



# Measuring and Addressing Indexical Bias in Information Retrieval

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@WilliamBarrHeld

Jane Dwivedi-Yu



@JaneDwivedi

Diyi Yang



@Diyi\_Yang

Motivation

Gooooooooooooole >

1 2 3 4 5 6 7 8 9 10

Next

Motivation

Google >  
1 2 3 4 5 6 7 8 9 10 Next

average search

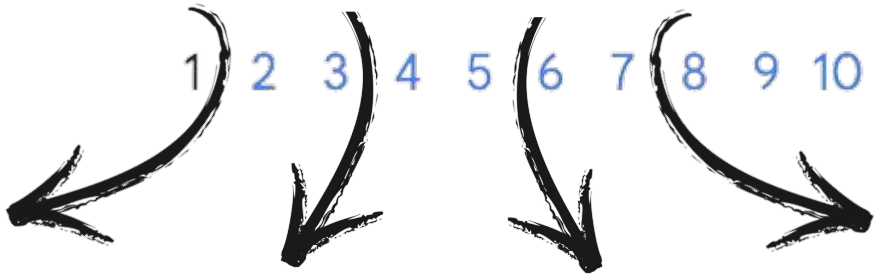


Motivation



1 2 3 4 5 6 7 8 9 10 Next

average search



not a chance

maybe you'll get lucky

losing hope

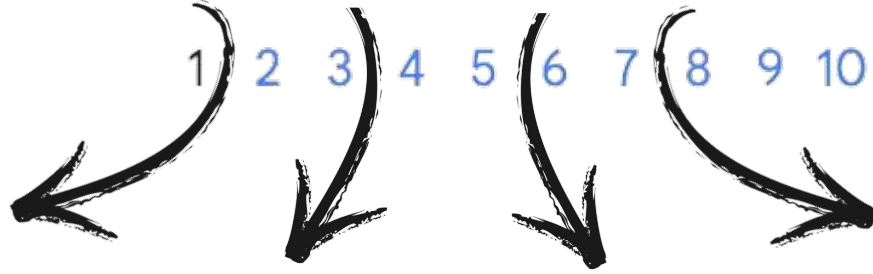
Q **Capitalism** vs. **Socialism**.

Motivation



1 2 3 4 5 6 7 8 9 10 Next

average search



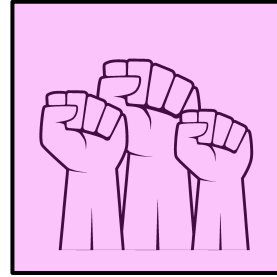
not a chance

maybe you'll get lucky

losing hope

Q **Capitalism** vs. **Socialism**.

Motivation



# Q Capitalism vs. Socialism.

Motivation

1.



2.



3.



4.



5.



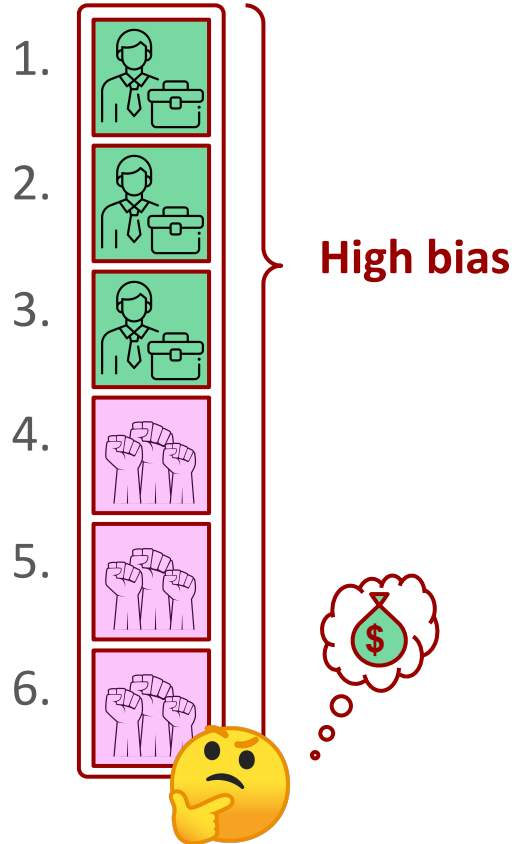
6.



High bias

# Q Capitalism vs. Socialism.

## Motivation





Q **Capitalism** vs. **Socialism**.

Motivation

1.



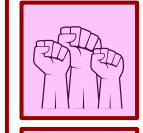
2.



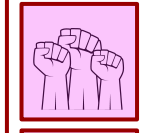
3.



4.



5.



6.



