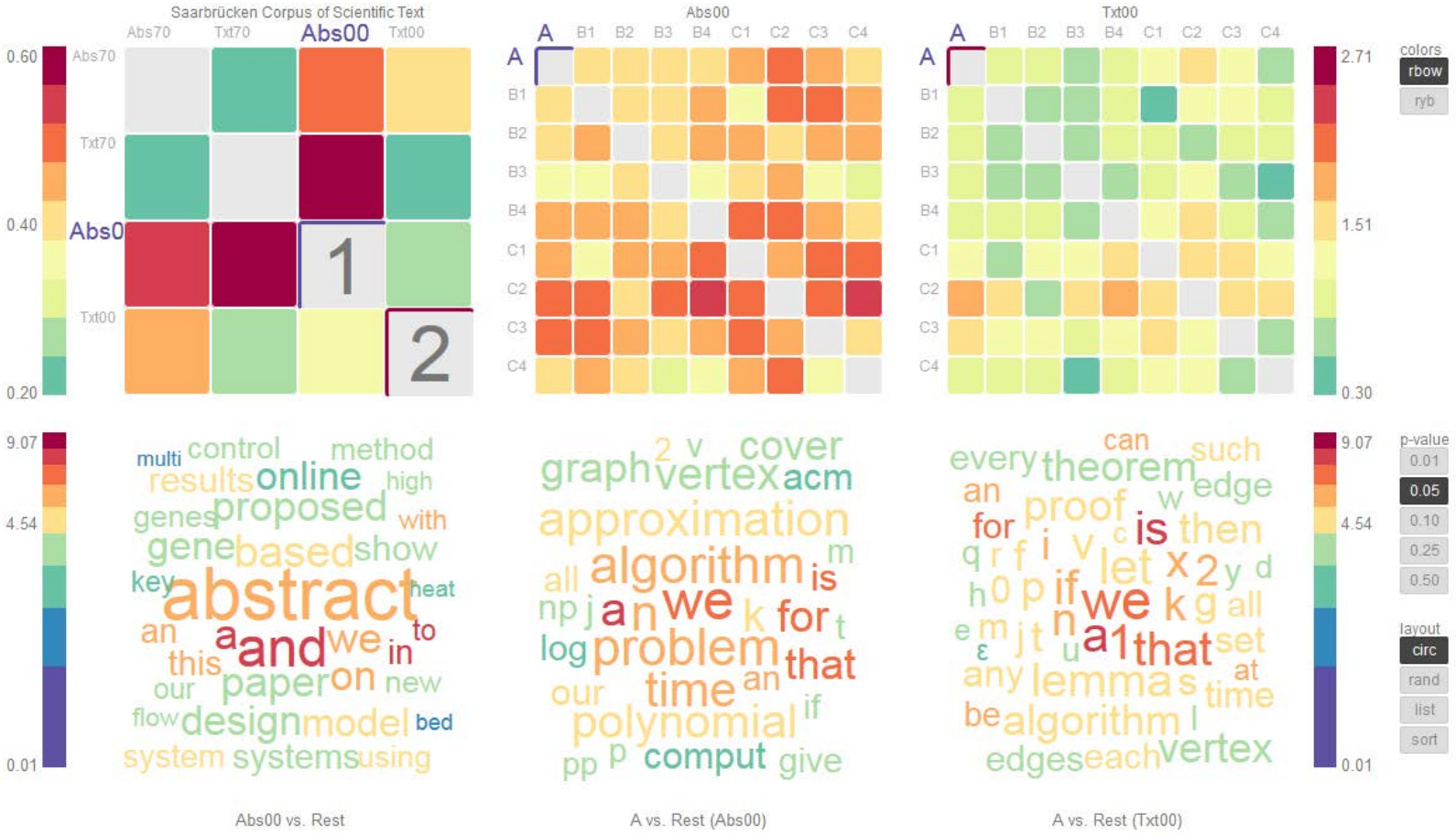


Corpus

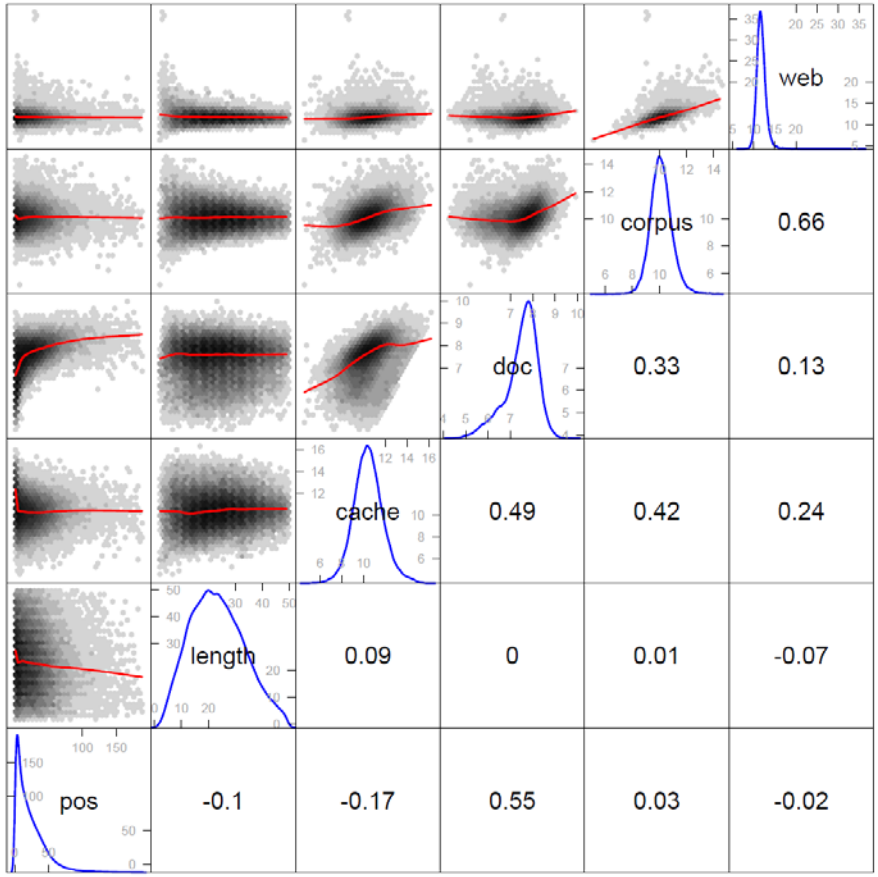


Web

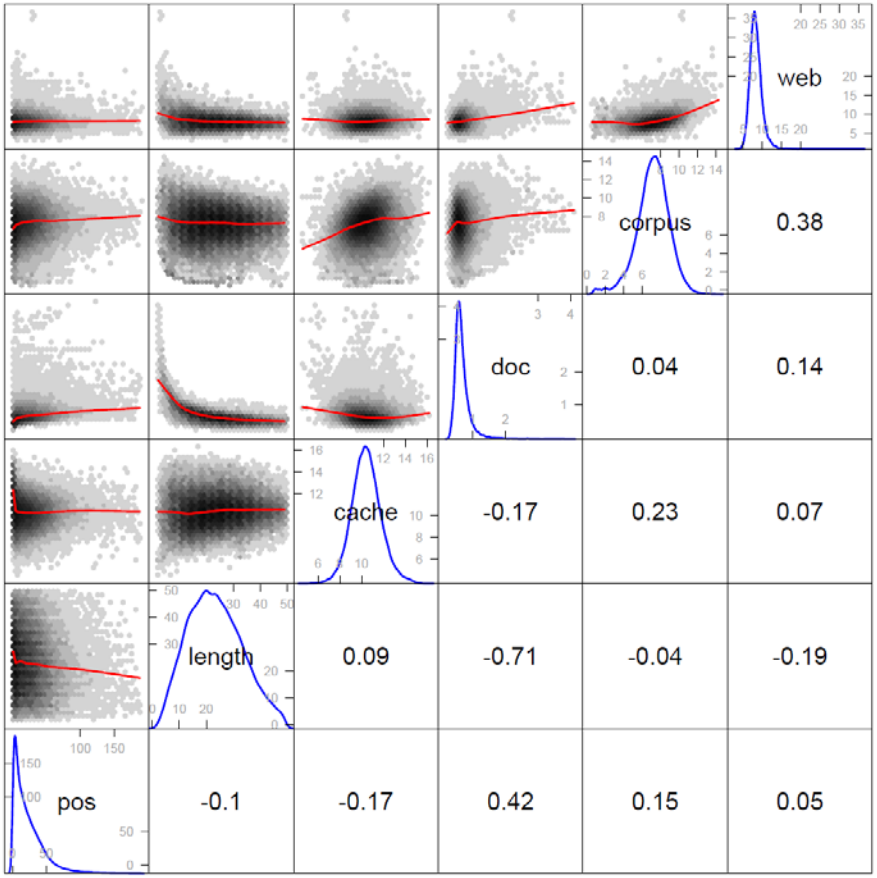
Relative Entropy: Abstracts vs. Text



WSJ: SPLOM

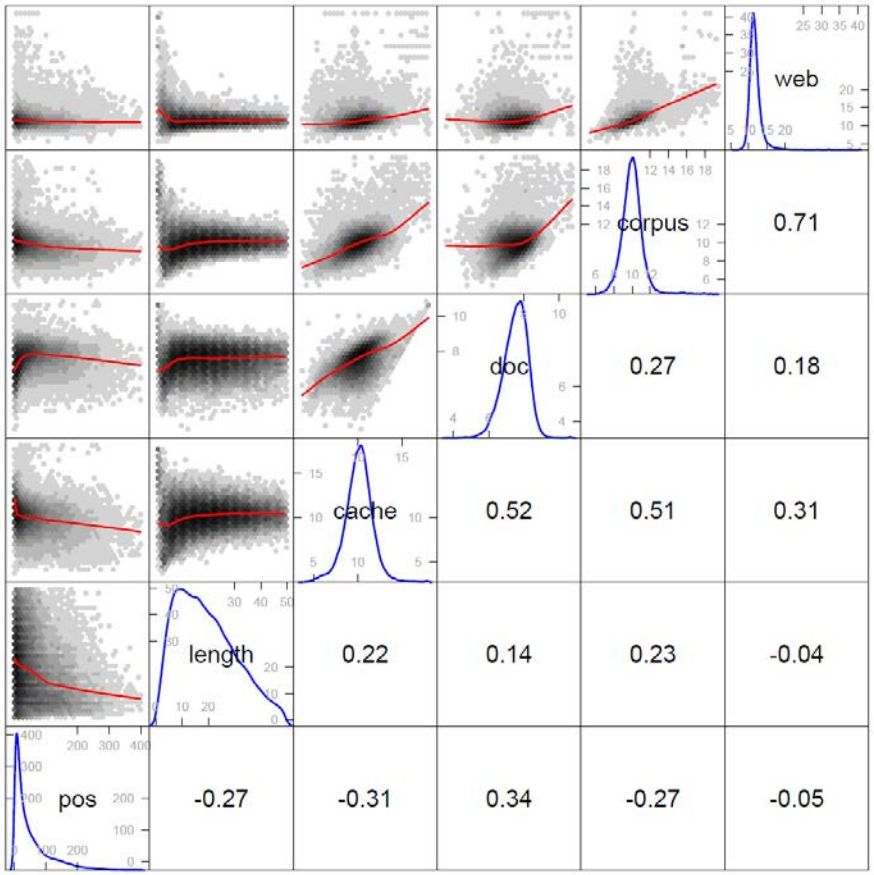


WSJ: no context

