

Taking uncertainty seriously

A Bayesian approach to word embedding bias estimation

Alicja Dobrzeniecka & Rafal Urbaniak
(LoPSE research group, University of Gdansk)

ExpSem2021, ESSLLI

Presentation plan

- Bias in word embeddings
- WEAT and MAC methods
- Methodological problems
- Limitations of pre-averaging in bias detection methods
- Accounting for uncertainty with Bayesian approach

Cosine-based measures of bias

Word embeddings

- Representation of words with vectors of real numbers
- Often built to predict the probability of co-occurrence

| word | 1 | 2 | 3 | 4 | ... |
|-------|-------|-------|-------|-------|-----|
| woman | 0.456 | 0.267 | 0.675 | 0.131 | ... |
| man | 0.451 | 0.897 | 0.472 | 0.088 | ... |

Cosine-based measures of bias

Cosine similarity & distance

$$\text{cosineSimilarity}(A, B) = \frac{A \cdot B}{\|A\| \|B\|} \quad (\text{Sim})$$

$$\text{cosineDistance}(A, B) = 1 - \text{cosineSimilarity}(A, B) \quad (\text{Distance})$$

- Geometric interpretation: direction (not length)
- $\text{cosineDistance} \in (0, 2)$
- Naive interpretation: proximity corresponds to semantic similarity

Cosine-based measures of bias

The worry

Word embeddings can learn implicit harmful biases

Cosine-based measures of bias

The worry

Word embeddings can learn implicit harmful biases

Cosine-based bias: basic intuition

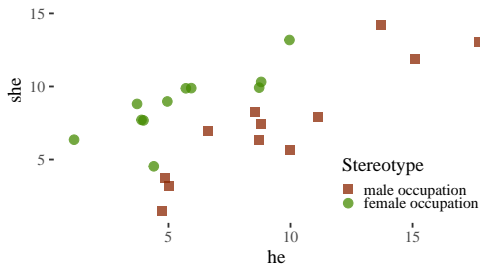
Stereotypically connected words are cosine-close

Cosine-based measures of bias

A visual example

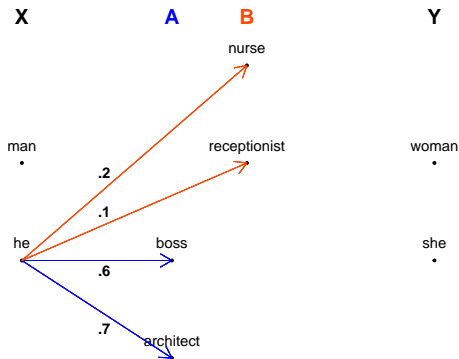
- feminine occupations: “homemaker”, “nurse”, “receptionist”, “librarian”, etc.
- masculine occupations: “maestro”, “captain”, “architect”, “boss”, etc.

GloVe on Wikipedia 2014 and Gigaword 5th ed.



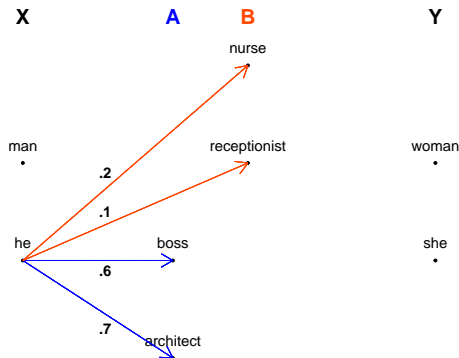
Cosine-based measures of bias

Example: Word Embedding Association Test (WEAT)



Cosine-based measures of bias

Example: Word Embedding Association Test (WEAT)



- $s_1 = s(\text{he}, A, B) = \frac{.6+.7}{2} - \frac{.2+.1}{2} = .65 - .15 = .5$
- $s_2 = s(\text{man}, A, B) = .3,$
 $s_3 = s(\text{woman}, A, B) = -.6, s_4 = s(\text{she}, A, B) = -.3$

$$\text{WEAT}(A, B) = \frac{(s_1 + s_2)/2 - (s_3 + s_4)/2}{sd(\{s_1, s_2, s_3, s_4\})} \approx 1.93$$

Cosine-based measures of bias

Example: Word Embedding Association Test (WEAT)