**SEME**

The Search  
Engine

Manipulation  
Effect

# Q Capitalism vs. Socialism.

Motivation

1.



2.



3.



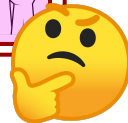
4.



5.



6.



**SEME**  
metric:  
**DUO**

*Discounted Uniformity of Opinions*

$$DU_0 = 1 - \frac{1}{Z} \sum \frac{\sigma_{1:i}^2}{\lg(i)}$$

# Q Capitalism vs. Socialism.

$\sigma_{1:2}^2$  zero variance

1.



2.



3.



4.



5.



6.



**SEME**  
metric:  
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*Discounted Uniformity of Opinions*

$$DU_0 = 1 - \frac{1}{Z} \sum \frac{\sigma_{1:i}^2}{\lg(i)}$$

# Q Capitalism vs. Socialism.

$\sigma_{1:2}^2$

$\sigma_{1:3}^2$  zero variance

1.



2.



3.



4.



5.



6.

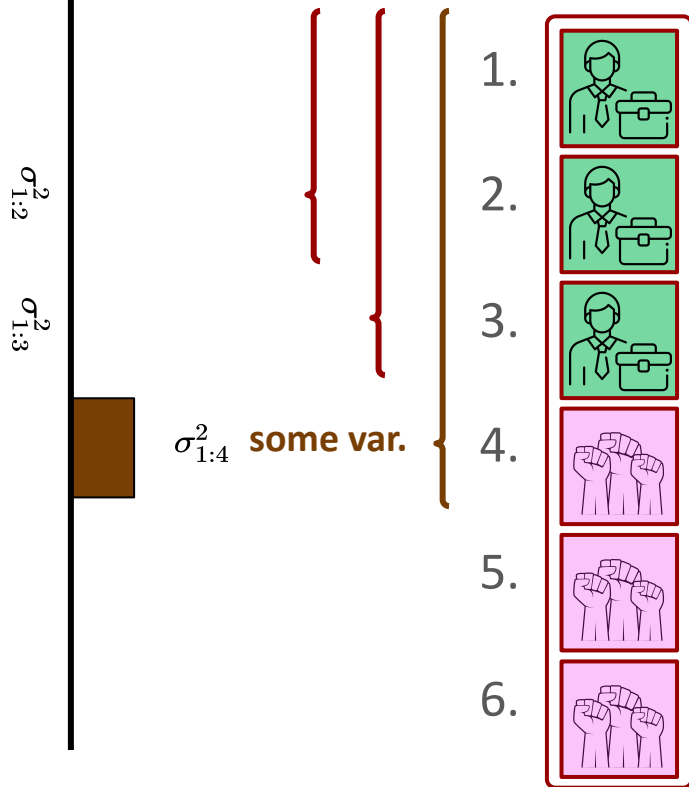


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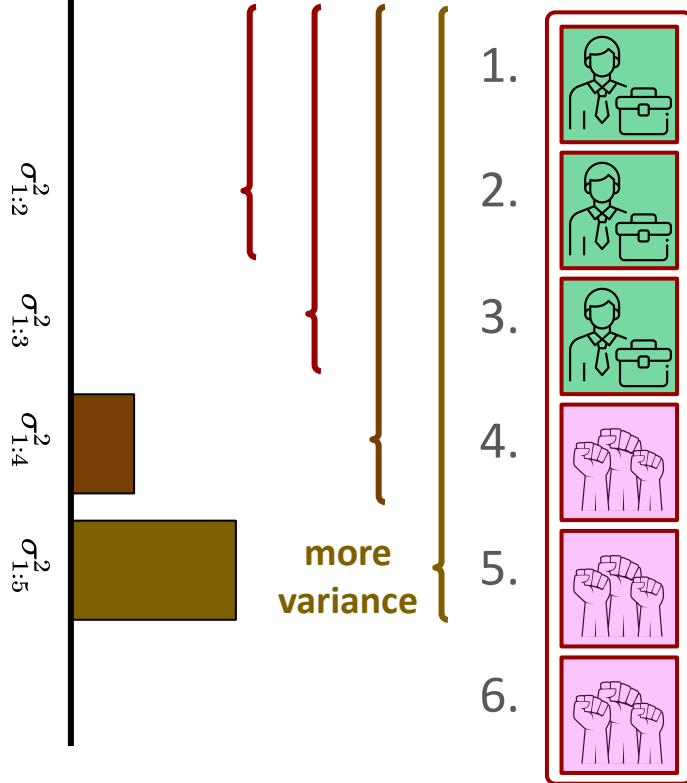


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metric:  
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# Q Capitalism vs. Socialism.

