A robust self-learning method for fully unsupervised cross-lingual mappings of word embeddings

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Introduction

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Monolingual corpus

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Basque

Monolingual corpus

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Basque — Monolingual corpus

English — Monolingual corpus

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no cross-lingual signal

English — Monolingual corpus

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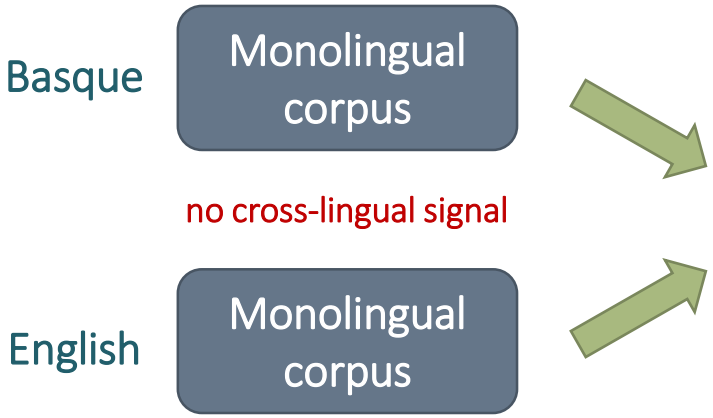

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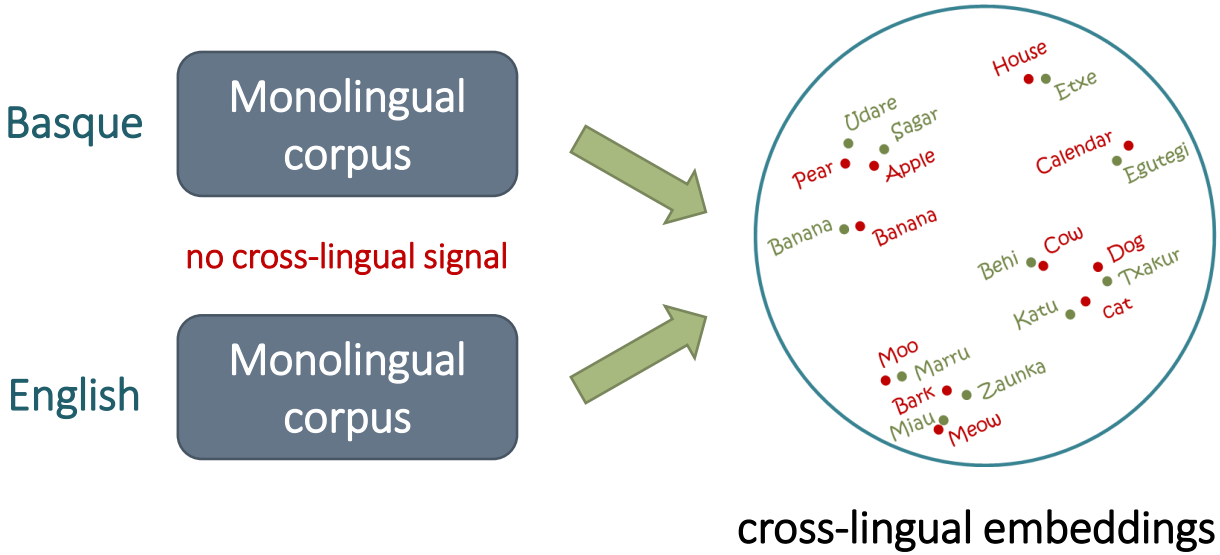

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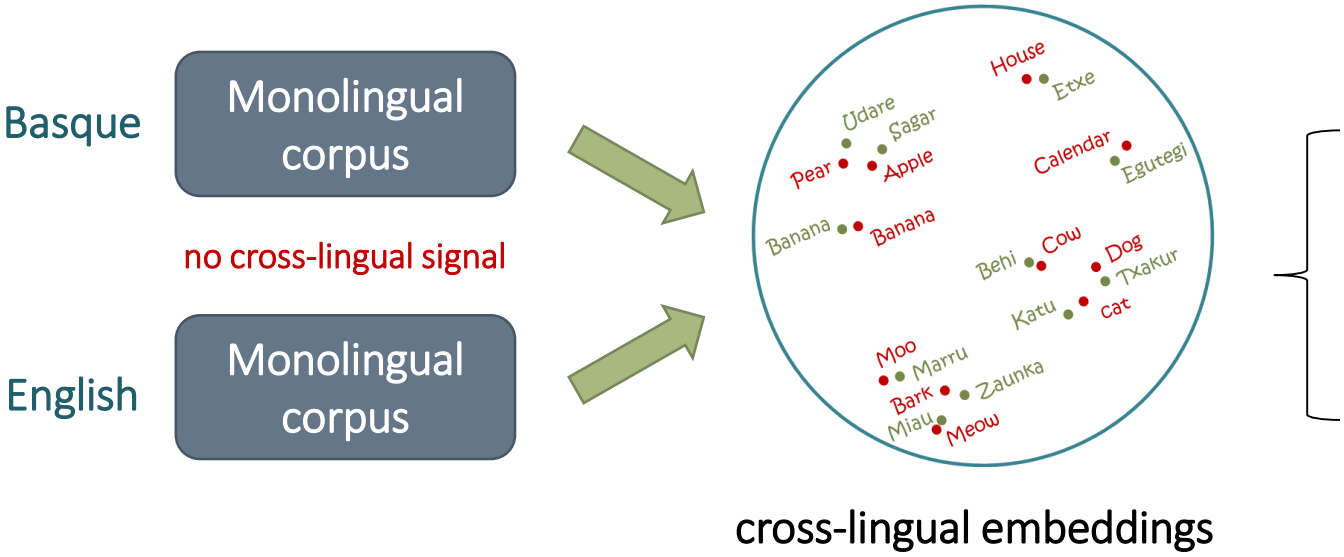

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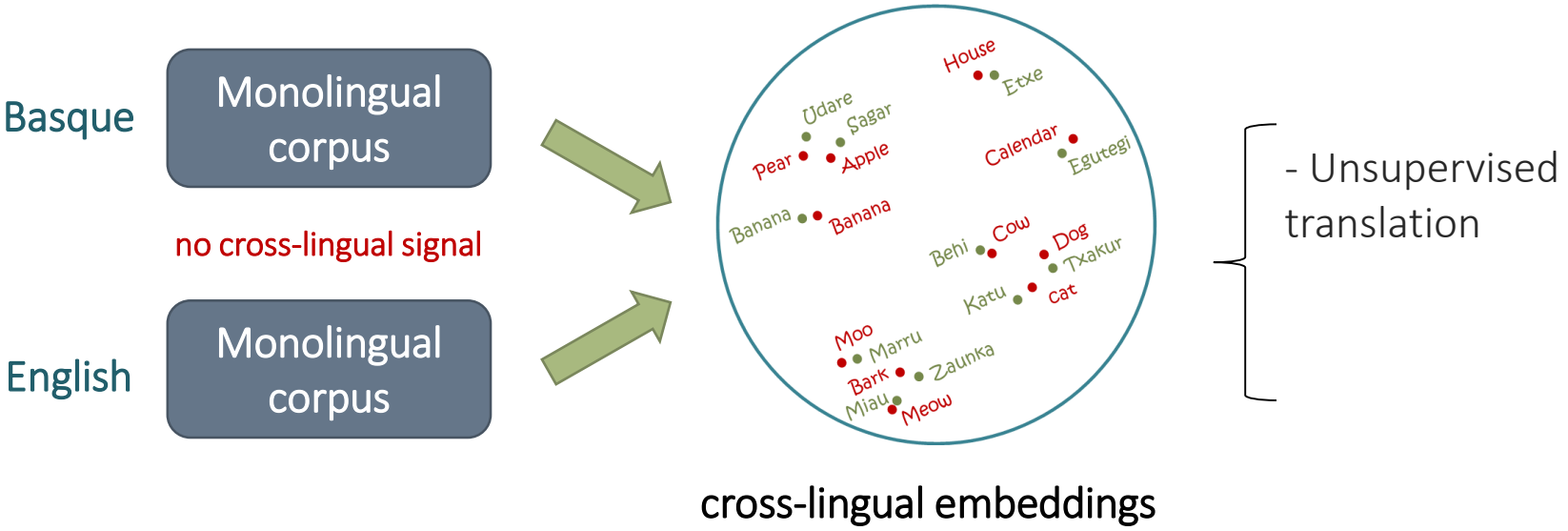

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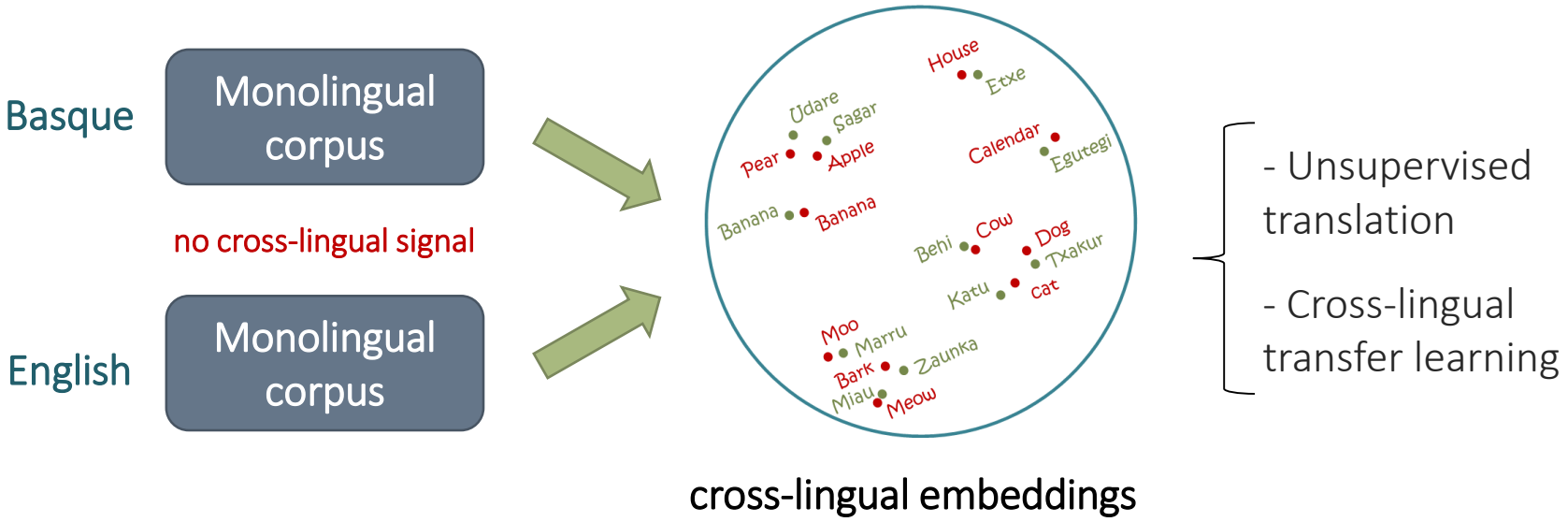

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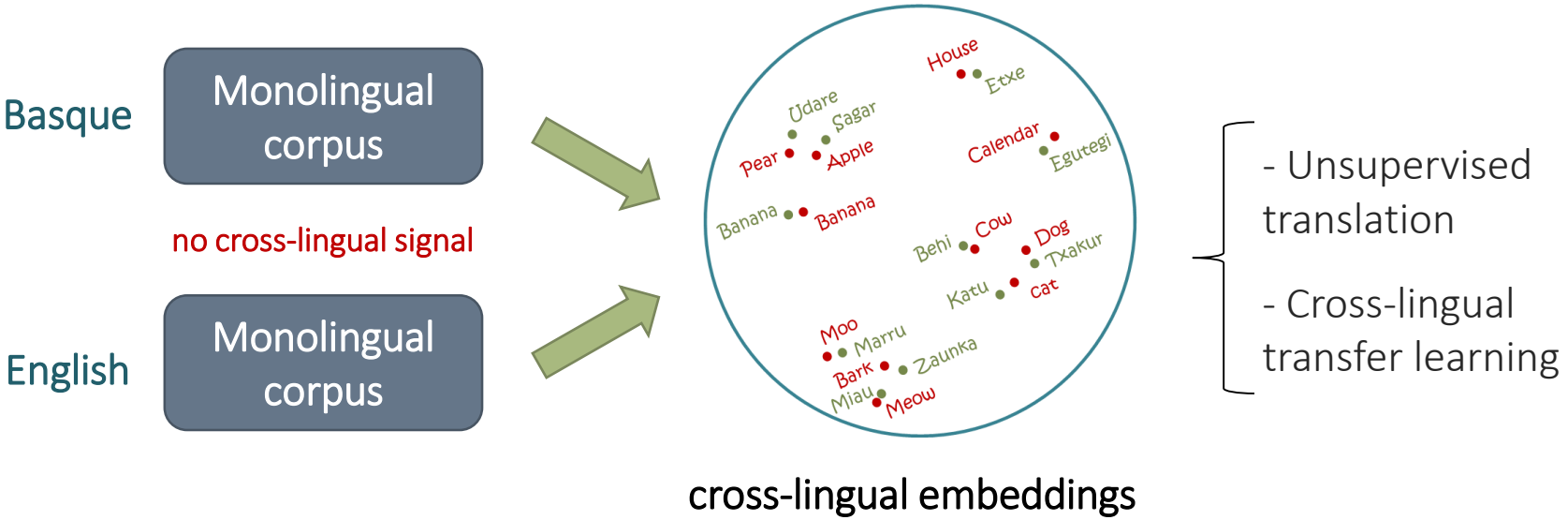

Previous work

(Zhang et al., 2017; Conneau et al., 2018)

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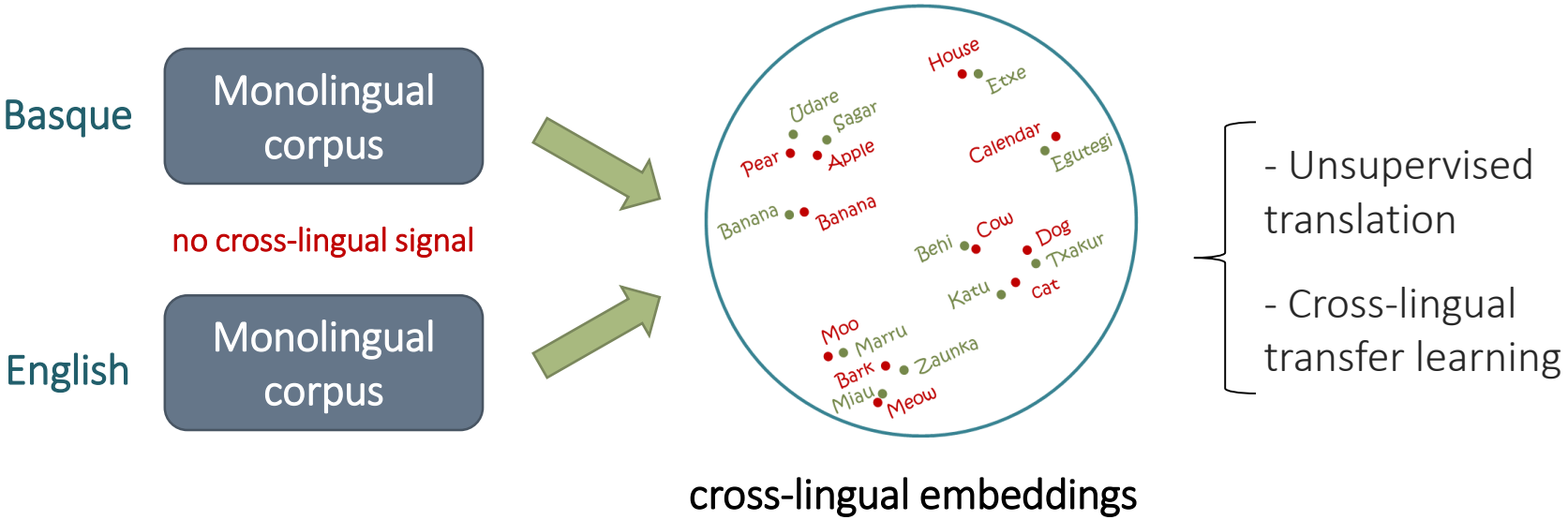

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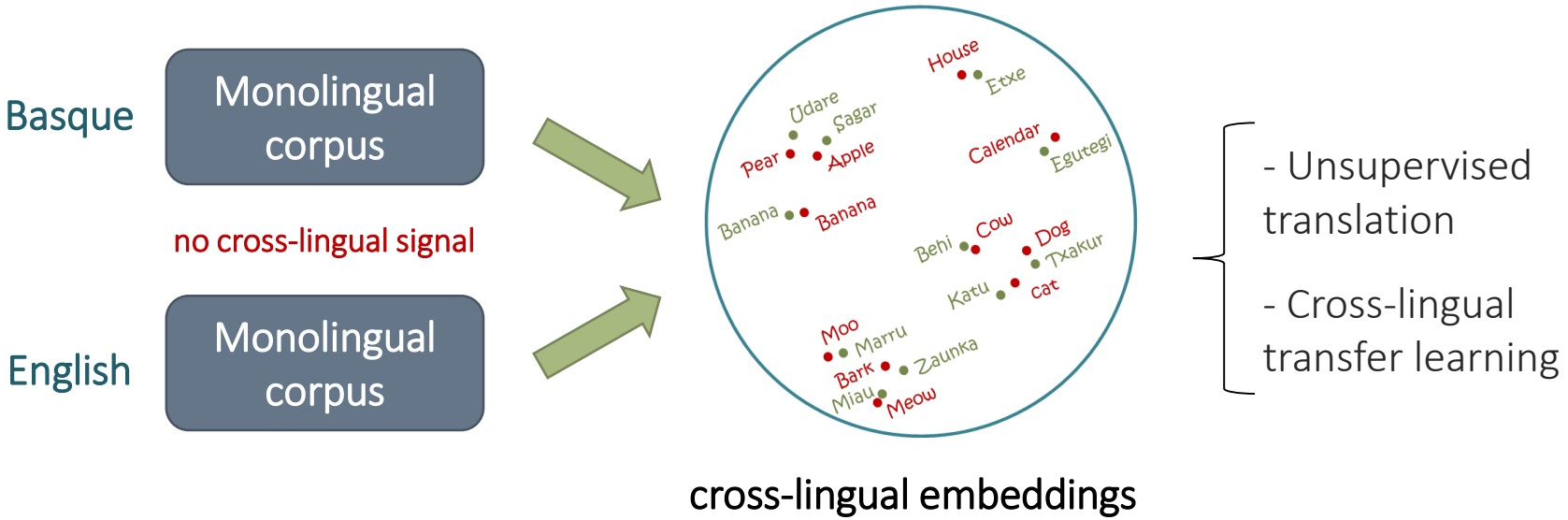