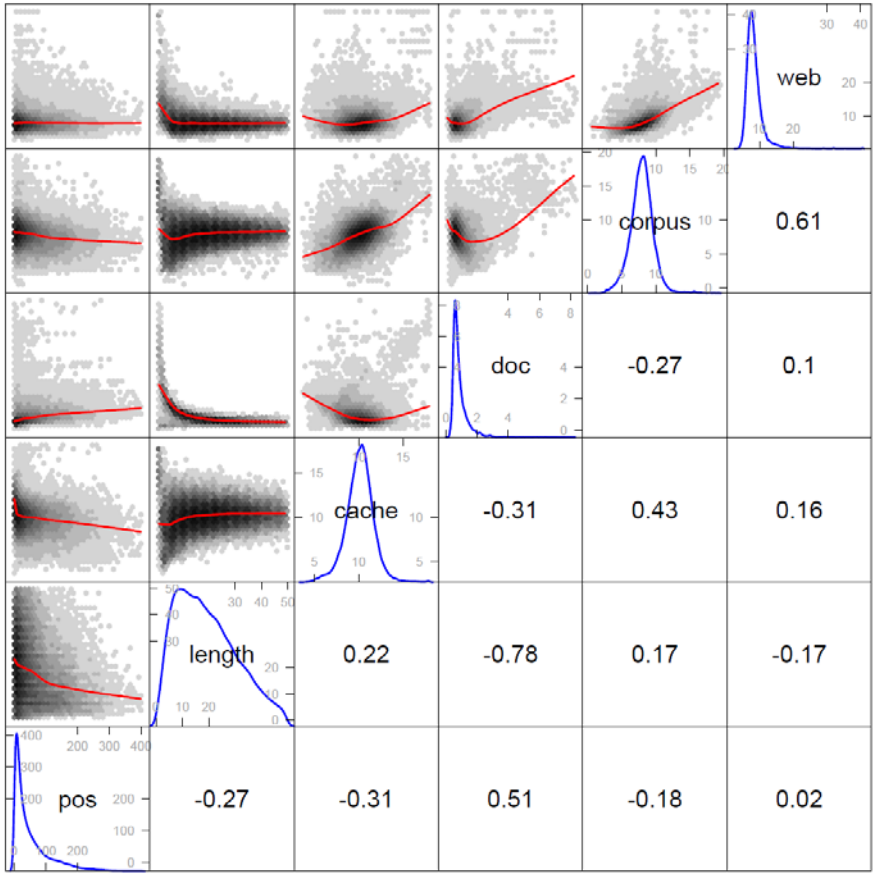


WSJ: 3gram context

FLOB: SPLOM

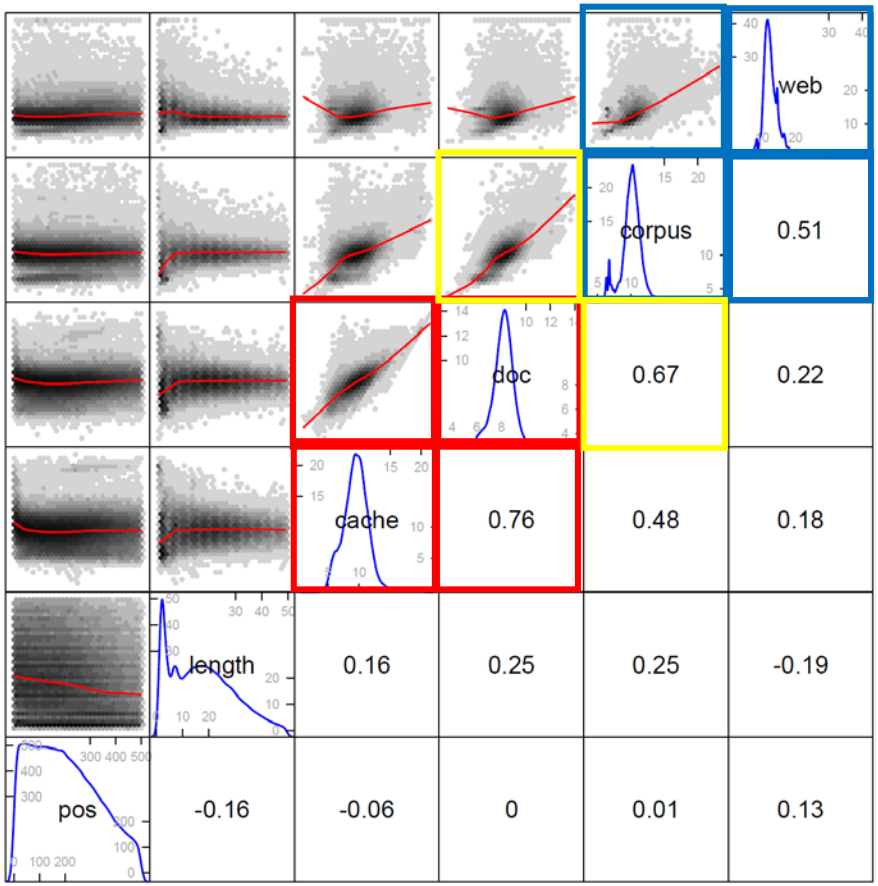


Flob: no context

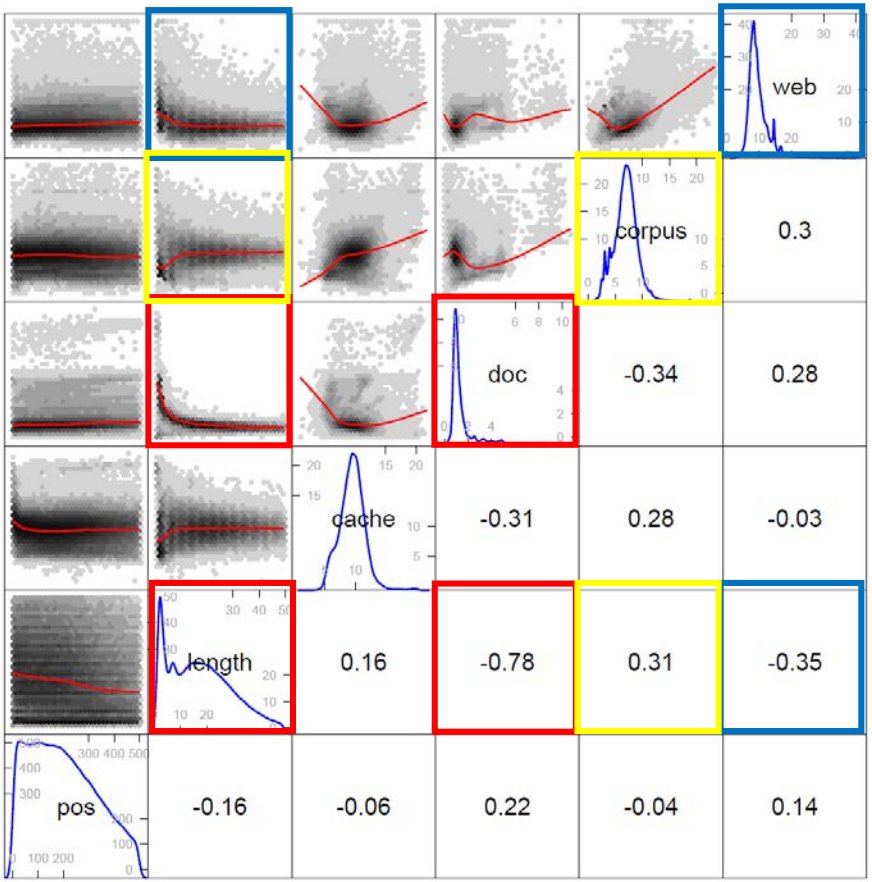


Flob: 3gram context

DaSciTex: SPLOM



DaSciTex: no context



DaSciTex: 3gram context

Summary

- Entropy & Frequency
  - Yet another good predictor for dirt.
- Entropy Rate Constancy Principle
  - Maybe not as universal as assumed
- Entropy Rate vs. Other Variables
  - Sentence position: inconclusive (only Cache LM)
  - Sentence length (Doc, 3Gram): strong correlation, by construction
- Correlation of LMs
  - Doc with Cache: by construction
  - Corpus with Web: not always
  - Doc with Corpus: in DaSciTex/Unigrams

Future Work

- Cleansing ☹
- Better Language Models
  - Phrases: Segmenting n-grams to maximize sentence entropy
  - Longer Ranges: (Unsupervised) Dependency Parsers
  - …
- Other contextual variables
  - POS (low hanging fruit)
  - Time
- Linguistically informed hypothesis testing

References

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