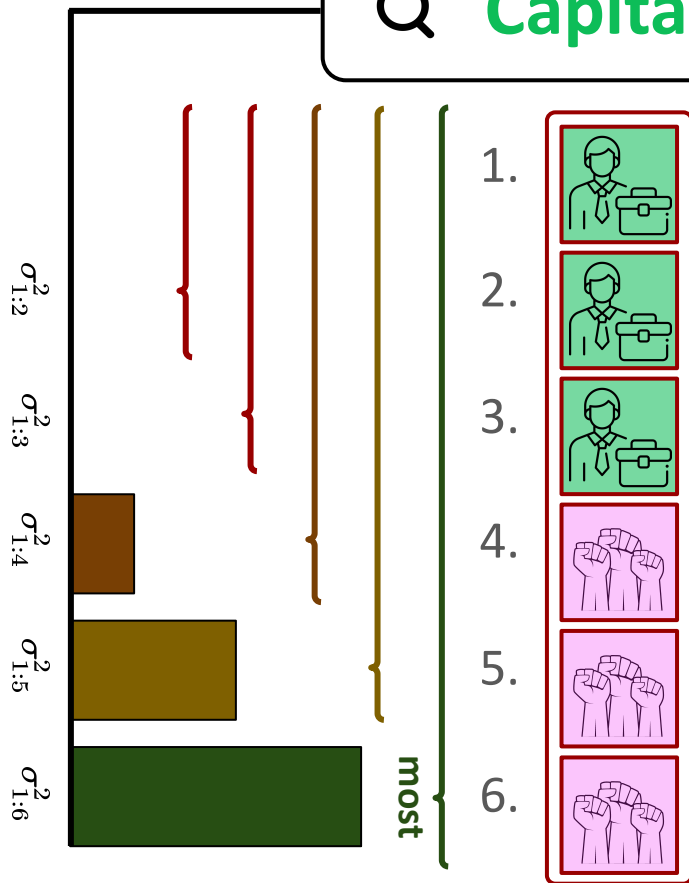


**SEME**  
metric:  
**DUO**

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# Q Capitalism vs. Socialism.