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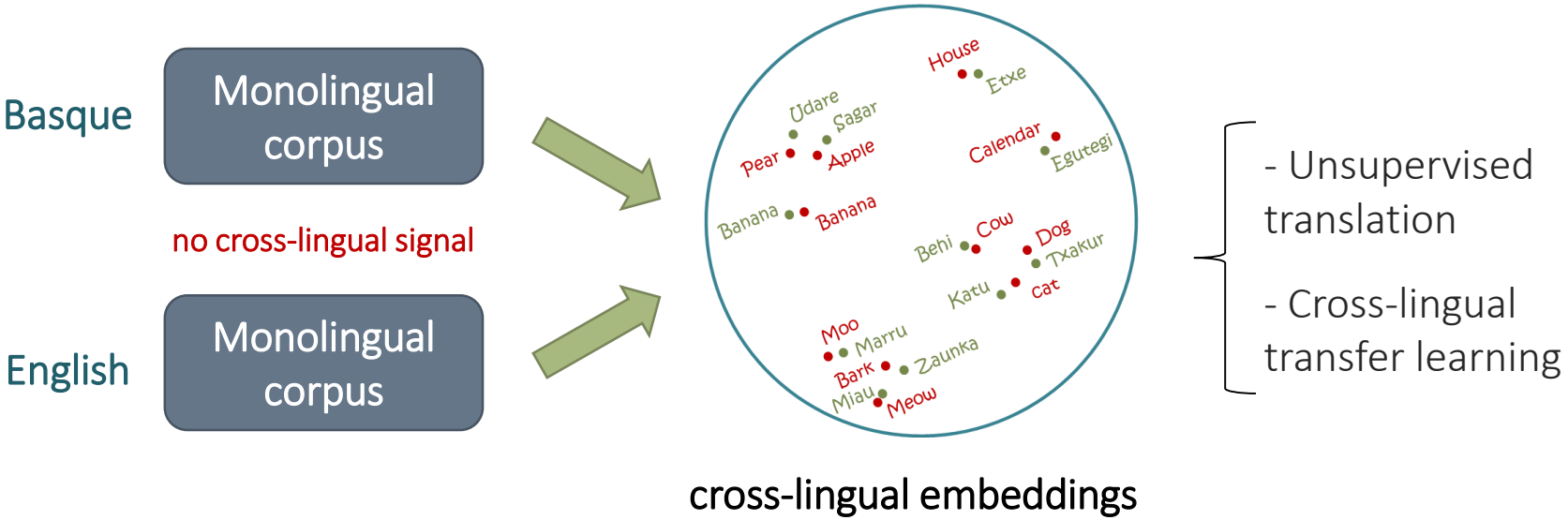

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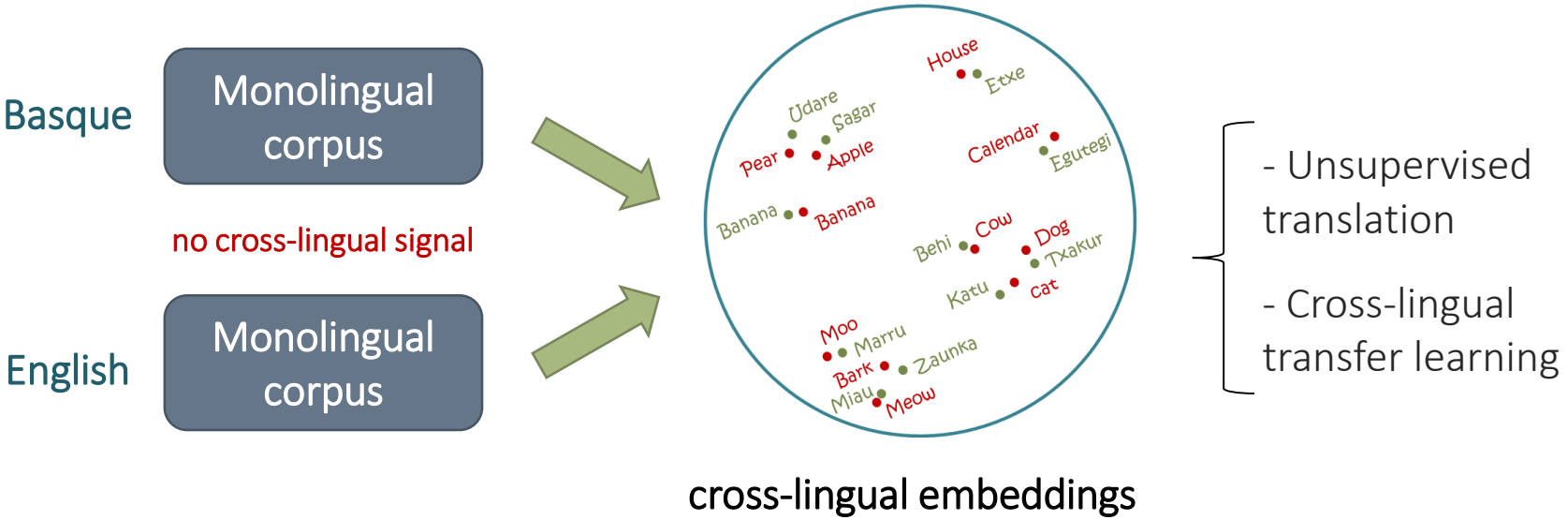

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  - Fail in more challenging datasets

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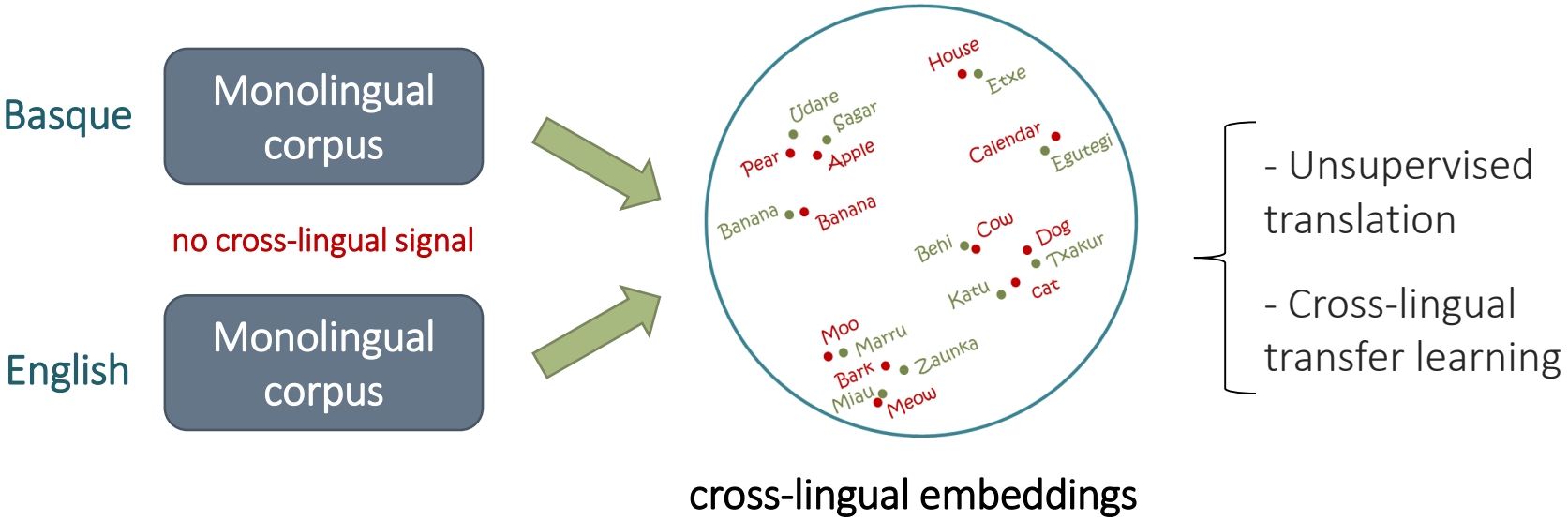

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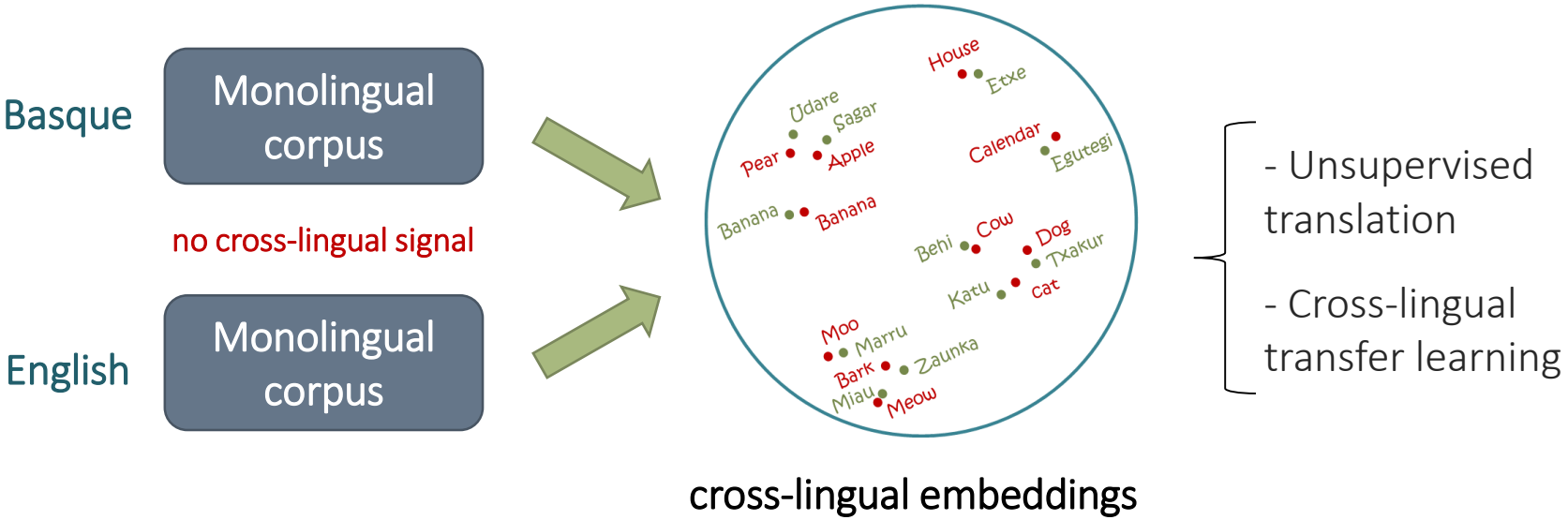

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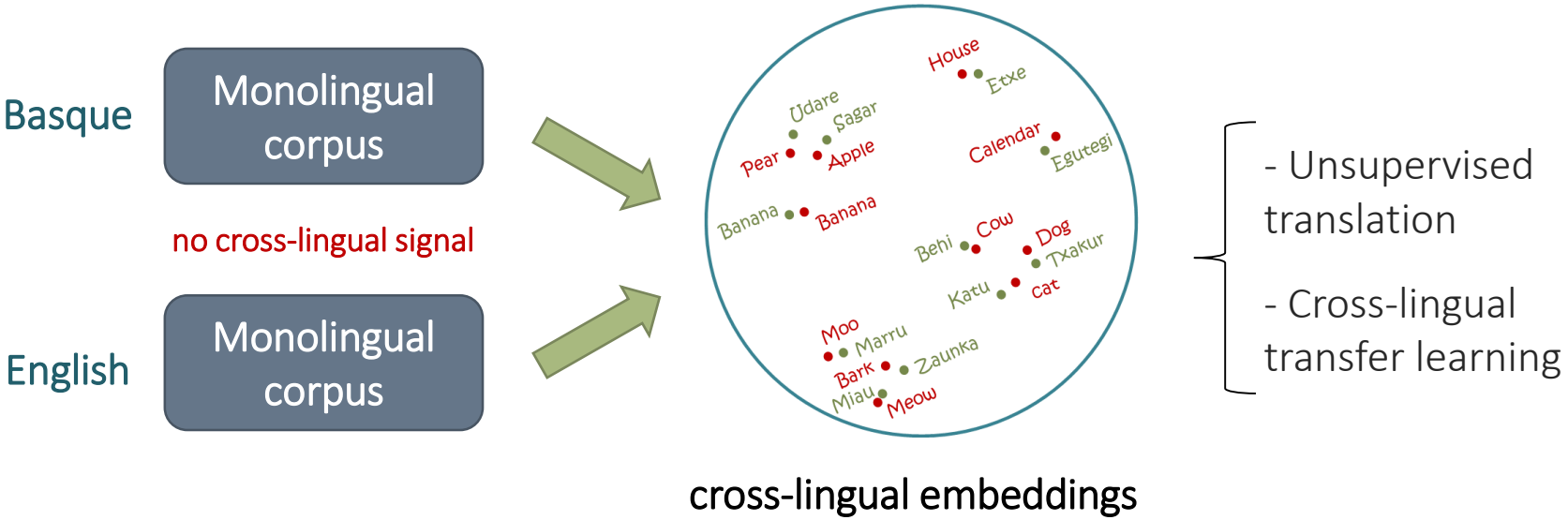

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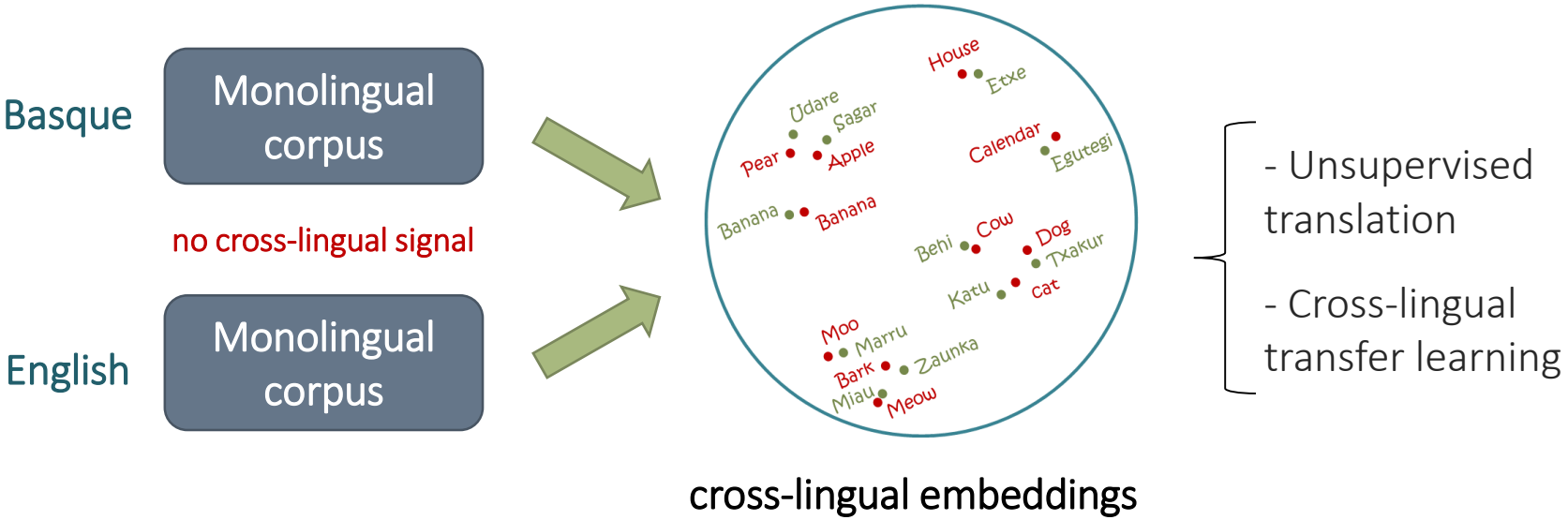

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- Works in challenging datasets

Cross-lingual embedding mappings

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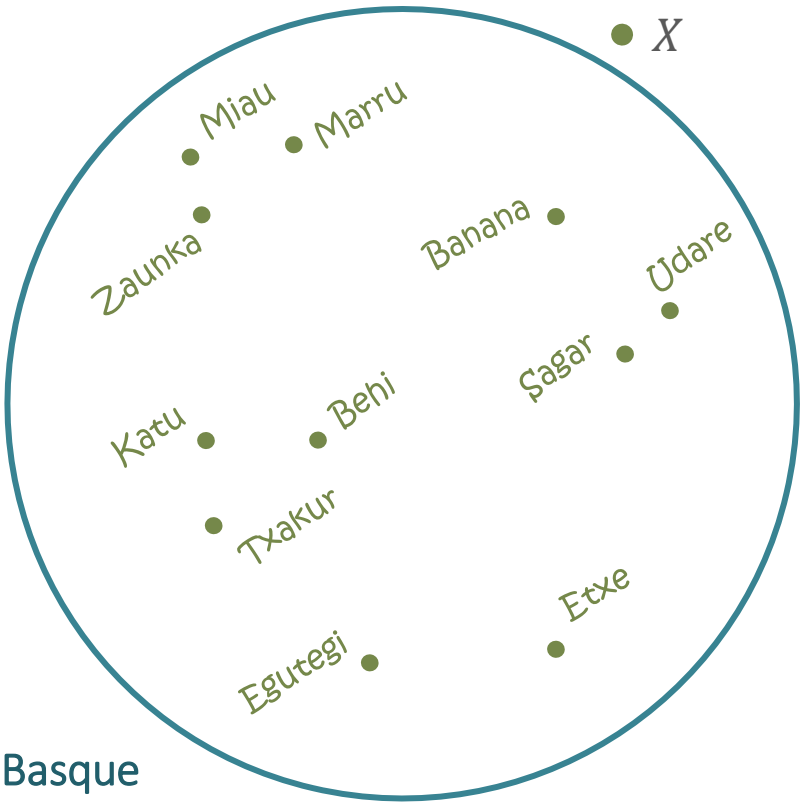