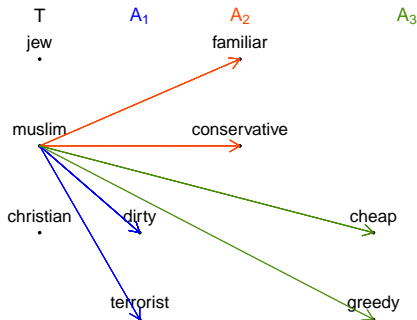
$$s(t, A, B) = \frac{\sum_{a \in A} f(t, a)}{|A|} - \frac{\sum_{b \in B} f(t, b)}{|B|}$$
$$WEAT(A, B) = \frac{\mu(\{s(x, A, B)\}_{x \in X}) - \mu(\{s(y, A, B)\}_{y \in Y})}{\sigma(\{s(w, A, B)\}_{w \in X \cup Y})}$$

- t is a term, A, B are sets of stereotype attribute words, X, Y are protected group words
- For instance, X might be a set of male names, Y a set of female names, A might contain stereotypically male-related career words, and B stereotypically female-related family words
- s -values are used as datapoints in statistical significance tests

(Caliskan, Bryson, & Narayanan, 2017) with extensions in (Lauscher & Glavas, 2019) and applications in (Garg, Schiebinger, Jurafsky, & Zou, 2018)

Cosine-based measures of bias

Our main target: Mean Average Cosine Similarity (MAC)



$$s_1 = s(\text{muslim}, A_1) = \frac{\cos(\text{muslim}, \text{dirty}) + \cos(\text{muslim}, \text{terrorist})}{2}$$

$$s_2 = s(\text{muslim}, A_2) = \frac{\cos(\text{muslim}, \text{familiar}) + \cos(\text{muslim}, \text{conservative})}{2}$$

\vdots

$$\text{MAC}(T, A) = \text{mean}(\{s_i | i \in 1, \dots, k\})$$

Cosine-based measures of bias

Our main target: Mean Average Cosine Similarity (MAC)

$$S(t_i, A_j) = \frac{1}{|A_j|} \sum_{a \in A_j} \cos(t, a)$$

$$MAC(T, A) = \frac{1}{|T||A|} \sum_{t_i \in T} \sum_{A_j \in A} S(t_i, A_j)$$

- $T = \{t_1, \dots, t_k\}$ is a class of protected words
- each $A_j \in A$ is a set of attributes stereotypically associated with a protected word
- The t-tests they employ are run on average cosines used to calculate MAC

(Manzini, Lim, Tsvetkov, & Black, 2019)

Cosine-based measures of bias

Our main target: Mean Average Cosine Similarity (MAC)

Table 2: A few rows from the religion dataset

| protectedWord | wordToCompare | cosineDistance | cosineSimilarity |
|---------------|---------------|----------------|------------------|
| jew | greedy | 0.6947042 | 0.3052958 |
| rabbi | greedy | 1.0306175 | -0.0306175 |
| rabbi | conservative | 0.7175887 | 0.2824113 |
| christian | uneducated | 0.5081939 | 0.4918061 |
| christianity | cheap | 1.2816164 | -0.2816164 |
| muslim | terrorist | 0.2726106 | 0.7273894 |

Cosine-based measures of bias

Known challenges

- Gender-direction: insufficient indicator of bias (Gonen & Goldberg, 2019)
- Use of analogies: unreliable (Nissim, Noord, & Goot, 2020)
- High sensitivity to irrelevant factors (Zhang, Sneyd, & Stevenson, 2020)

Some methodological problems

Word list choice is unprincipled

We run with it for comparison

Some methodological problems

Word list choice is unprincipled

We run with it for comparison

No design considerations to sample size

We statistically gauge the uncertainty that arises from raw sample sizes

Some methodological problems

No word class distinction and no control group

We make the subclasses clear, add human neutral predicates and neutral predicates for control. We used L2-Reddit corpus and GoogleNews (we present the results for Reddit for brevity).