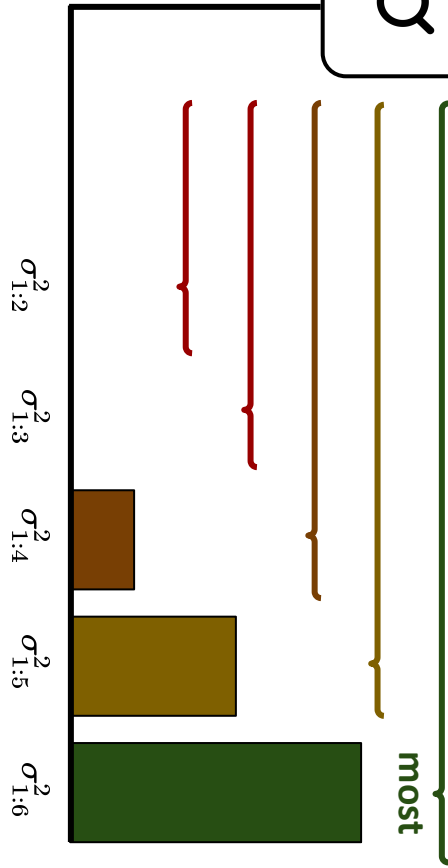


**SEME**  
metric:  
**DUO**

*Discounted Uniformity of Opinions*

$$DUO = 1 - \frac{1}{Z} \sum \frac{\sigma^2_{1:i}}{\lg(i)}$$

# Q Capitalism vs. Socialism.



- 1.
  - 2.
  - 3.
  - 4.
  - 5.
  - 6.
- 

High bias  
DUO = 1

**SEME**  
metric:  
**DUO**

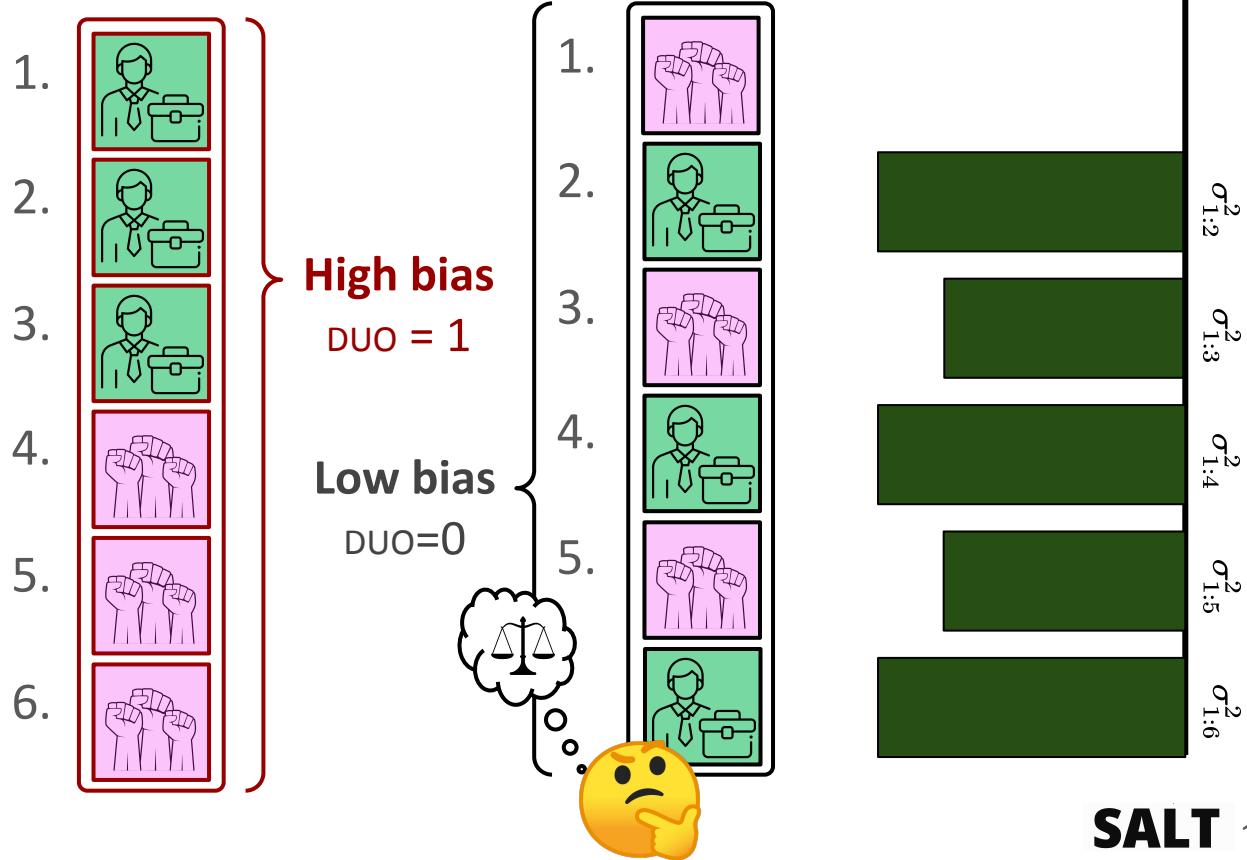
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# Q Capitalism vs. Socialism.



# Contributions

- 1) The DUO Positional Bias **Metric**

# Contributions

- 1) The DUO Positional Bias **Metric**
- 2) Wiki-Balance Bias **Corpora**

# Contributions

- 1) The DUO Positional Bias **Metric**
- 2) Wiki-Balance Bias **Corpora**
- 3) SEME **Human Behavioral Study**

# Contributions

- 1) The DUO Positional Bias **Metric**
- 2) Wiki-Balance Bias **Corpora**
- 3) SEME **Human Behavioral Study**
- 4) Bias **Audit** Evaluations

# Contributions

- 1) The DUO Positional Bias **Metric**
- 2) Wiki-Balance Bias **Corpora**
- 3) SEME **Human Behavioral Study**
- 4) Bias **Audit** Evaluations



**PAIR**

perspective-aligned  
information  
retrieval

A large, abstract watercolor splash in shades of purple, pink, and yellow, centered on a white background. The splash has a soft, painterly texture with various tones and some darker spots.

**DUO**

# Positional Bias Metric

## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i} \quad \leftarrow \text{discount lower ranks}$$

$i$  document index



## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i} \quad \leftarrow \text{discount lower ranks}$$

$i$  document index

$u$  utility function

## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i} \quad \leftarrow \text{discount lower ranks}$$