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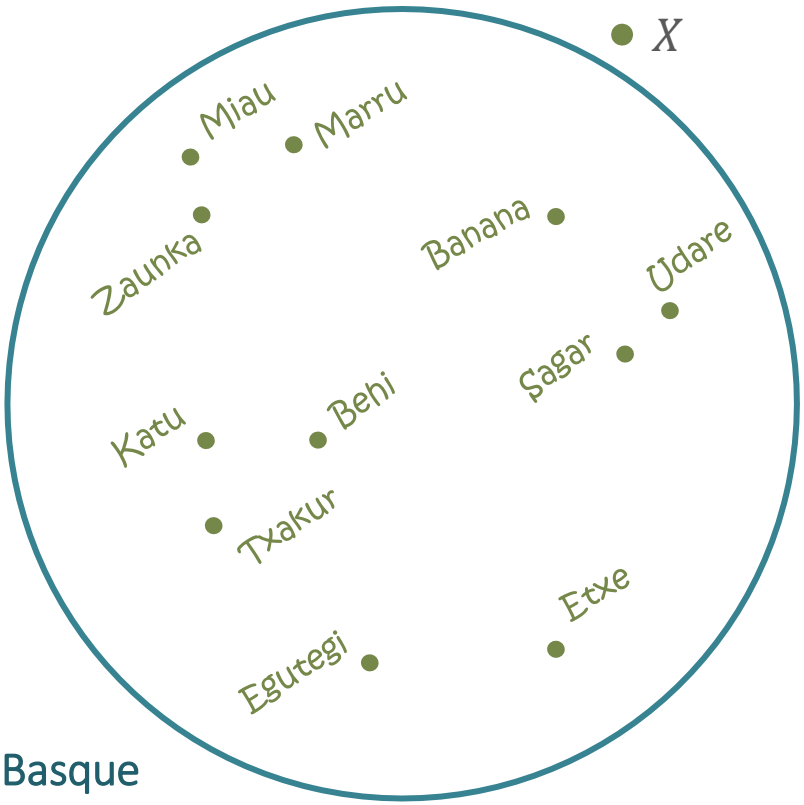

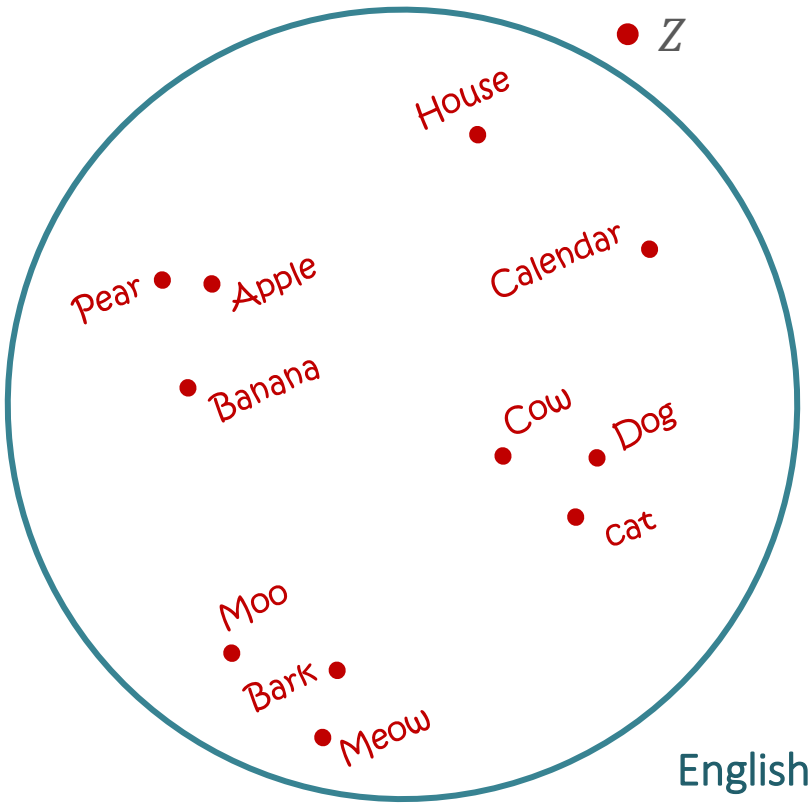

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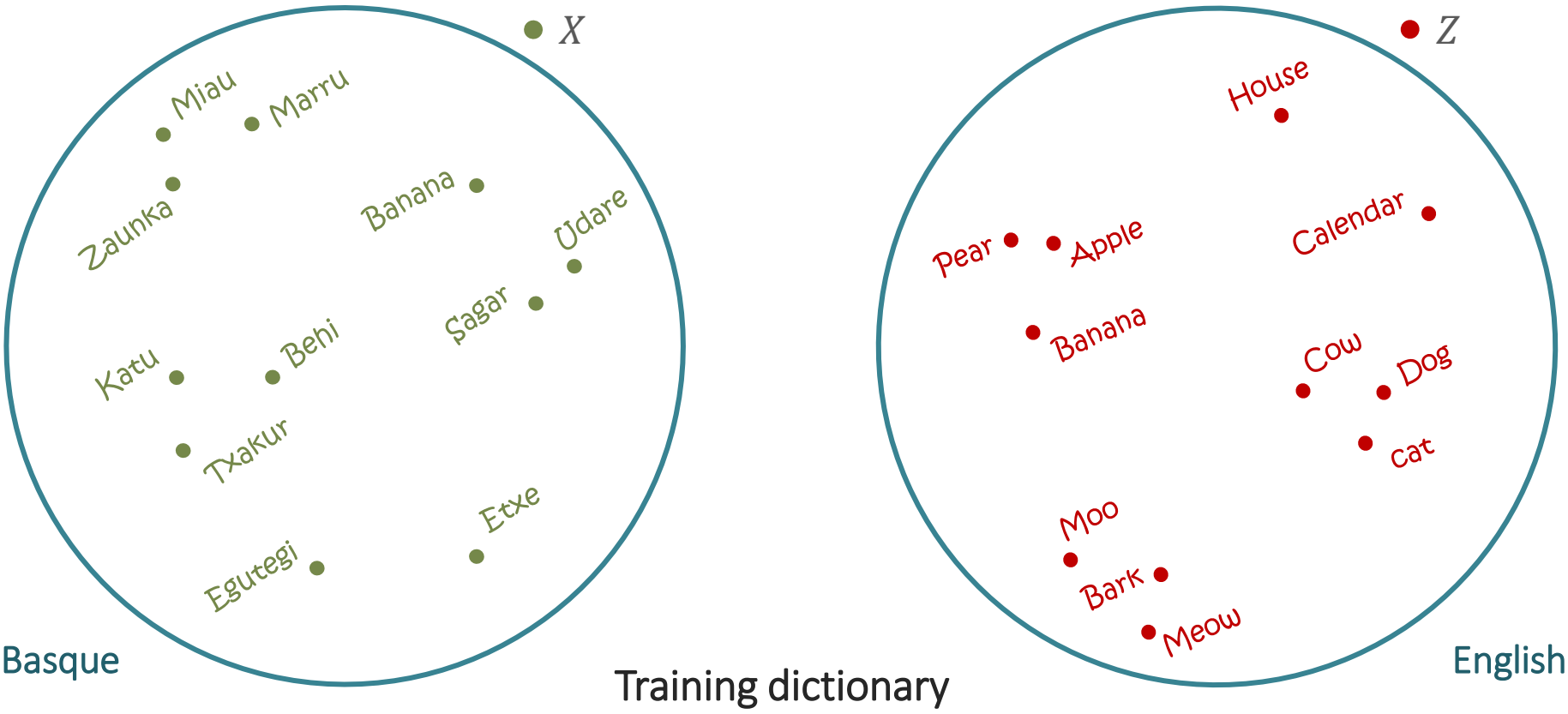
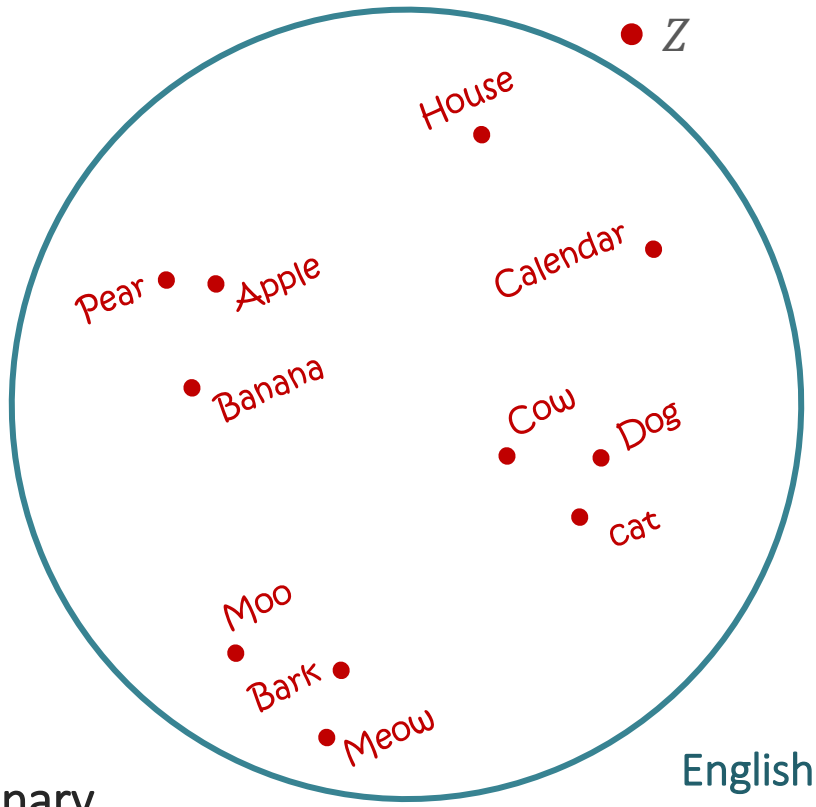


Cross-lingual embedding mappings

Basque

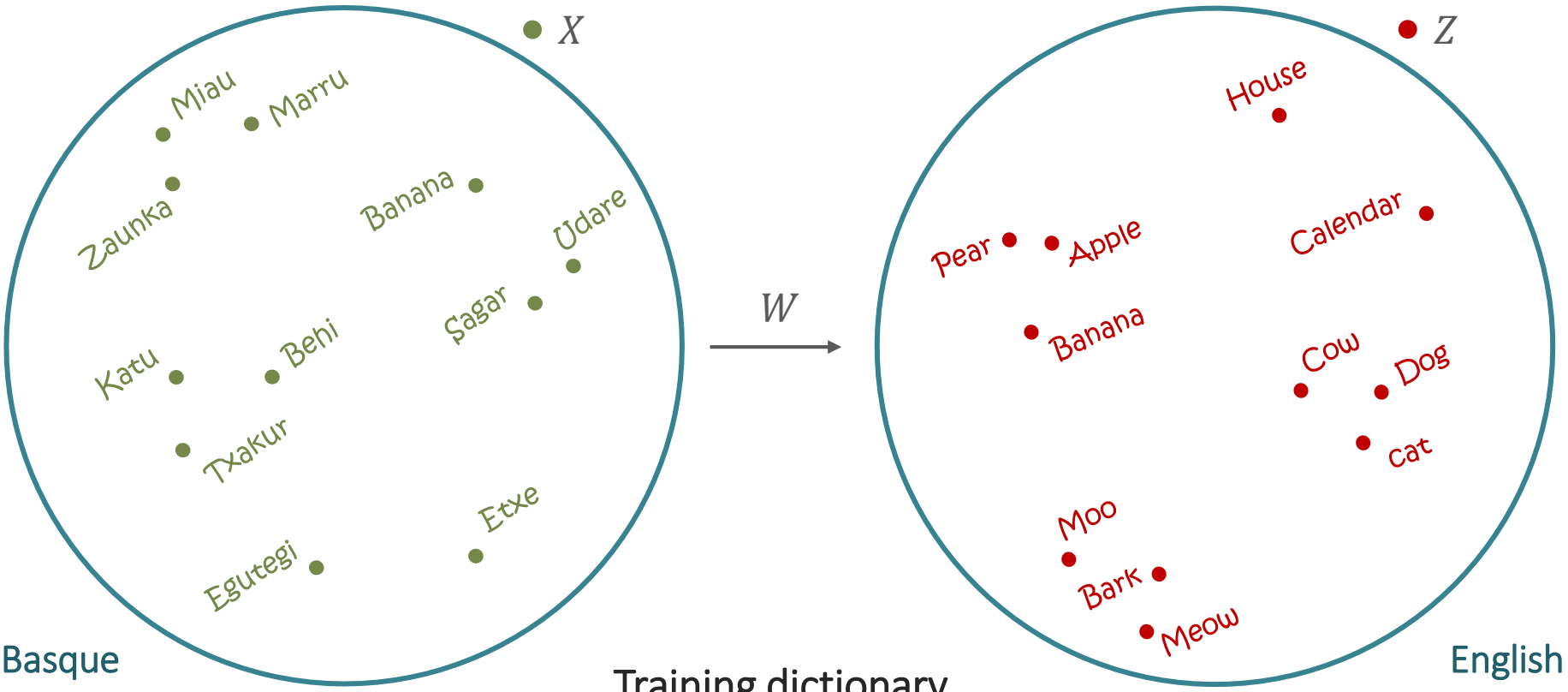


English

Training dictionary

Txakur	Dog
Sagar	Apple
⋮	⋮
Egutegi	Calendar

Cross-lingual embedding mappings



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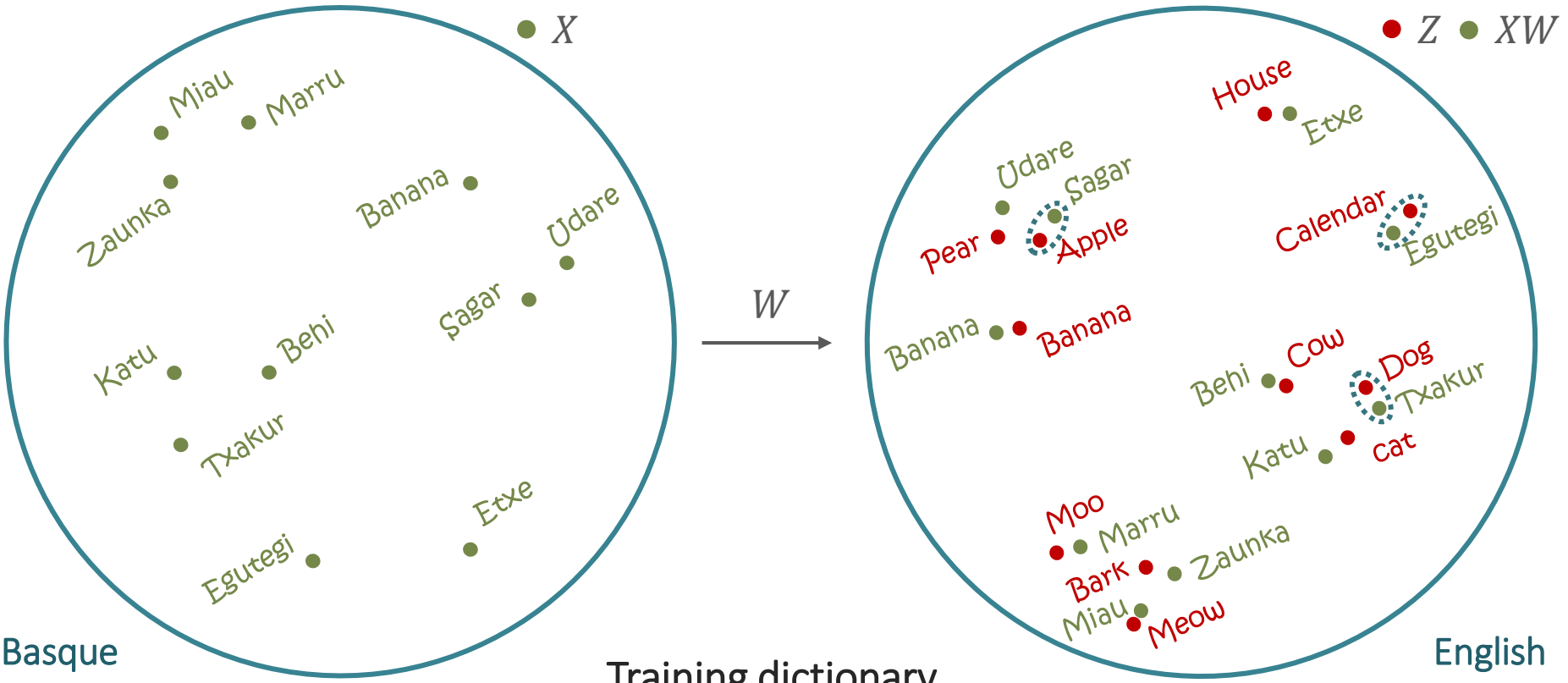