Table 3: Rows from extended religion dataset.

| protectedWord | wordToCompare | wordClass | cosineDistance | cosineSimilarity | connection |
|---------------|---------------|-----------|----------------|------------------|------------|
| torah | hairy | jewish | 1.170 | -0.170 | associated |
| christian | dirty | muslim | 0.949 | 0.051 | different |
| judaism | cheap | jewish | 1.232 | -0.232 | associated |
| christianity | familial | christian | 0.645 | 0.355 | associated |
| mosque | approve | neutral | 0.995 | 0.005 | none |
| imam | carry | human | 0.993 | 0.007 | human |
| mosque | merging | neutral | 0.868 | 0.132 | none |
| muslim | nationalized | neutral | 0.870 | 0.130 | none |

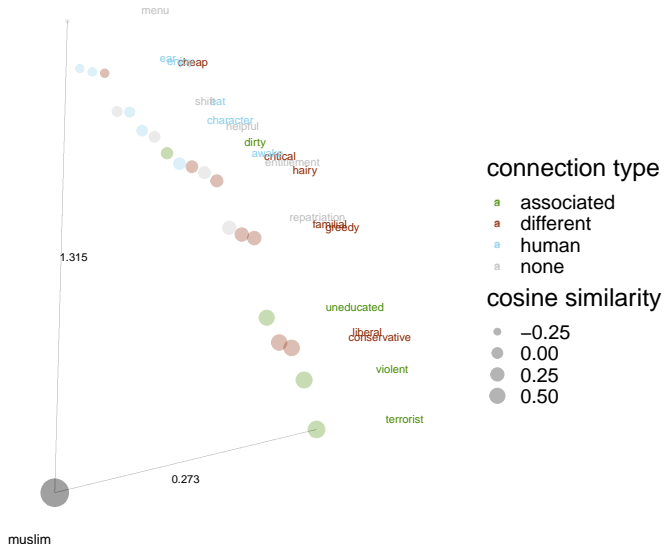
Some methodological problems

Outliers and surprisingly dissimilar words

We study those by visualizations and uncertainty estimates

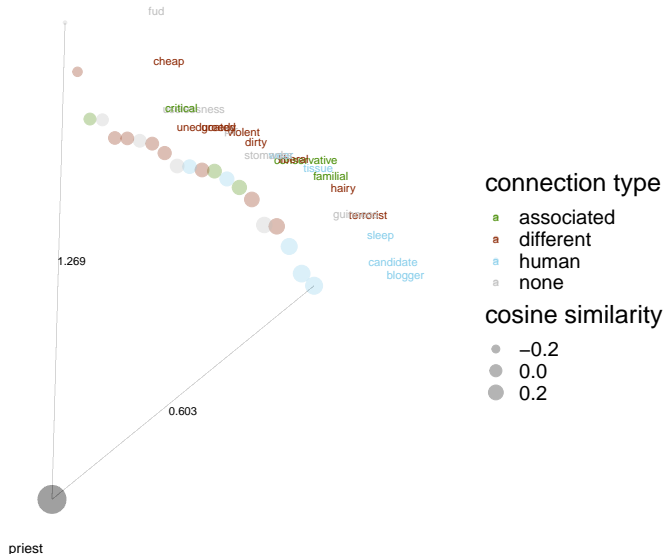
Some methodological problems

Distances for “muslim”



Some methodological problems

Distances for “priest”



Some methodological problems

No principled interpretation

| Religion Debiasing | MAC (distance) |
|-----------------------------------|----------------|
| Biased | 0.859 |
| Hard Debaised | 0.934 |
| Soft Debaised ($\lambda = 0.2$) | 0.894 |

- What values are sufficient for the presence of bias and what differences are sign of real improvement?
- Low p -values are not high effect indicators!
- We compare HPDIs.

The problem with pre-averaging

Key conceptual issues

- It throws away information about sample sizes
- It ignores variation in the raw data, which leads to false confidence

The problem with pre-averaging

Key conceptual issues

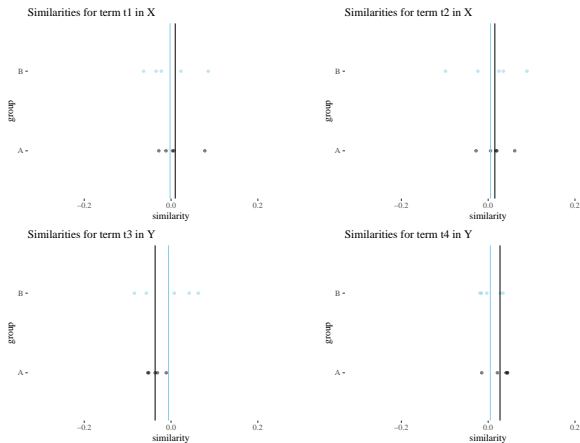
- It throws away information about sample sizes
- It ignores variation in the raw data, which leads to false confidence

Our simulation

Suppose all similarities for two classes are randomly drawn from the same distribution, $\text{Normal}(\mu = 0, \sigma = .05)$, you still can get a really high WEAT!