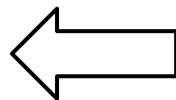
$i$  document index

$u$  utility function

$r$  rank ordering

## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i}$$



**utility**  
based on  
idea-balance

$$u_V(i, r) = \frac{1}{i} \sum_{j=1}^i (p_j - \bar{p})^2$$

## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i}$$

$p_j$  polarization score  
 $\bar{p}$  (avg)

$$u_V(i, r) = \frac{1}{i} \sum_{j=1}^i (p_j - \bar{p})^2$$

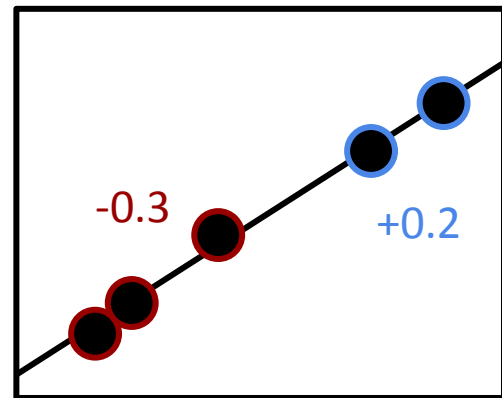
**idea-balance**

is the variance in  
document polarization

## DUO *Positional Bias Metric*

$$\text{DCG}(r, u) = \sum_{i=1}^{|r|} \frac{u(i, r)}{\log_2 i}$$

$$u_V(i, r) = \frac{1}{i} \sum_{j=1}^i (p_j - \bar{p})^2 \leftarrow$$



polarization scores  
come *automatically*  
from PCA on **polarized**  
doc embeddings **SALT** 29

A large, abstract watercolor splash in shades of orange, pink, and purple serves as a background for the title text.

# Wiki-Balance Corpus of Polarized Documents

A large, abstract watercolor splash in shades of orange, pink, and purple, centered on a white background. The splash has a soft, painterly texture with various tones and some darker spots.

# Wiki-Balance

## SYNTHETIC

# Wiki-Balance *Synthetic Corpus*



topics

Politics

History

Environment

Culture

Language

People



# Wiki-Balance Synthetic Corpus



topics

**Politics**

China

gun control

**243 topics**

**History**

**Environment**

**Culture**

**Language**

**People**

# Wiki-Balance Synthetic Corpus



topics

Politics

China

gun control



History

Cuban Missile Crisis



122 topics

Environment

Culture

Language

People

# Wiki-Balance Synthetic Corpus



topics

Politics

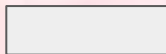
China

gun control



History

Cuban Missile Crisis



Environment

recycling

■ 26 topics

Culture

Language

People

# Wiki-Balance Synthetic Corpus

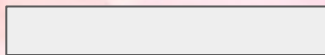


topics

## Politics

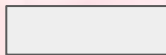
China

gun control



## History

Cuban Missile Crisis



## Environment

recycling



## Culture

Nike Air Max



110 topics

## Language

## People

# Wiki-Balance Synthetic Corpus



topics

## Politics

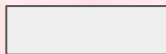
China

gun control



## History

Cuban Missile Crisis



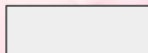
## Environment

recycling



## Culture

Nike Air Max



## Language

Sapir-Whorf



## People

# Wiki-Balance Synthetic Corpus



topics

Politics — China

gun control



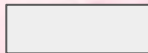
History — Cuban Missile Crisis



Environment — recycling



Culture — Nike Air Max

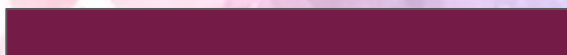


Language — Sapir-Whorf



People — Taylor Swift

Freud



427 topics

# Wiki-Balance *Synthetic Corpus*



topics

## Politics

China

gun control

## History

Cuban Missile Crisis

## Environment

recycling

## Culture

Nike Air Max

## Language

Sapir-Whorf

## People

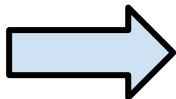
Taylor Swift

Freud

# Wiki-Balance *Synthetic Corpus*



topics



Give me 10 debate  
questions about  $\${topic}$

## Politics

China

gun control

background checks enough?

## History

Cuban Missile Crisis

US response appropriate?

## Environment

recycling

Effective at reducing waste?

## Culture

Nike Air Max

Are they a symbol of status and wealth?

## Language

Sapir-Whorf

Can it be tested empirically?

## People

Taylor Swift

Has her image been consistent?

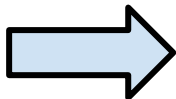
Freud



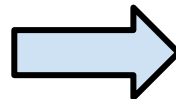
# Wiki-Balance *Synthetic Corpus*



topics



Give me 10 debate questions about  $\${topic}$



$\${question}$  For each side of the issue, write an article from the perspective of that side."

## Politics

China

gun control

background checks enough?

## History

Cuban Missile Crisis

US response appropriate?

## Environment

recycling

Effective at reducing waste?

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Nike Air Max

Are they a symbol of status and wealth?

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Can it be tested empirically?