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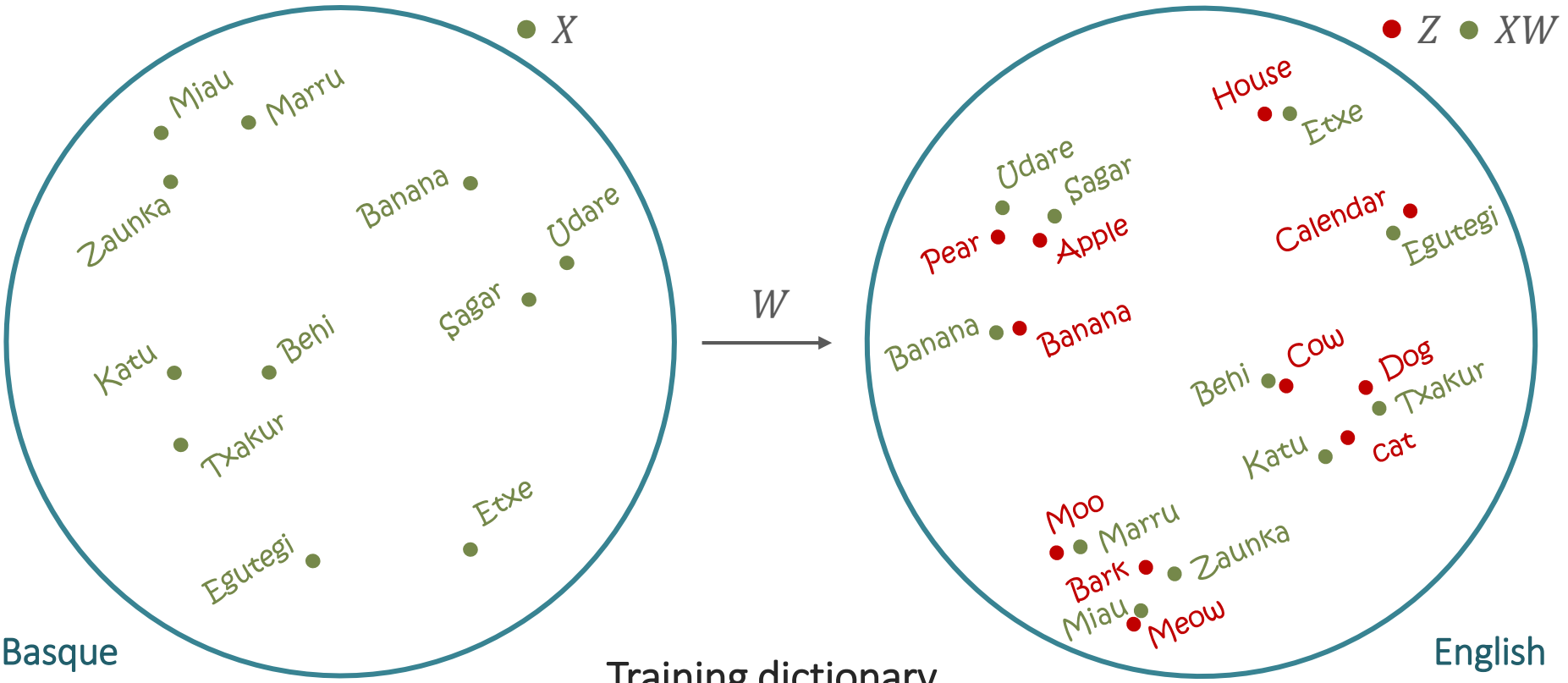

Training dictionary

$$\begin{matrix}\text{Txakur}\\ \text{Sagar}\\ \vdots\\ \text{Egutegi}\end{matrix}\begin{bmatrix}X_{1,*}\\ X_{2,*}\\ \vdots\\ X_{n,*}\end{bmatrix} \quad \Big| \quad \begin{bmatrix}Z_{1,*}\\ Z_{2,*}\\ \vdots\\ Z_{n,*}\end{bmatrix}\begin{matrix}\text{Dog}\\ \text{Apple}\\ \vdots\\ \text{Calendar}\end{matrix}$$

Cross-lingual embedding mappings

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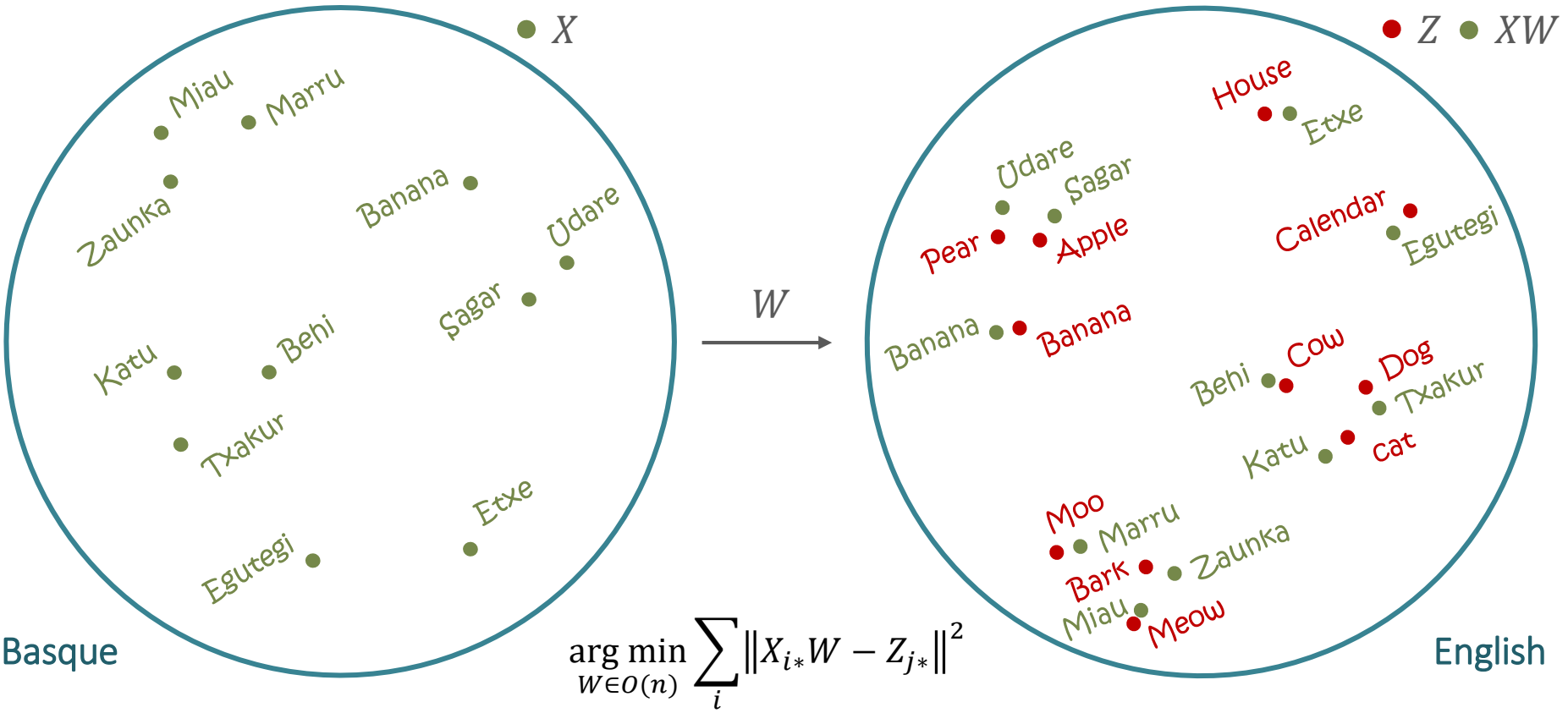
$$\begin{matrix}\text{Txakur}\\ \text{Sagar}\\ \vdots\\ \text{Egutegi}\end{matrix}\begin{bmatrix}X_{1,*}\\ X_{2,*}\\ \vdots\\ X_{n,*}\end{bmatrix}[W] \approx \begin{bmatrix}Z_{1,*}\\ Z_{2,*}\\ \vdots\\ Z_{n,*}\end{bmatrix}\begin{matrix}\text{Dog}\\ \text{Apple}\\ \vdots\\ \text{Calendar}\end{matrix}$$

Cross-lingual embedding mappings



$$\arg\min_{W \in O(n)} \sum_i \|X_{i*}W - Z_{j*}\|^2$$

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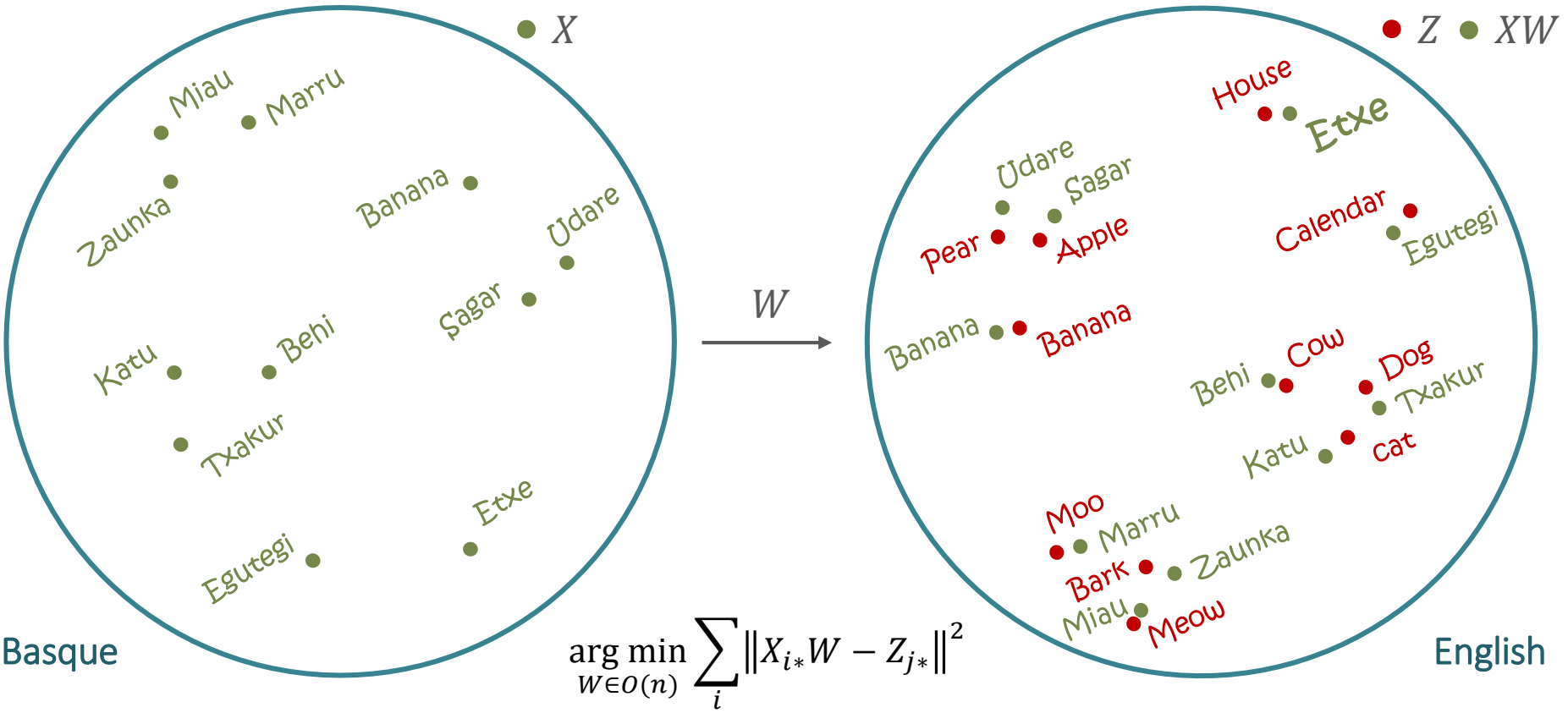

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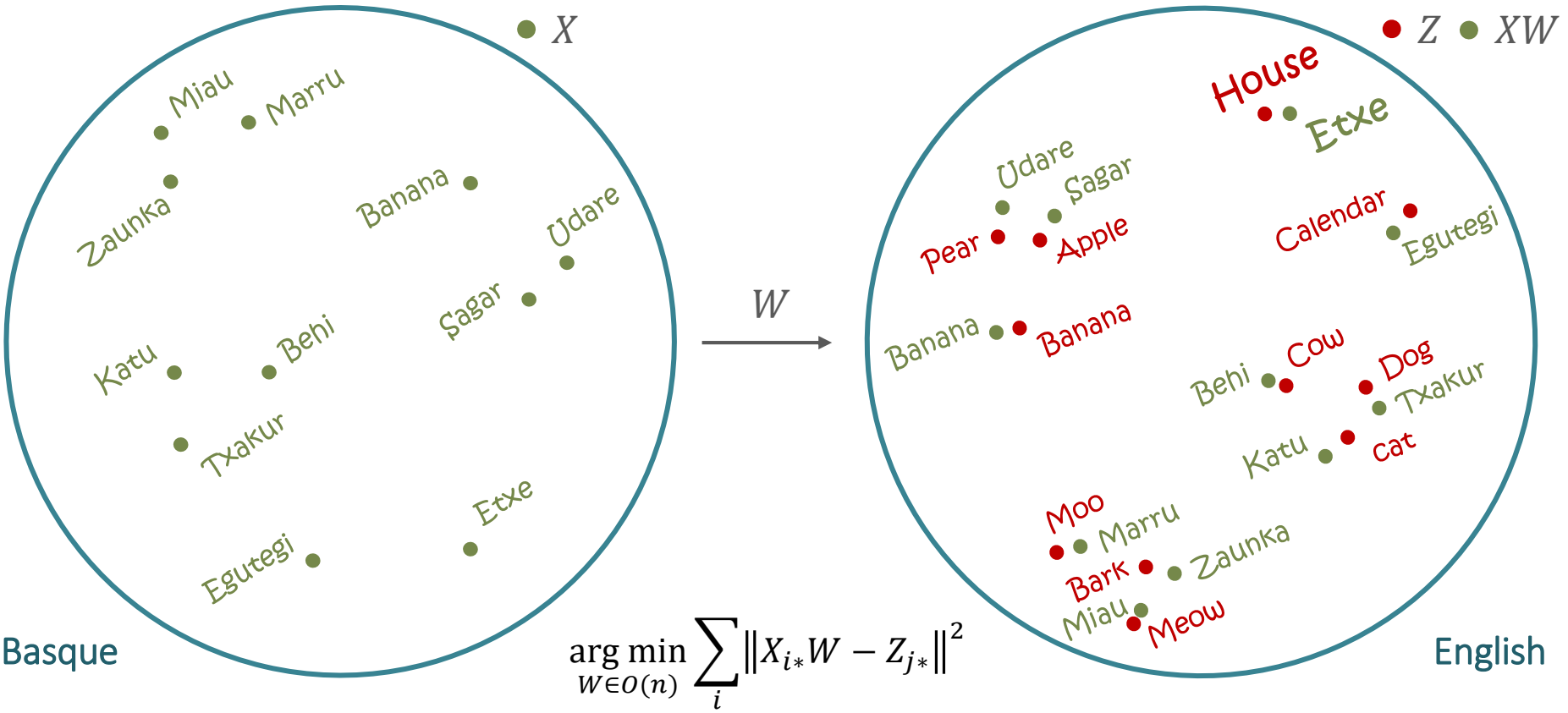

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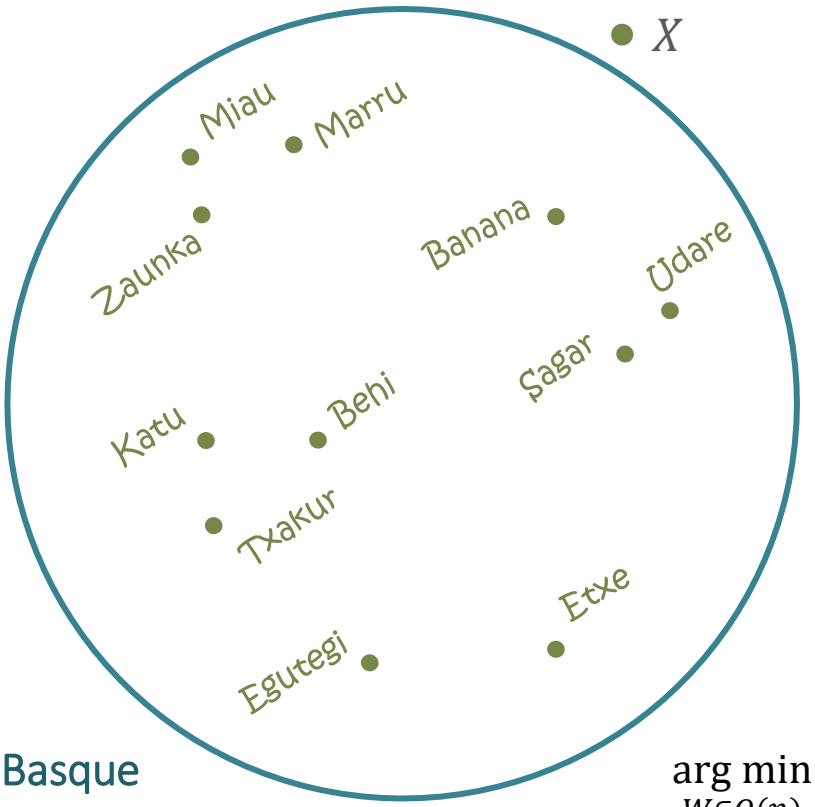
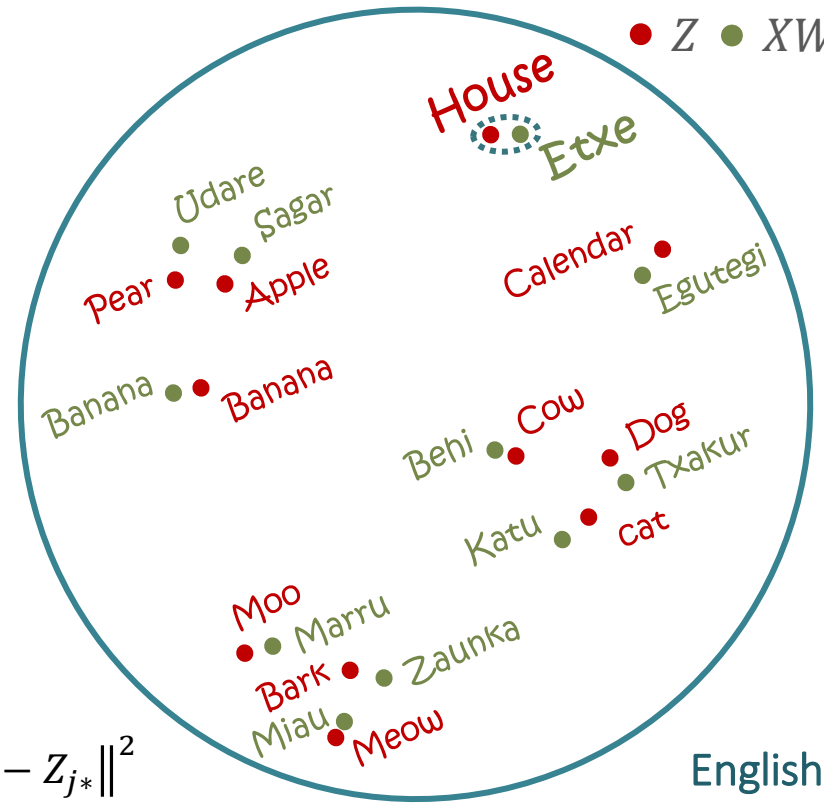