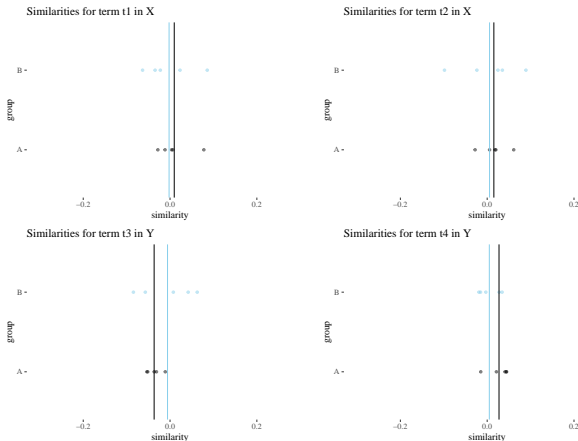
The problem with pre-averaging

One simulation



The problem with pre-averaging

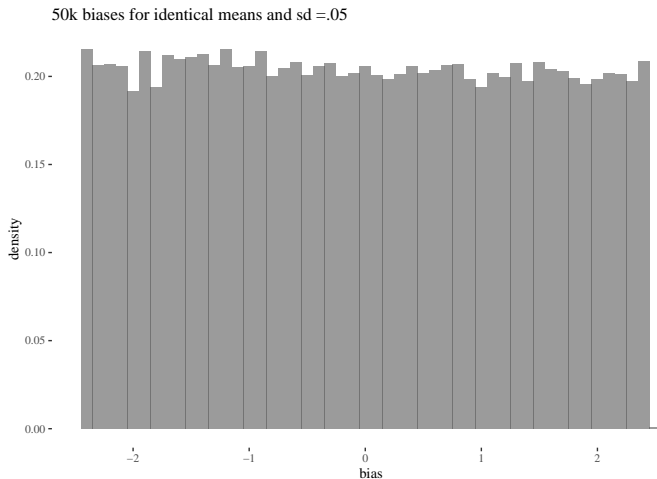
One simulation



- Raw sd in data is 0.045
- The sd of means is 0.023
- The WEAT score is 1.825
- The largest effect size reported by Caliskan et al. (2017) is 1.81!

The problem with pre-averaging

50k simulations (same parameters)



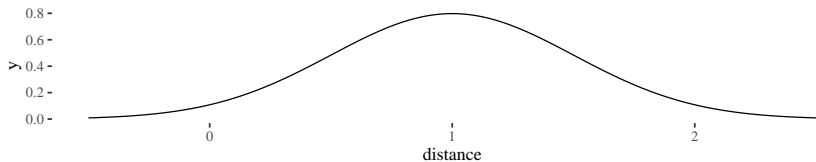
Advantages of the Bayesian way

- Direct impact of sample sizes
- Straightforward interpretation in terms of posterior probabilities
- Freedom to choose granularity level
- More honest risk assessment and decision making