## People

Taylor Swift

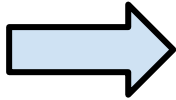
Has her image been consistent?

Freud

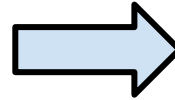
# Wiki-Balance *Synthetic Corpus*



topics



Give me 10 debate questions about  $\{topic\}$



$\{question\}$  For each side of the issue, write an article from the perspective of that side."

**Pos. 1**

Recycling is a proven, **effective method for reducing waste** and conserving natural resources. By recycling materials, we are significantly reducing the amount of waste sent to landfills,

Environment

recycling

*Effective at reducing waste?*

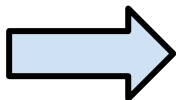
**Pos. 2**

*it is **not a sustainable** way to reduce waste and conserve natural resources. Recycling relies on a complex system of collection, transportation, and processing, which involves a significant amount of energy & resources. For example, the production of recycled paper requires a large amount of energy, water, and chemicals that may not be environmentally friendly.*

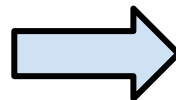
# Wiki-Balance *Evaluation Corpora*






topics



Give me 10 debate questions about  $\{topic\}$



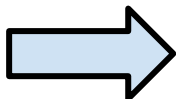
$\{question\}$  For each side of the issue, write an article from the perspective of that side."

Corpus	Mean Relevance	Mean Faithfulness	Mean Coherence	Mean Fluency	Non-Toxic
<i>Synthetic</i> 	<b>4.7</b> / 5.0	<b>4.9</b> / 5.0	<b>4.9</b> / 5.0	<b>4.9</b> / 5.0	 

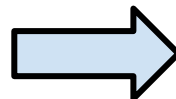
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topics



Give me 10 debate questions about  $\${topic}$



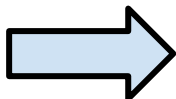
$\${question}$  For each side of the issue, write an article from the perspective of that side.”

Corpus	Domains	Topics	Queries	Docs
<i>Synthetic</i> 	15	1.4k	4k	32k

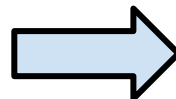
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topics



Give me 10 debate questions about  $\{topic\}$



$\{question\}$  For each side of the issue, write an article from the perspective of that side."

Corpus	Domains	Topics	Queries	Docs
<i>Synthetic</i> 	15	1.4k	4k	32k
<i>Natural</i> 	15	1.4k	450	4.6k

A large, soft watercolor splash in shades of green and blue is positioned in the center-right of the slide, partially overlapping the text.

**SEME**

Human Behavioral  
Study

# SEME *Human Behavioral Study*

## **Goals:**

- 1) show that **DUO measures** salient **indexical bias**
- 2) show that measurable **bias leads to SEME**

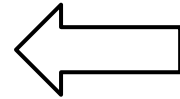
# SEME *Human Behavioral Study*

## Goals:

- 1) show that **DUo-P measures salient indexical bias**
- 2) show that measurable **bias leads to SEME**  
**(more biased rankings should shift opinion more)**



# SEME *Human Behavioral Study*



controversial topic  
in focus

**Q:** Can **anarchism** offer a **viable alternative** to the coercive power of the state, or will it inevitably **descend into violence**?

**Perspective** **viable alternative**



SEARCH

Anarchism - Stanford Encyclopedia  
<https://plato.stanford.edu/entries/anarchism/>

by A Fiala · 2017 · Cited by 39 —  
... on **state power**, viewing centralized, monopolistic **coercive power** ... **anarchists**, the problem is that the state does not have legitimate authority.

Anarchism and Nonviolence: Time for a 'Complementarity ...'  
<https://wagingnonviolence.org>

The negation of **violence** doesn't necessarily mean the negation of domination or **coercion**. ... anarchy would be a democracy based on **non-violence**.

**Summarize your own opinion answer with evidence**

Anarchism is not about chaos, but rather about removing unnecessary hierarchical institutions in a non-violent manner.





# SEME Human Behavioral Study

**Q:** Can **anarchism** offer a **viable alternative** to the coercive power of the state, or will it inevitably **descend into violence**?

---

**Perspective** **viable alternative**

 -3 -2 **-1** 0 1 2 3 



SEARCH

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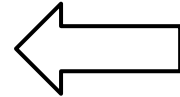
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**Summarize your own opinion answer with evidence**

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 -3 -2 -1 0 1 **2** 3 

user provides  
prior opinion  $O_{\text{prior}}$



# SEME Human Behavioral Study

**Q:** Can **anarchism** offer a **viable alternative** to the coercive power of the state, or will it inevitably **descend into violence**?