Basque

W



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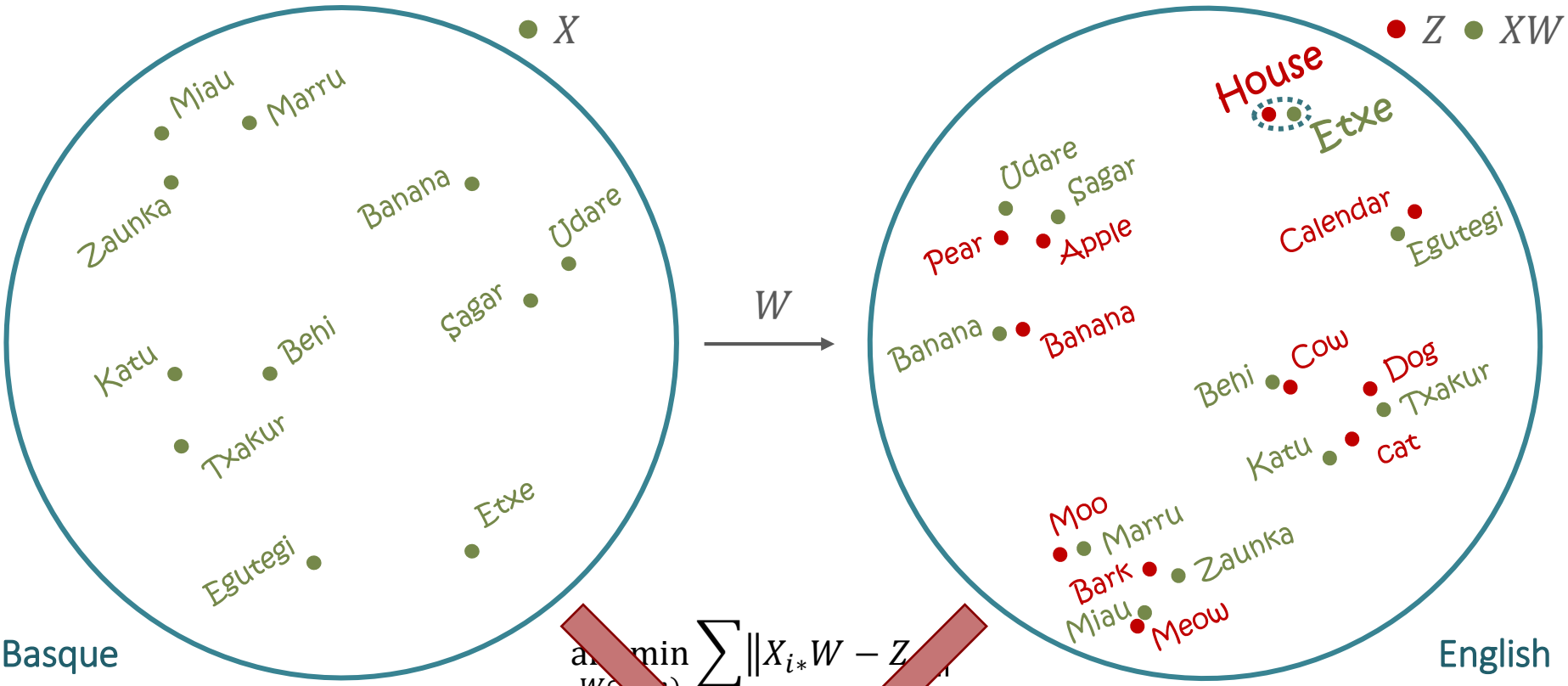

$$\underset{W}{\text{a}}\min \sum_i \|X_{i*}W - Z$$

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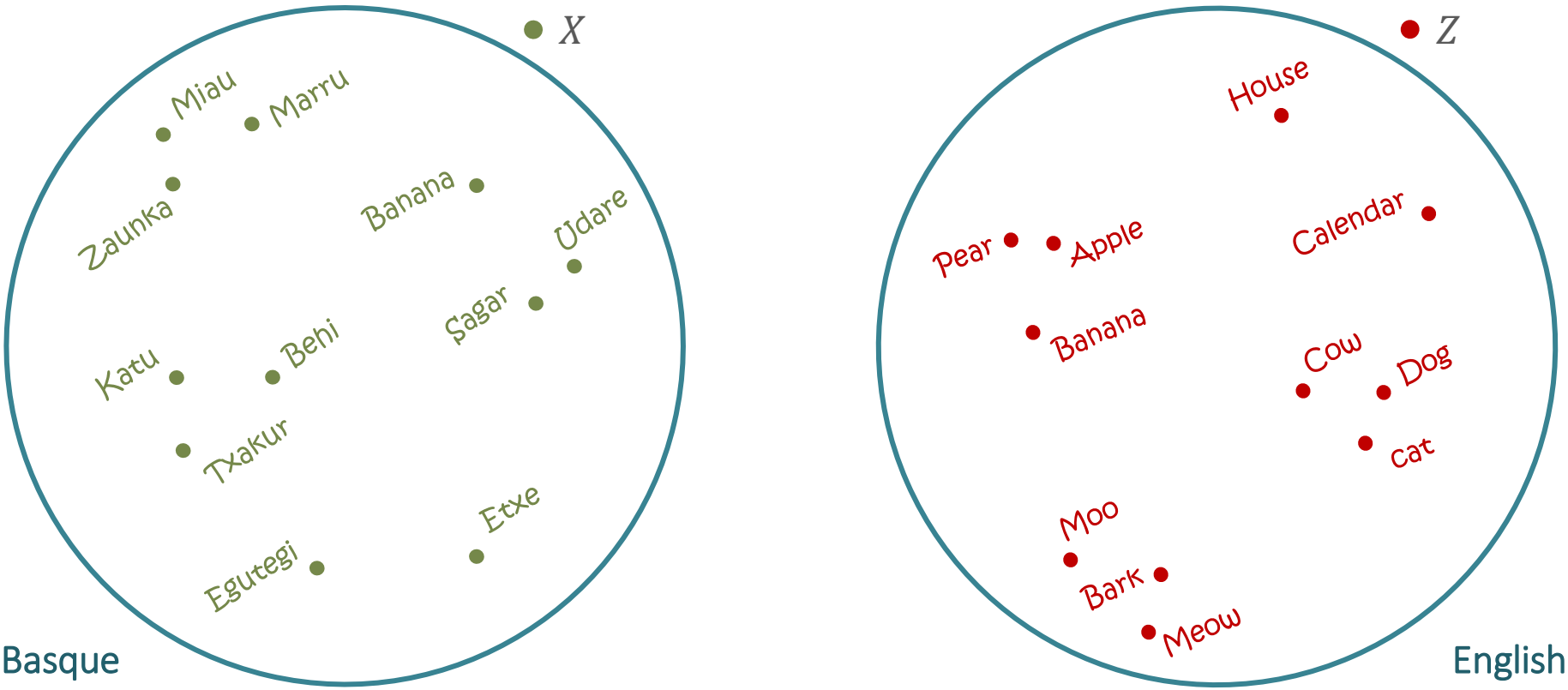

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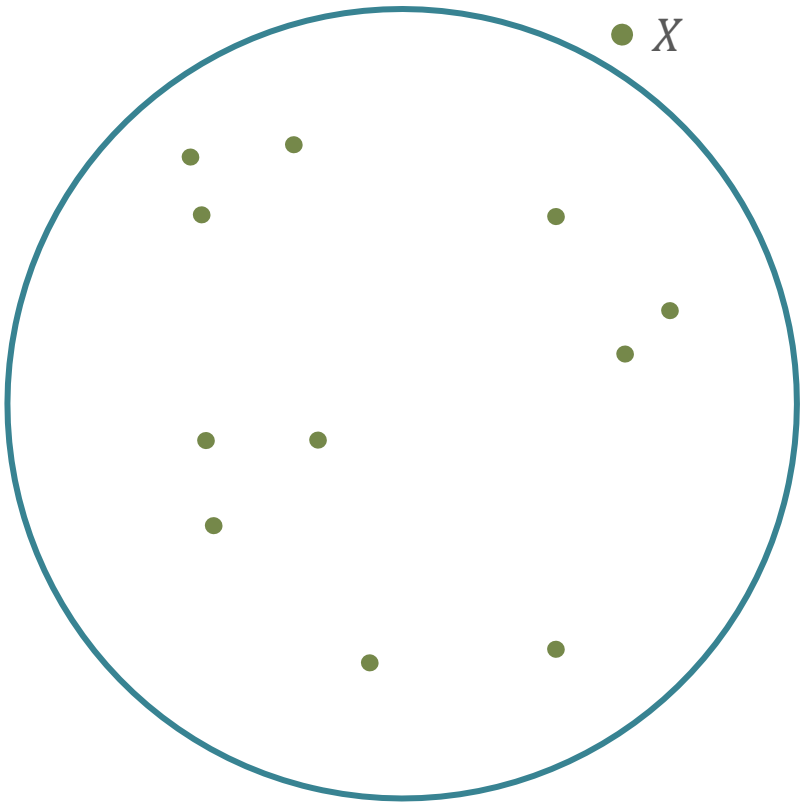

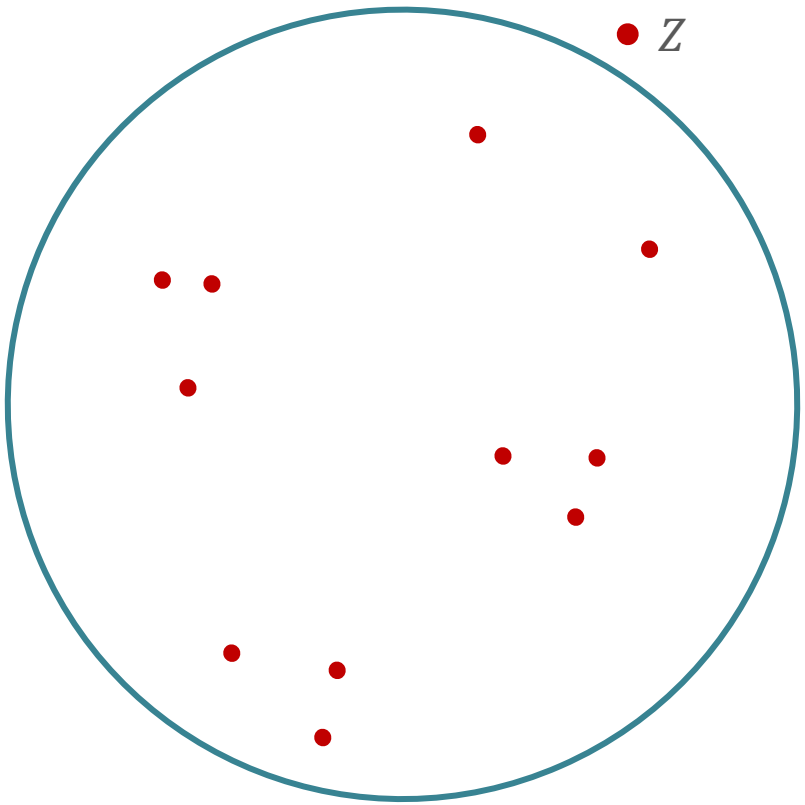

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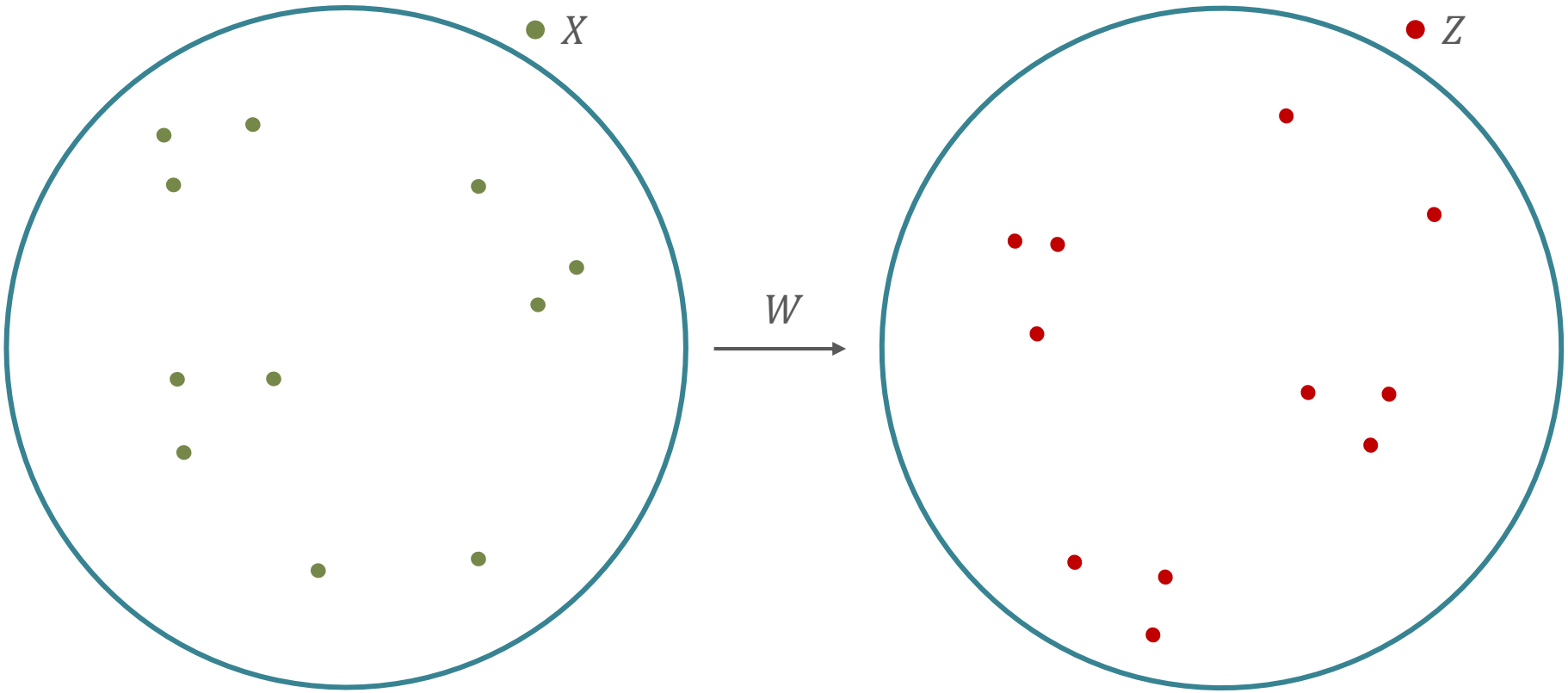

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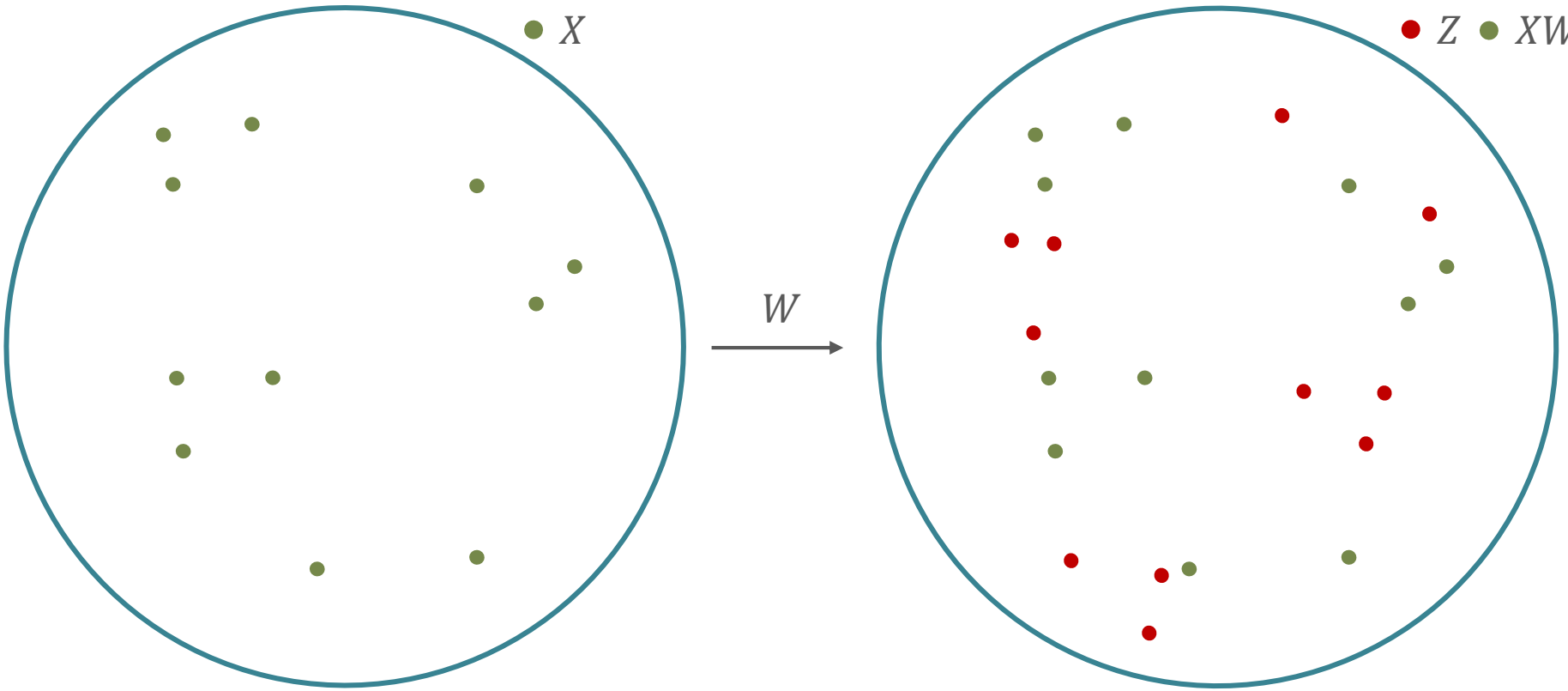