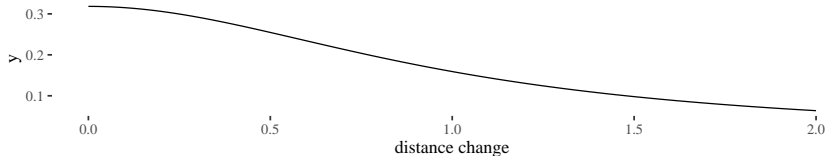
Bayesian model

Choosing priors

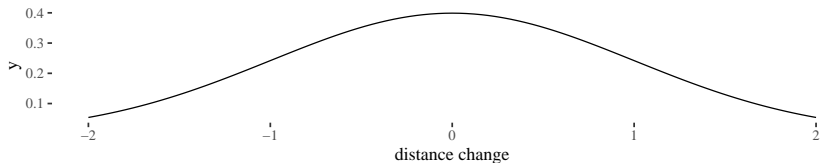
Prior for mean distances



Prior for standard deviation



Prior for coefficients

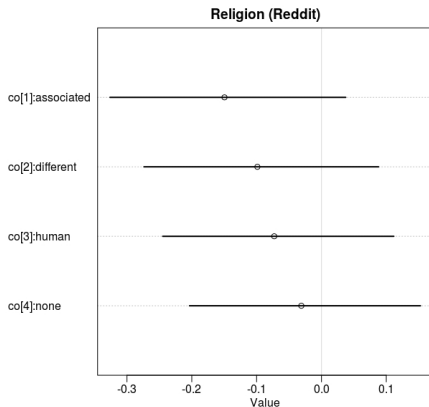


Bayesian model architecture

```
library(rethinking)
options(buildtools.check = function(action) TRUE )
religionCoefs <- ulam(
  alist(
    cosineDistance ~ dnorm(mu,sigma),
    mu <- m + co[con],
    m ~ dnorm(1,.5),
    co[con] ~ dnorm(0,.5),
    sigma ~ dcauchy(0,1)
  ),
  data = religion,
  chains=2 , iter=8000 , warmup=1000,
  log_lik = TRUE
)
```

Dataset-level coefficients

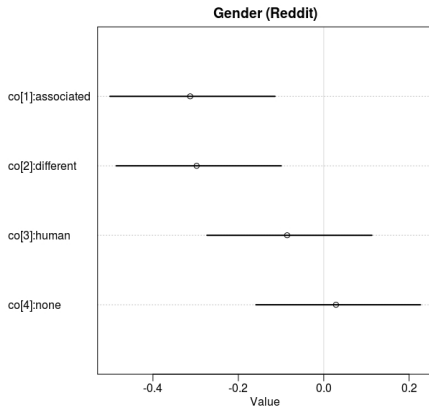
Religion with 89%-compatibility intervals (HPDI)



- All HPDIs overlap with 0
- Differences between classes are relatively small
- Coefficients for Race are similar

Dataset-level coefficients

Gender with 89%-compatibility intervals (HPDI)

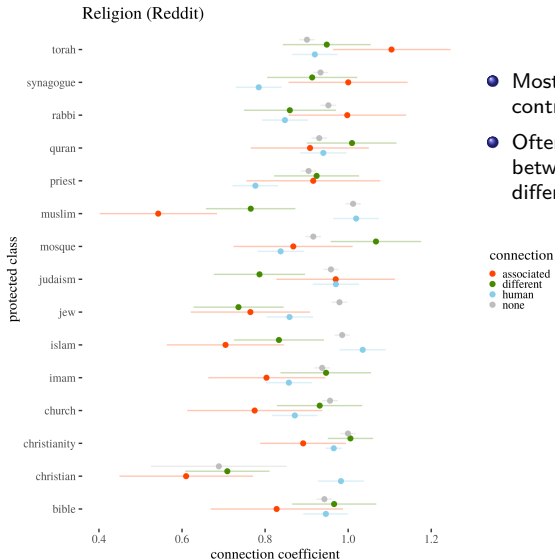


- Associated and different are away from 0
- But they were supposed to be opposites and are very close to each other (co-occurrence?)
- Differences between classes are still relatively small

Bayesian model architecture

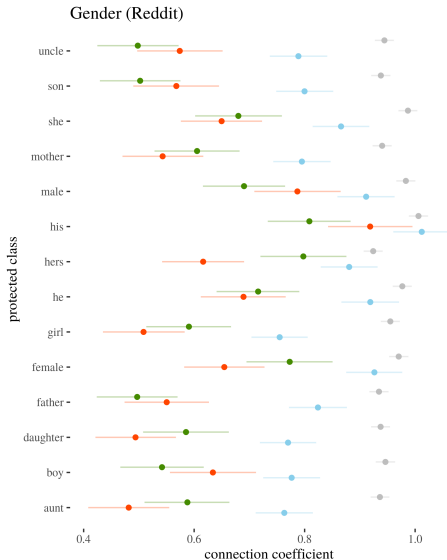
```
library(rethinking)
options(buildtools.check = function(action) TRUE )
religionCoefs <- ulam(
  alist(
    cosineDistance ~ dnorm(mu,sigma),
    mu <- m[pw] + co[con],
    m[pw] ~ dnorm(1,.5),
    co[con] ~ dnorm(0,.5),
    sigma ~ dcauchy(0,1)
  ),
  data = religion,
  chains=2 , iter=8000 , warmup=1000,
  log_lik = TRUE
)
```