---

**Persp:** **viable alternative**



**SEARCH**

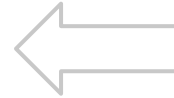
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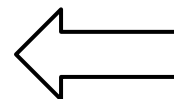
**Summarize your own opinion answer with evidence**

Anarchism is not about chaos, but rather about removing unnecessary hierarchical institutions in a non-violent manner.





$O_{\text{prior}}$



**biased search**

yields either **most** or **least**  
biased ranking according to  
metric  $\mu_{DU_0}^+$

# SEME Human Behavioral Study

**Q:** Can **anarchism** offer a **viable alternative** to the coercive power of the state, or will it inevitably **descend into violence**?

---

**Persp:** **viable alternative**

 -3 -2 -1 0 1 2 3

SEARCH

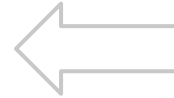
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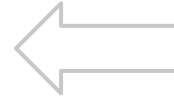
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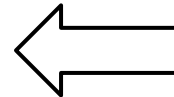
 -3 -2 -1 0 1 2 3



$O_{prior}$



$\mu_{DU_0}^+$



after the user gives  
**close consideration**

# SEME Human Behavioral Study

**Q:** Can **anarchism** offer a **viable alternative** to the coercive power of the state, or will it inevitably **descend into violence**?

---

**Persp:** **viable alternative**

-3 -2 -1 0 1 2 3

SEARCH

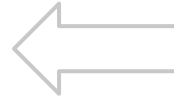
Anarchism - Stanford Encyclopedia  
<https://plato.stanford.edu/entries/anarchism/>  
by A Fiala · 2017 · Cited by 39 —  
... on **state power**, viewing centralized, monopolistic **coercive power** ... **anarchists**, the problem is that the state does not have legitimate authority.

Anarchism and Nonviolence: Time for a 'Complementarity ...'  
<https://wagingnonviolence.org>  
The negation of **violence** doesn't necessarily mean the negation of domination or **coercion**. ... anarchy would be a democracy based on **non-violence**.

**Summarize your own opinion answer with evidence**

Anarchism is not about chaos, but rather about removing unnecessary hierarchical institutions in a non-violent manner.

-3 -2 -1 0 1 2 3

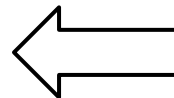


$O_{\text{prior}}$



$\mu_{DU_0}^+$

they offer a  
**posterior  
opinion**



$O_{\text{posterior}}$

# SEME Human Behavioral Study

**Question: *does more bias change opinion more?***

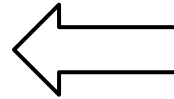
**SEARCH**

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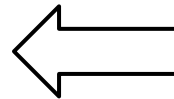
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**Summarize your own opinion answer with evidence**

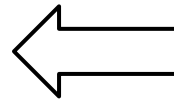
Anarchism is not about chaos, but rather about removing unnecessary hierarchical institutions in a non-violent manner.



$O_{\text{prior}}$



$\mu_{DU_0}^+$



$O_{\text{posterior}}$

# SEME *Human Behavioral Study*

**Question:** *is  $\beta_2$  non-zero (w/ significance)?*

$$O_{\text{posterior}} = \beta_0 + \beta_1 O_{\text{prior}} + \beta_2 \mu_{\text{DU}_0}^+ + \epsilon$$

# SEME Human Behavioral Study

**Question:** *is  $\beta_2$  non-zero (w/ significance)?*

$$O_{\text{posterior}} = \beta_0 + \beta_1 O_{\text{prior}} + \beta_2 \mu_{\text{DU}_0}^+ + \epsilon$$

**Answer:** *yes!*



# SEME Human Behavioral Study

**Question:** *is  $\beta_2$  non-zero (w/ significance)?*

$$O_{\text{posterior}} = \beta_0 + \beta_1 O_{\text{prior}} + \beta_2 \mu_{\text{DU}_0}^+ + \epsilon$$

**Answer:** *yes!* \*

\*  $\beta_2=0.392$ ;  $R^2=0.489$ ;  $p=0.036$

# SEME Human Behavioral Study

**Question: is  $\beta_2$  *non-zero* (w/ significance)?**

$$O_{\text{posterior}} = \beta_0 + \beta_1 O_{\text{prior}} + \beta_2 \mu_{\text{DU}_0}^+ + \epsilon$$

**Answer: *yes!* \*\***

\*  $\beta_2=0.392$ ;  $R^2=0.489$ ;  $p=0.036$

\* *only when the user clicks article links*

# DUO *Validations*

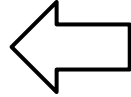
A large, abstract watercolor splash in shades of teal, light blue, yellow, and pink, centered on the page.