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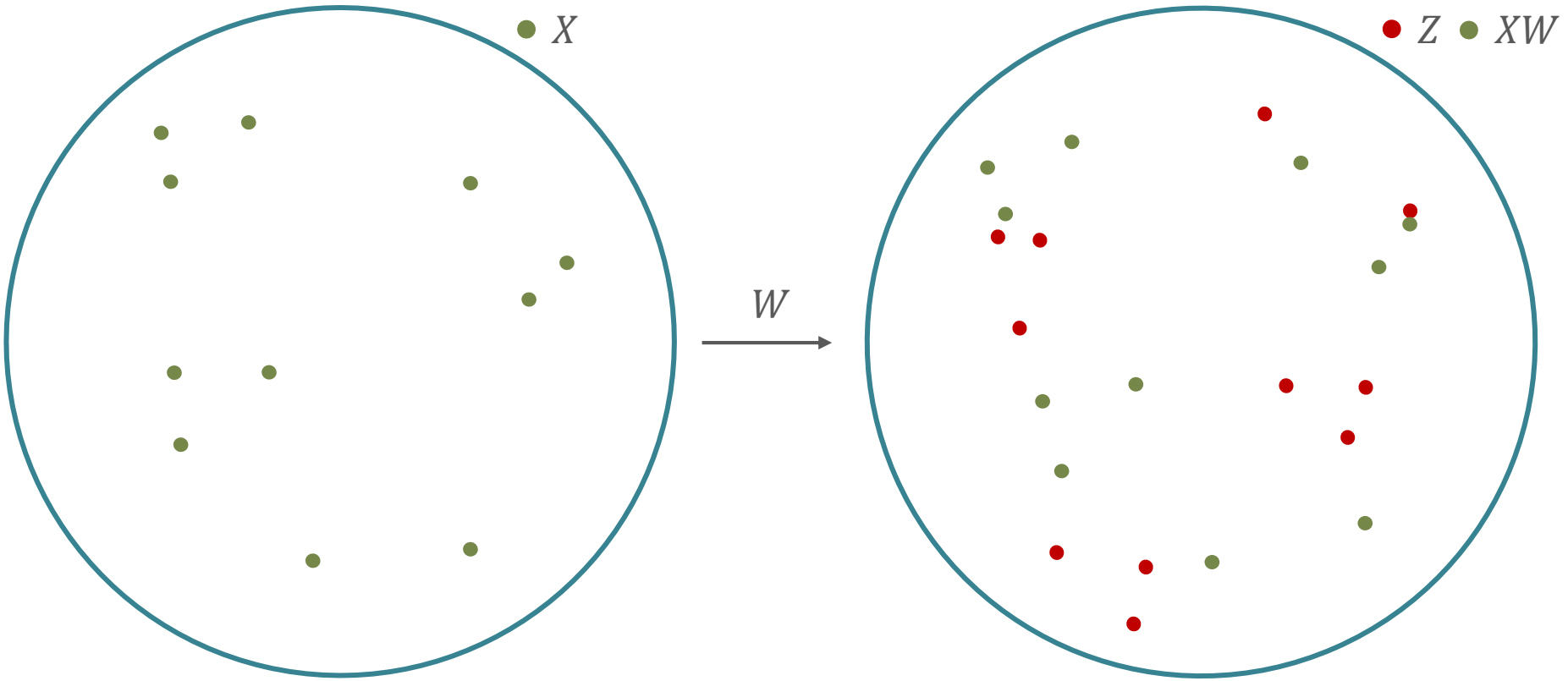

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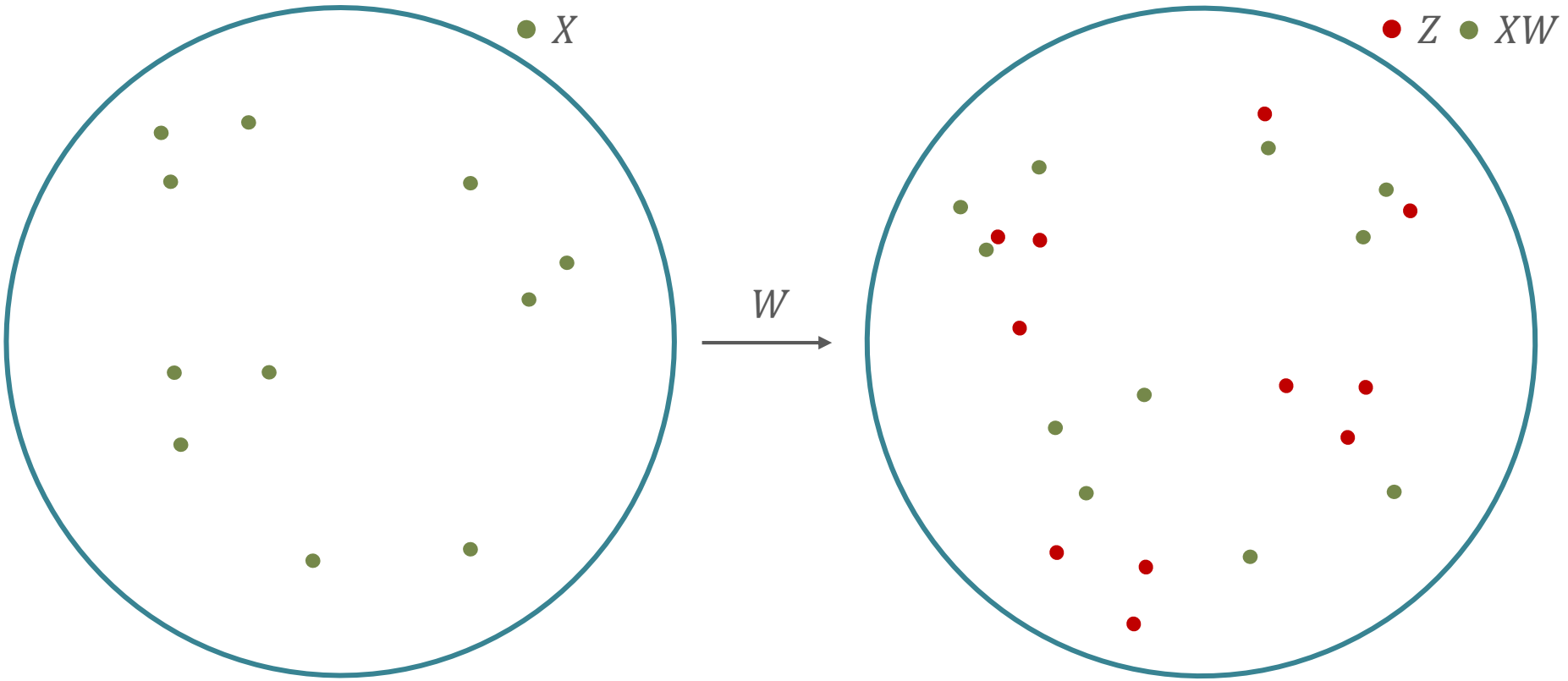

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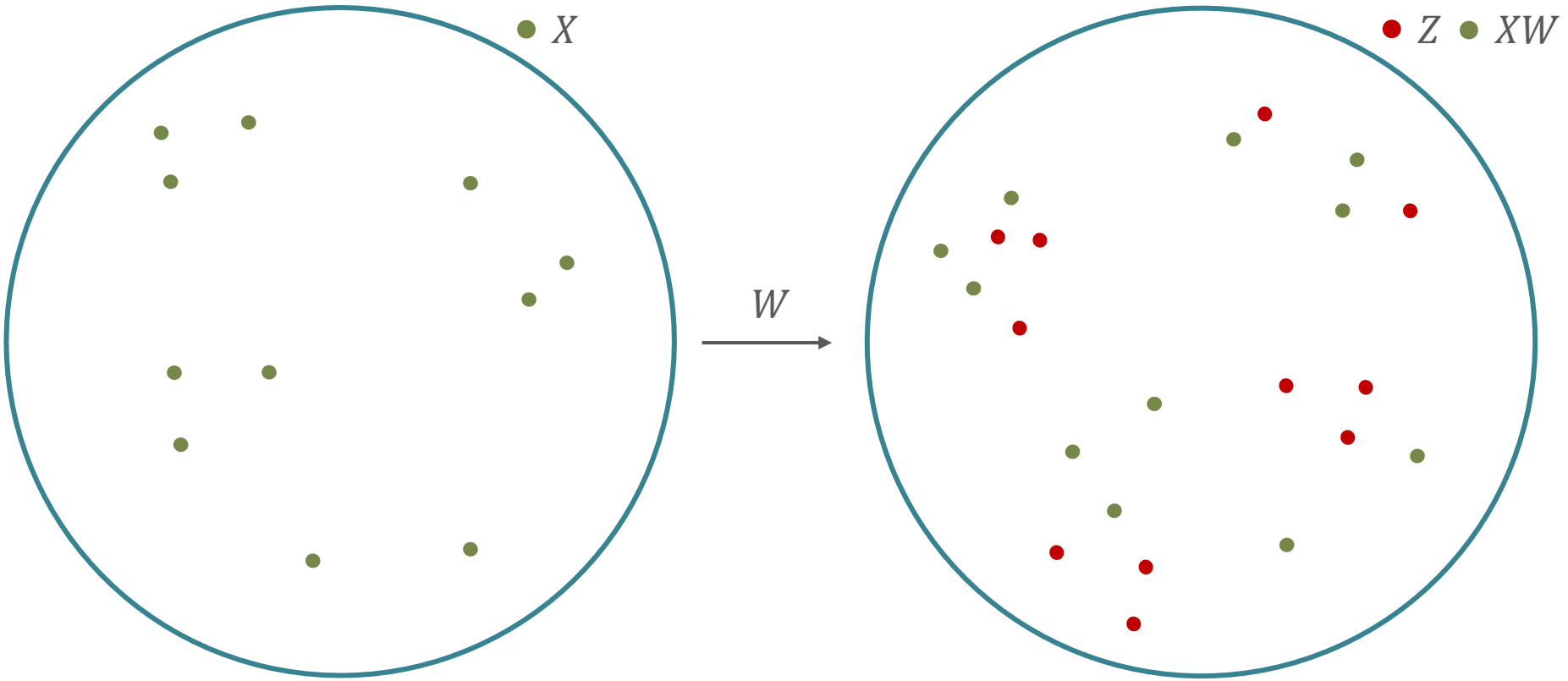

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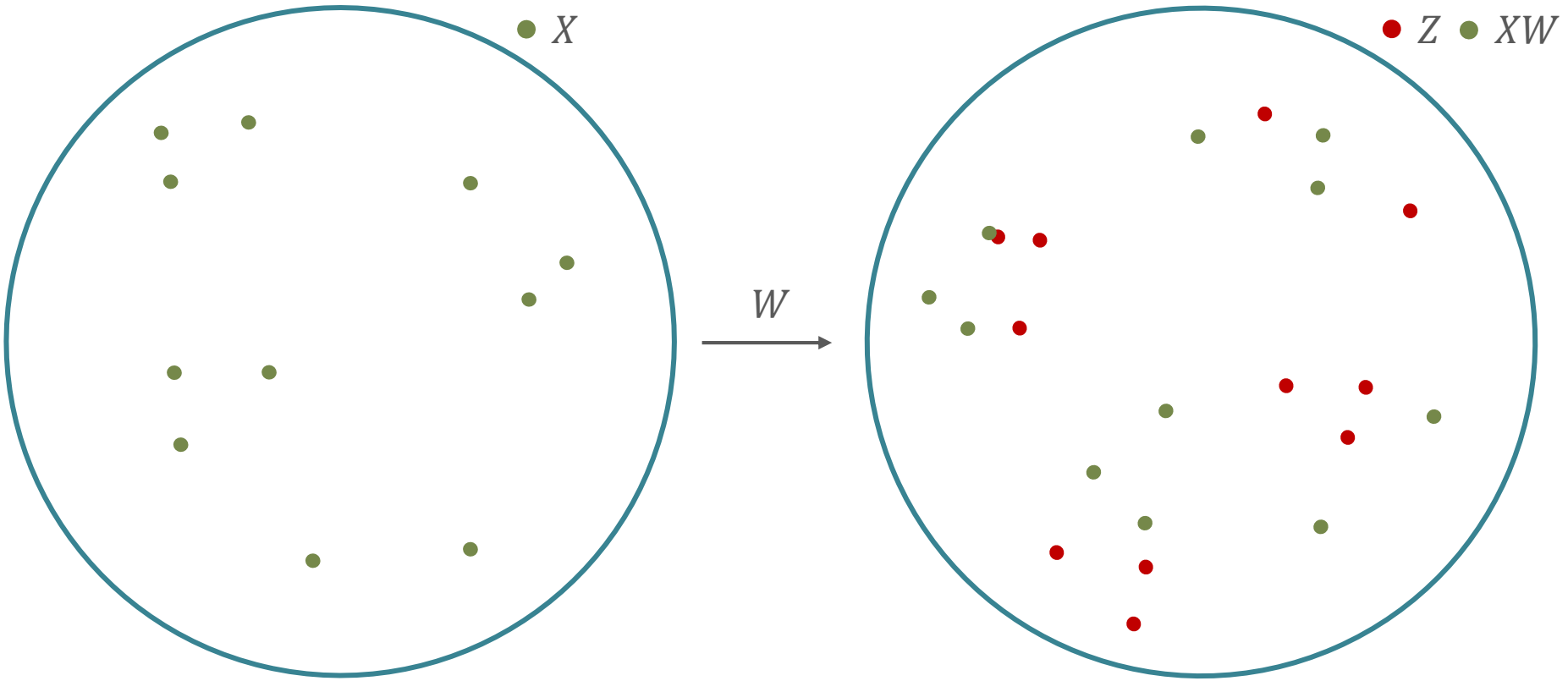

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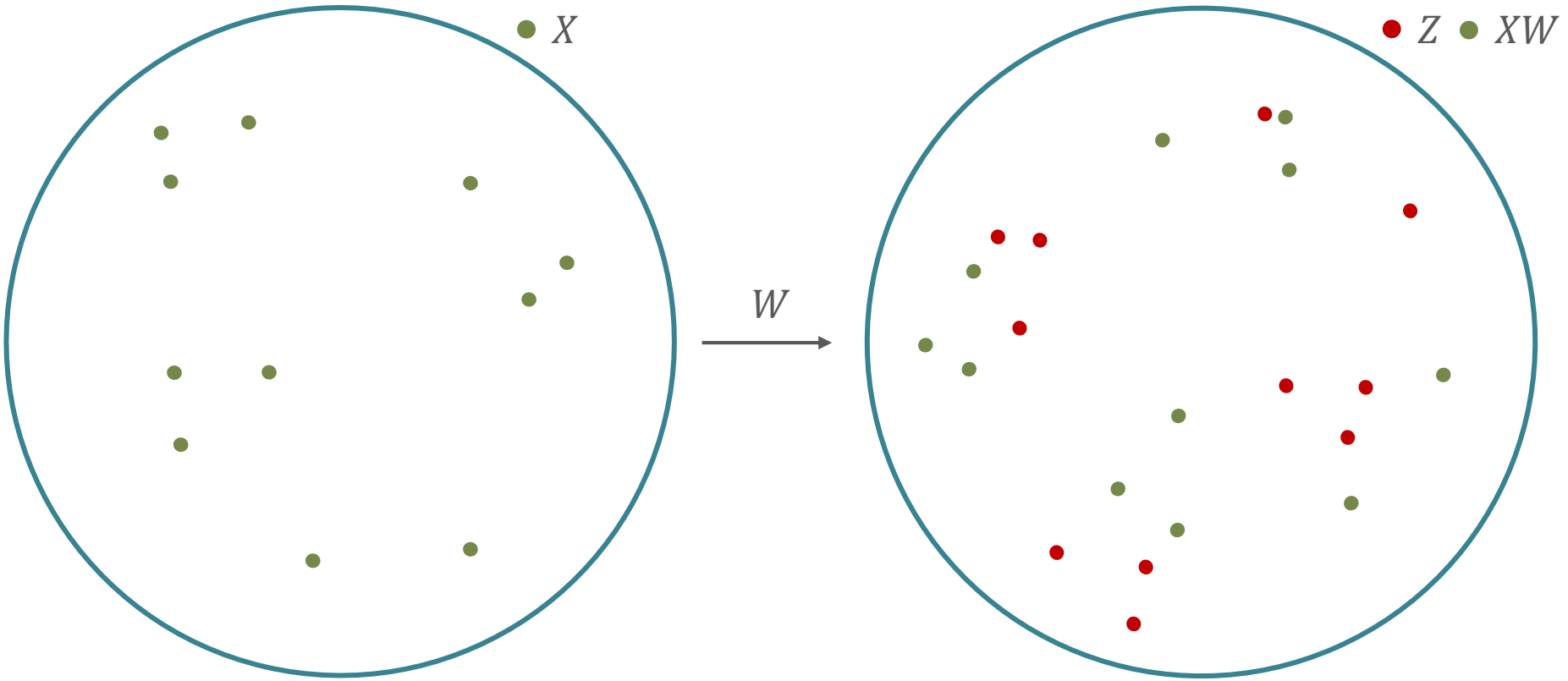