Word-level coefficients



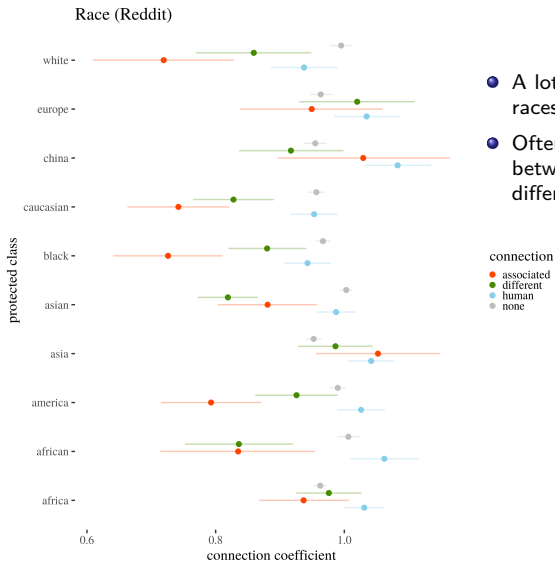
- Most intervals overlap with control groups
- Often not too much difference between associated and different

Word-level coefficients



- Male attributes: strong co-occurrence with female attributes
- Sometimes different is closer than associated
- Almost no overlap with control groups

Word-level coefficients



- A lot of variation between races
- Often not much difference between associated and different

Thank you!

Summary

- Bias in word embeddings
- WEAT and MAC methods
- Methodological problems
- Limitations of pre-averaging in bias detection methods
- Accounting for uncertainty with Bayesian approach

Further work

- Including contrasts in Bayesian calculation
- Performance cross-validation in comparison to other methods (regular linear regression, KNN, ...)
- Downstream tasks and connection with intrinsic evaluation
- Testing data from the original Implicit Association Test (IAT)
- Applying uncertainty to WEAT and better word lists
- Looking at other similarity measures

References

- Caliskan, A., Bryson, J. J., & Narayanan, A. (2017). Semantics derived automatically from language corpora contain human-like biases. *Science*, 356(6334), 183–186. <https://doi.org/10.1126/science.aal4230>
- Garg, N., Schiebinger, L., Jurafsky, D., & Zou, J. (2018). Word embeddings quantify 100 years of gender and ethnic stereotypes. *Proceedings of the National Academy of Sciences*, 115(16), E3635–E3644. <https://doi.org/10.1073/pnas.1720347115>
- Gonen, H., & Goldberg, Y. (2019). Lipstick on a pig: Debiasing methods cover up systematic gender biases in word embeddings but do not remove them. *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, 609–614. Minneapolis, Minnesota: Association for Computational Linguistics. <https://doi.org/10.18653/v1/N19-1061>
- Lauscher, A., & Glavas, G. (2019). Are we consistently biased? Multidimensional analysis of biases in distributional word vectors. *CoRR*, abs/1904.11783. Retrieved from <http://arxiv.org/abs/1904.11783>
- Manzini, T., Lim, Y. C., Tsvetkov, Y., & Black, A. W. (2019). *Black is to criminal as caucasian is to police: Detecting and removing multiclass bias in word embeddings*. Retrieved from <http://arxiv.org/abs/1904.04047>
- Nissim, M., Noord, R. van, & Goot, R. van der. (2020). Fair is better than sensational: Man is to doctor as woman is to doctor. *Computational Linguistics*, 46(2), 487–497. https://doi.org/10.1162/coli_a_00379
- Zhang, H., Sneyd, A., & Stevenson, M. (2020). *Robustness and reliability of gender bias assessment in word embeddings: The role of base pairs*. Retrieved from <http://arxiv.org/abs/2010.02847>