PAIR

**Bias Audit**  
Evaluations

# PAIR *Bias Audit Evaluations*

	Natural
Corpus	Relevance
<i>BM-25</i>	0.75



BM-25 is a **strong relevant baseline**

# PAIR *Bias Audit Evaluations*

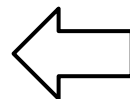
Natural

Corpus	Relevance
<i>BM-25</i>	0.75
<i>SPARTA</i>	0.65
<i>SPLADE</i>	0.75
<i>ANCE</i>	0.71
<i>SBERT</i>	0.75
<i>Use-QA</i>	0.68
<i>CoBERT</i>	0.72

# PAIR Bias Audit Evaluations

Natural

Corpus	Relevance	DUO Bias
<i>BM-25</i>	0.75	0.66
<i>SPARTA</i>	0.65	0.65
<i>SPLADE</i>	0.75	0.67
<i>ANCE</i>	0.71	0.67
<i>SBERT</i>	0.75	0.65
<i>Use-QA</i>	0.68	0.64
<i>ColBERT</i>	0.72	0.65

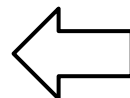


least biased ≠  
most relevant

# PAIR Bias Audit Evaluations

Natural

Corpus	Relevance	DUO Bias
BM-25	0.75	0.66
SPARTA	0.65	0.65
SPLADE	0.75	0.67
ANCE	0.71	0.67
SBERT	0.75	0.65
Use-QA	0.68	0.64
ColBERT	0.72	0.65



most relevant =  
most biased



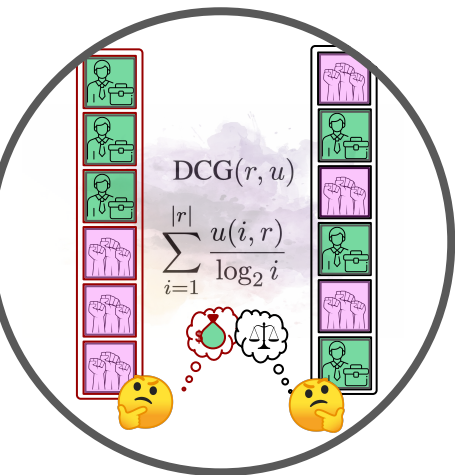
# PAIR *Bias Audit Evaluations*

Corpus	Relevance	DUO Bias
--------	-----------	----------

<i>SPLADE</i>	0.75	0.67
---------------	------	------

Domain	DUO Bias
Entertainment	0.68
Environment	0.67
Languages	0.71
Media & Culture	0.67
Psychiatry	0.62
Sex & Gender	0.59

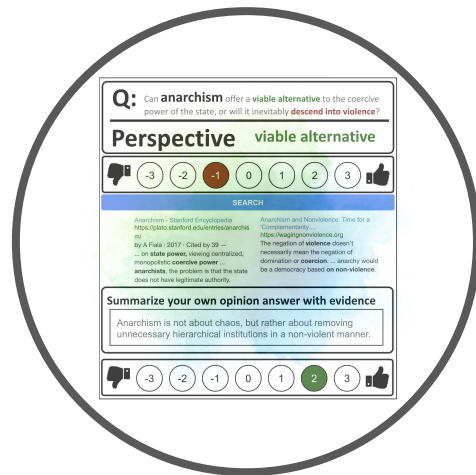
# PAIR Summary



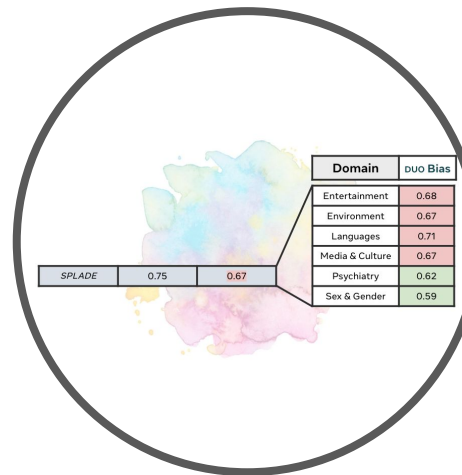
DUO  
Metric



Wiki-Balance  
Corpus



Experimental  
Outcomes



Bias  
Audit



# Measuring and Addressing Indexical Bias in Information Retrieval

Caleb Ziems



@cjziems

William Held



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Jane Dwivedi-Yu



@JaneDwivedi

Diyi Yang



@Diyi\_Yang