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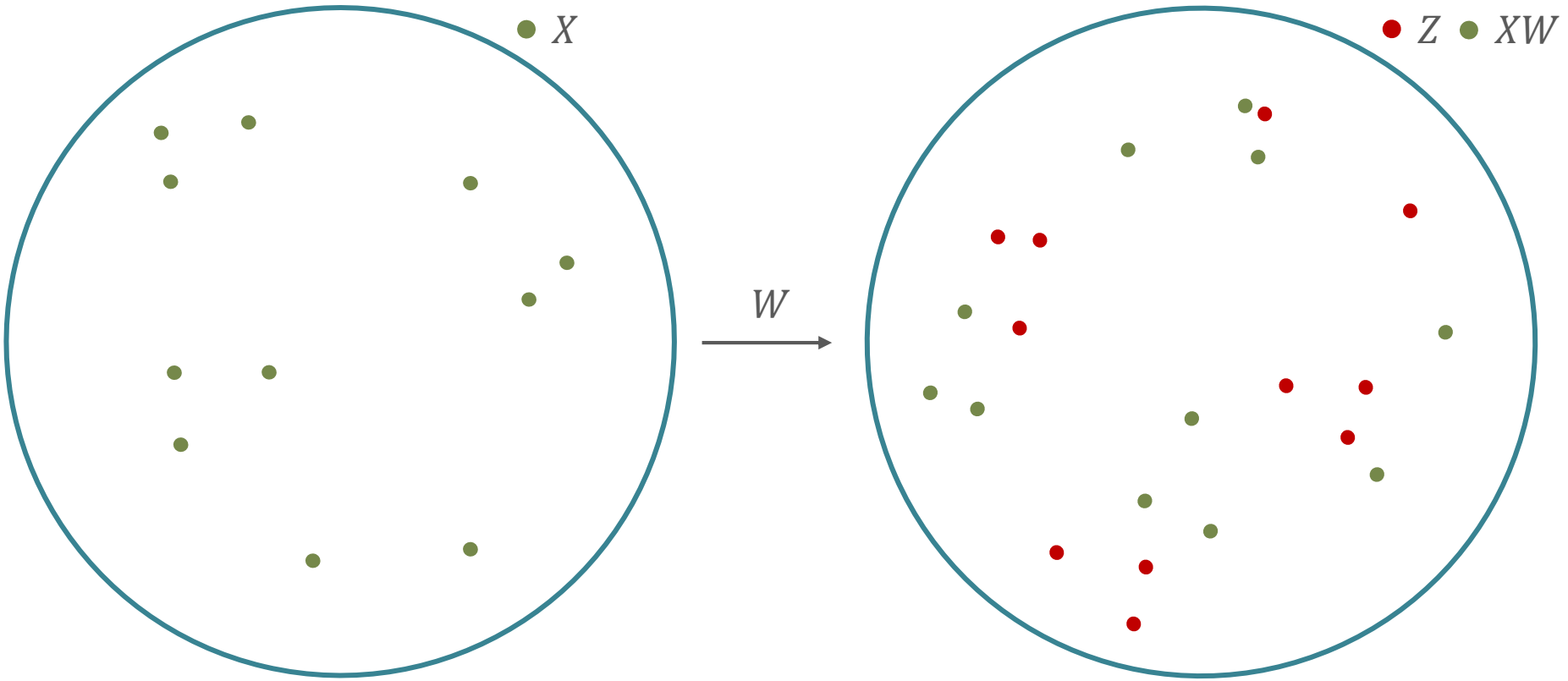

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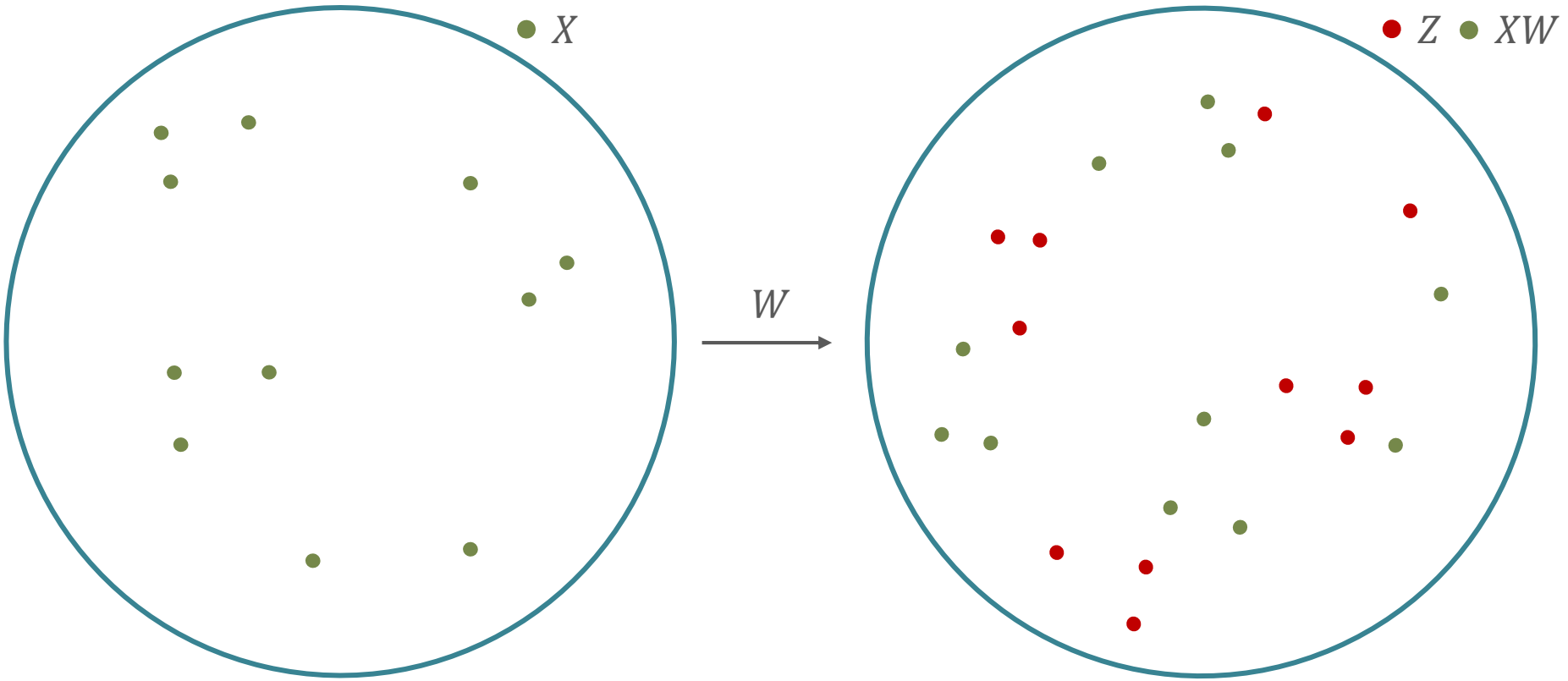

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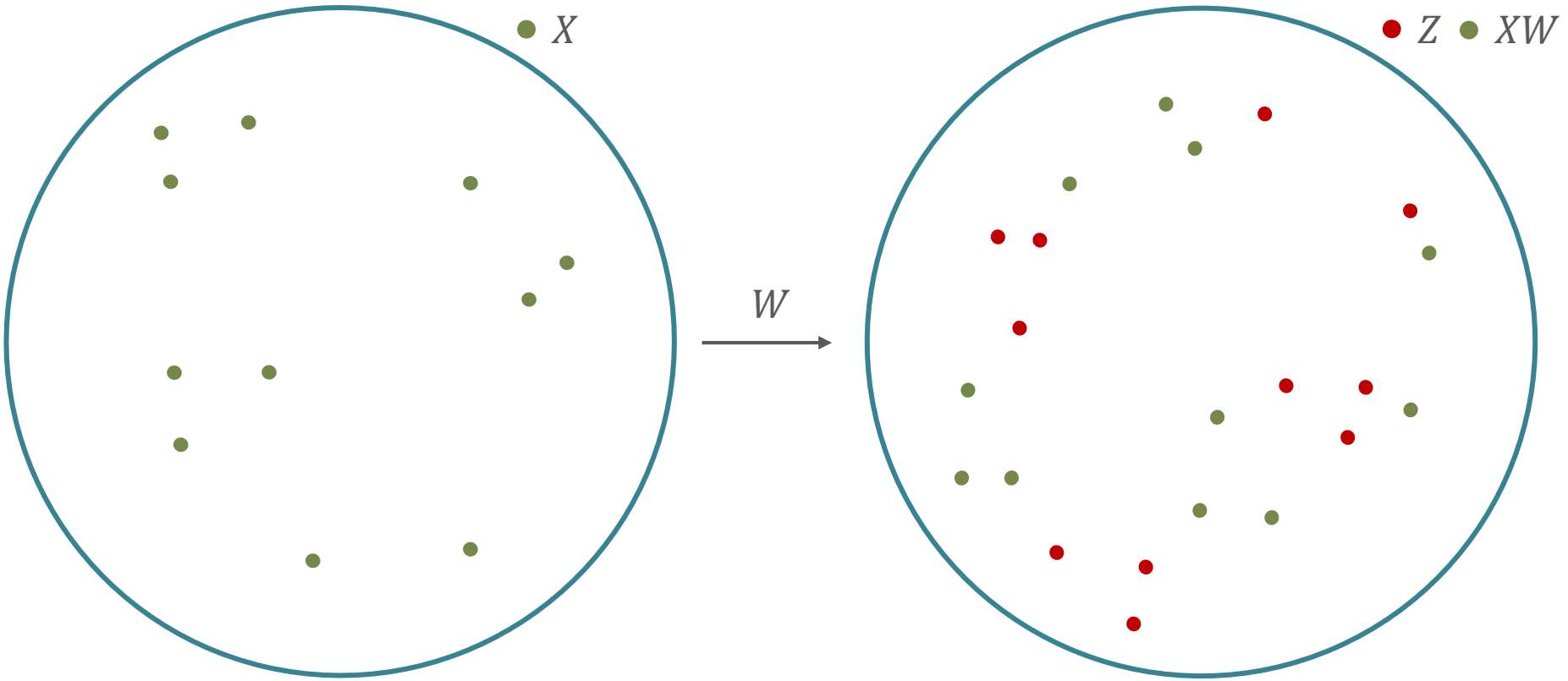

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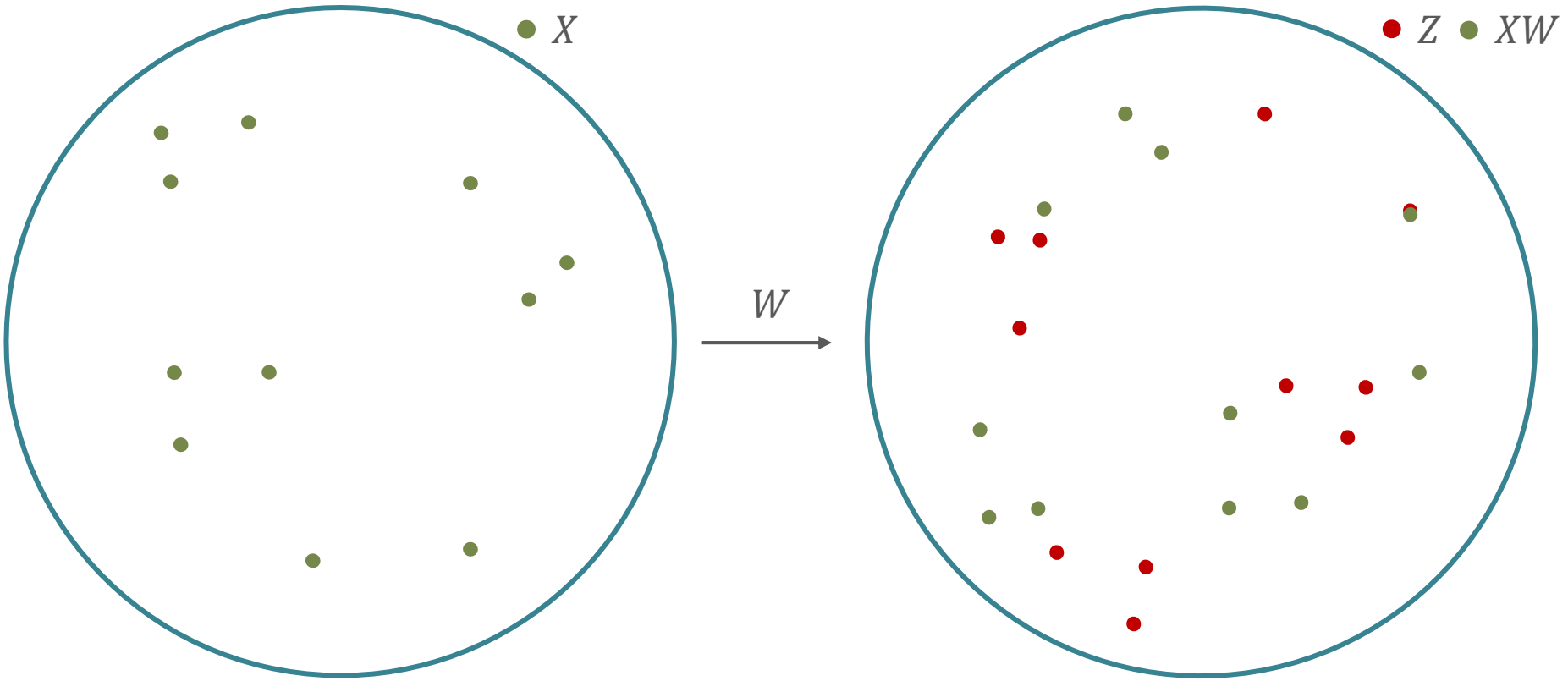

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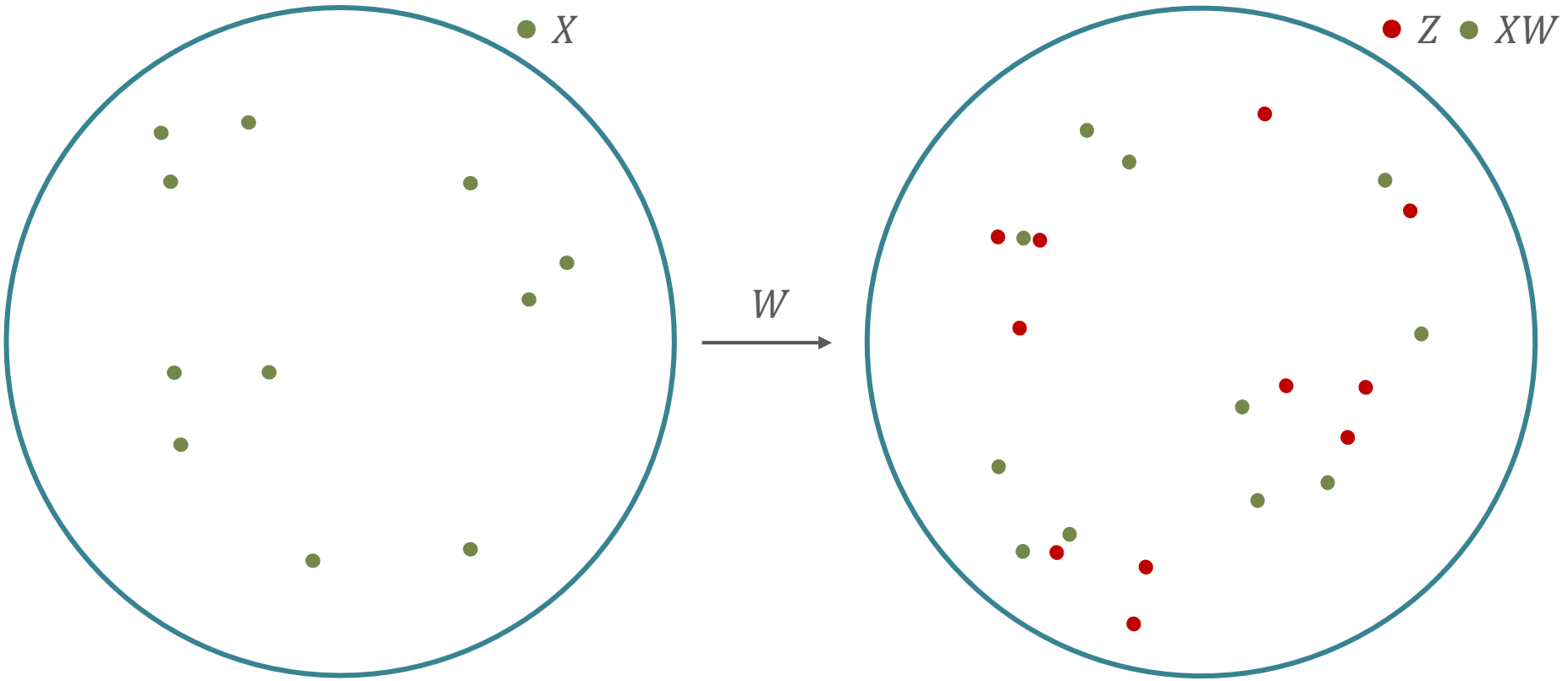

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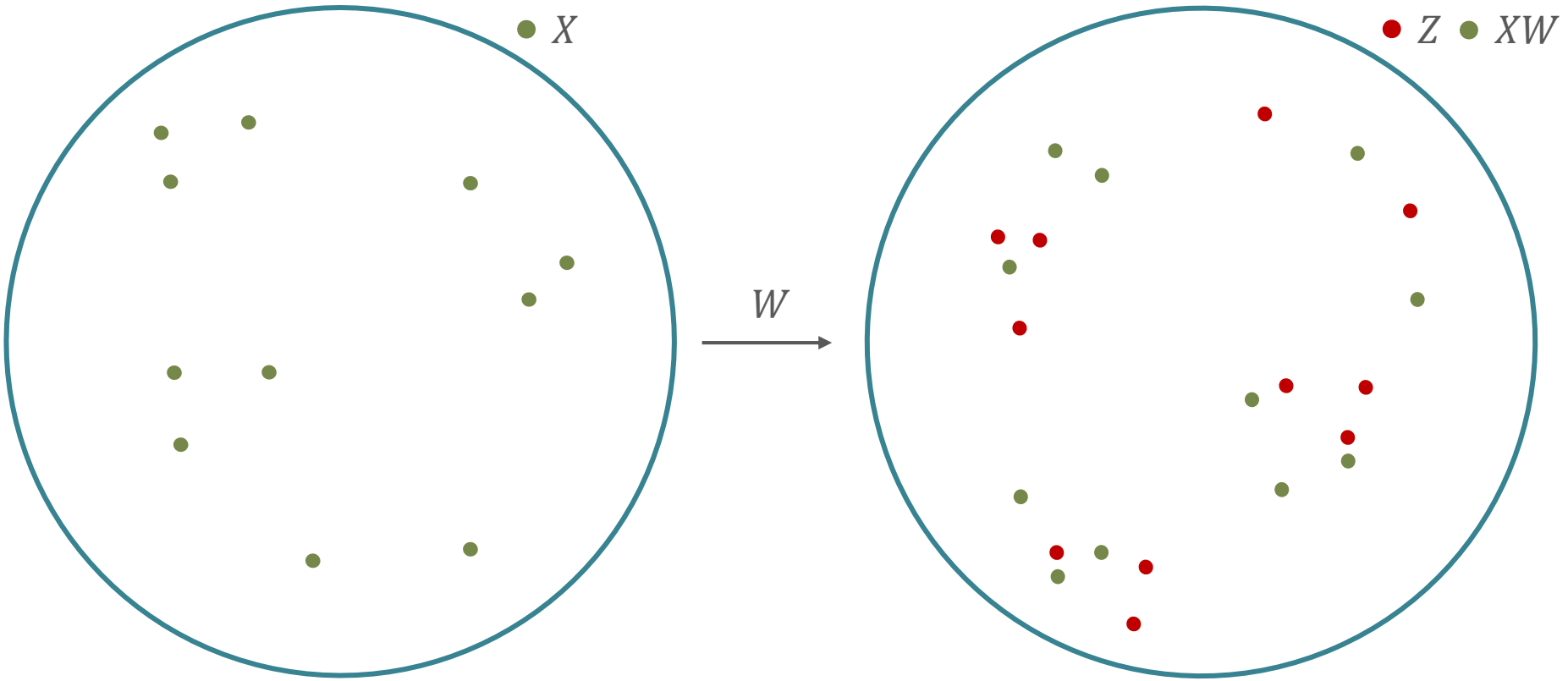

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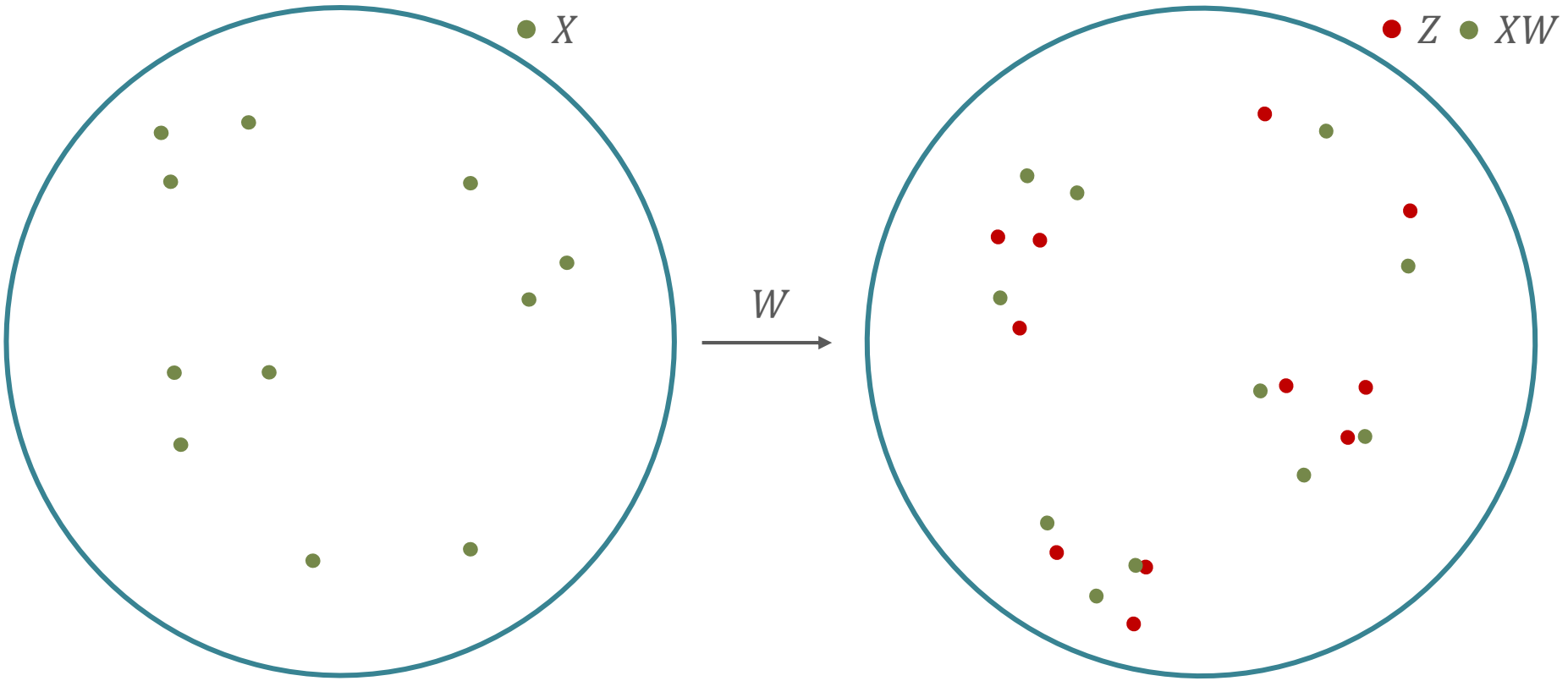

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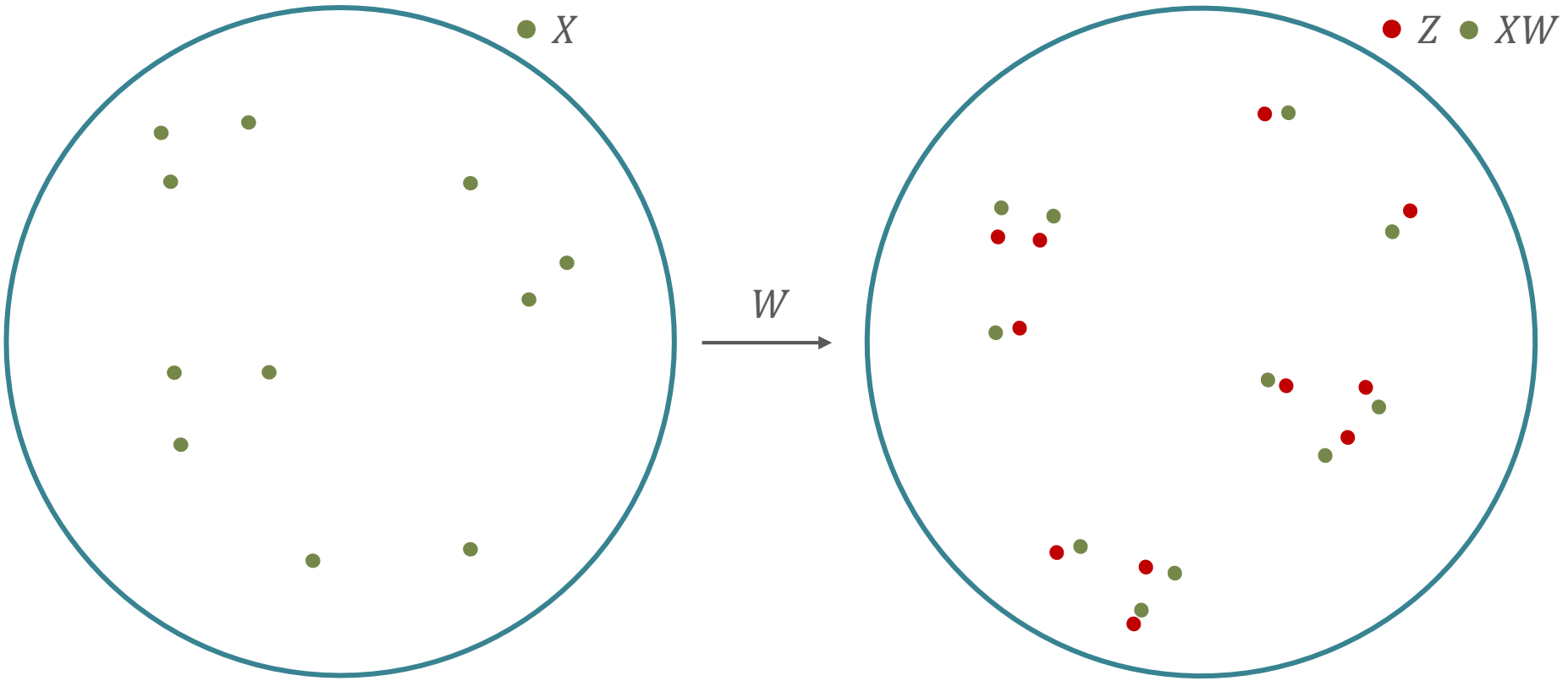

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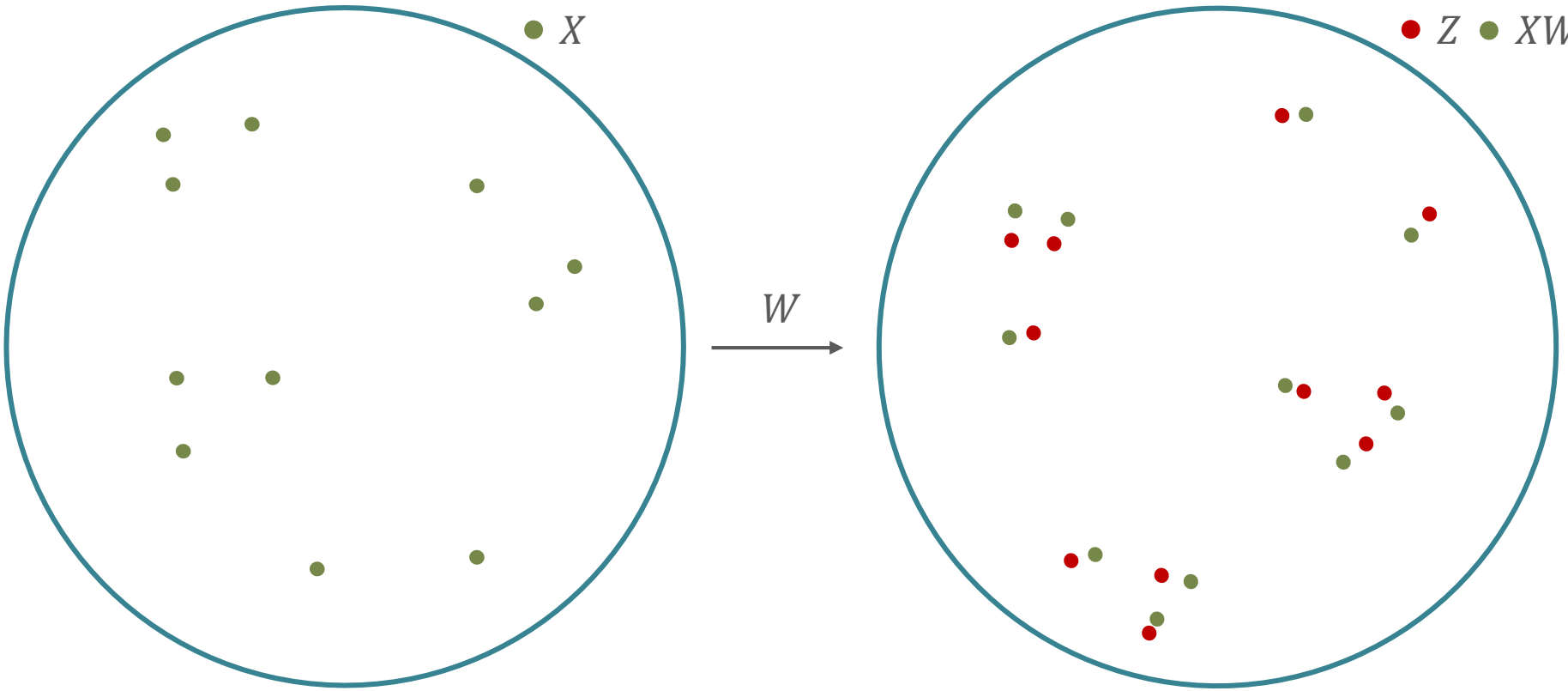


$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Cross-lingual embedding mappings

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

Dictionary

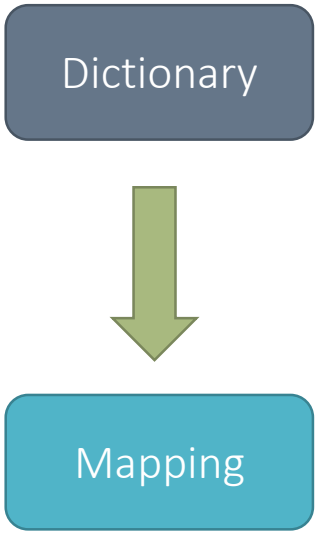
$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

Dictionary

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

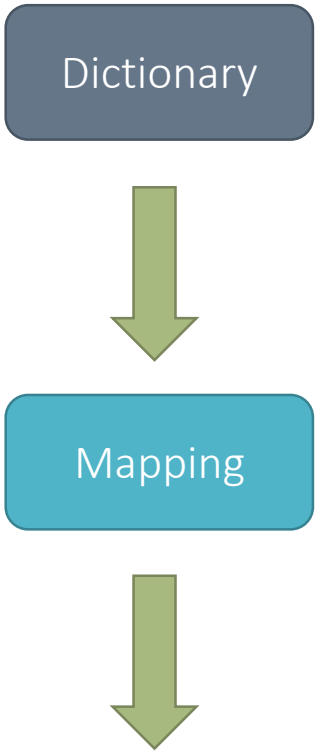
Artetxe et al. (ACL 2017)



$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

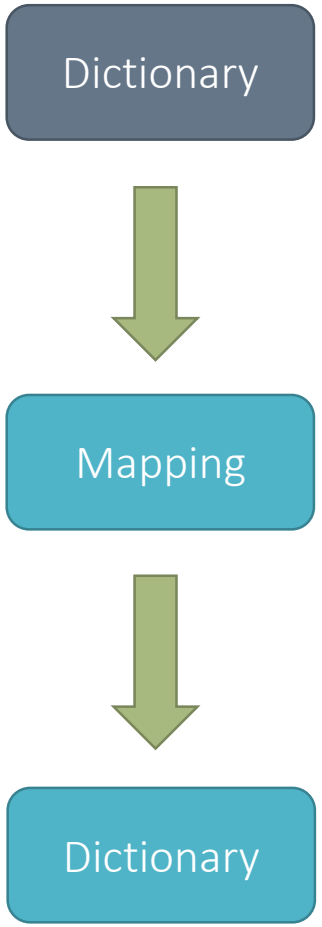
Artetxe et al. (ACL 2017)

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$



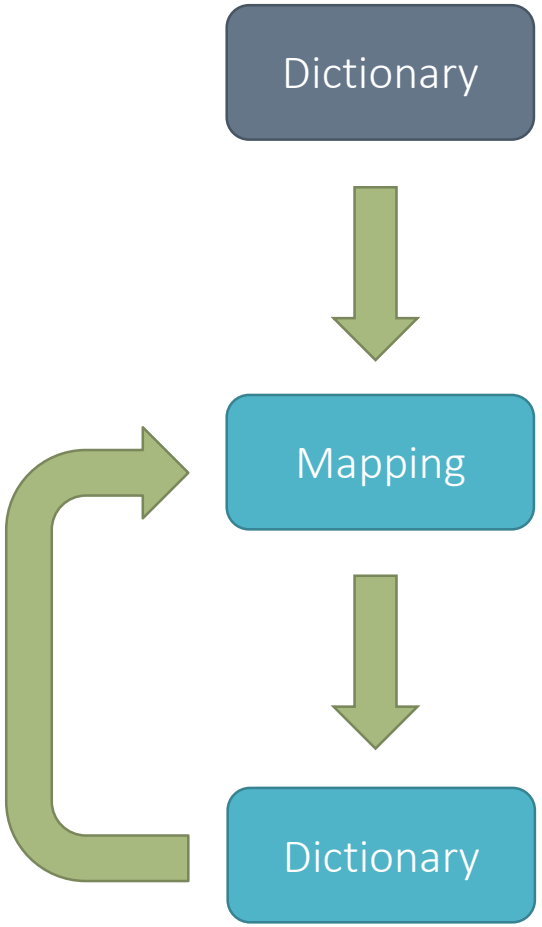
Artetxe et al. (ACL 2017)

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$



Artetxe et al. (ACL 2017)

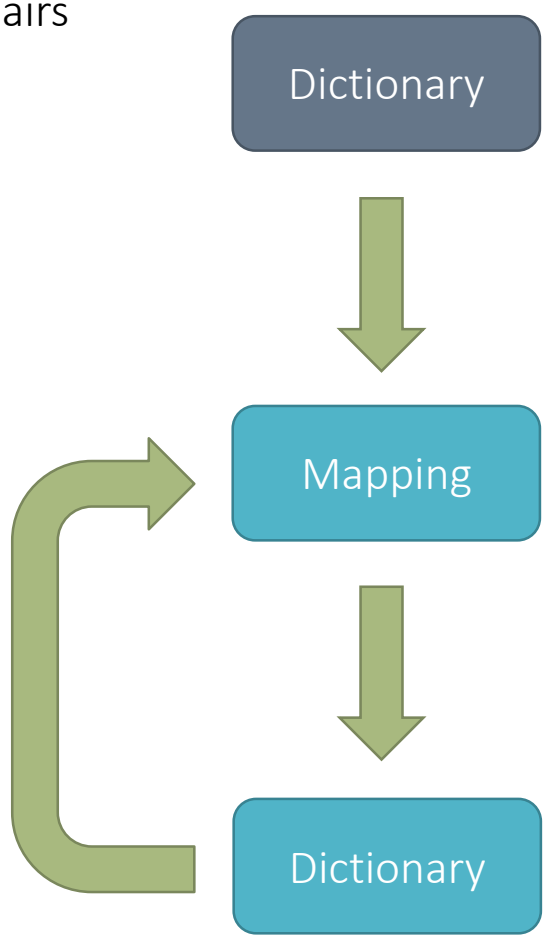
$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$



Artetxe et al. (ACL 2017)

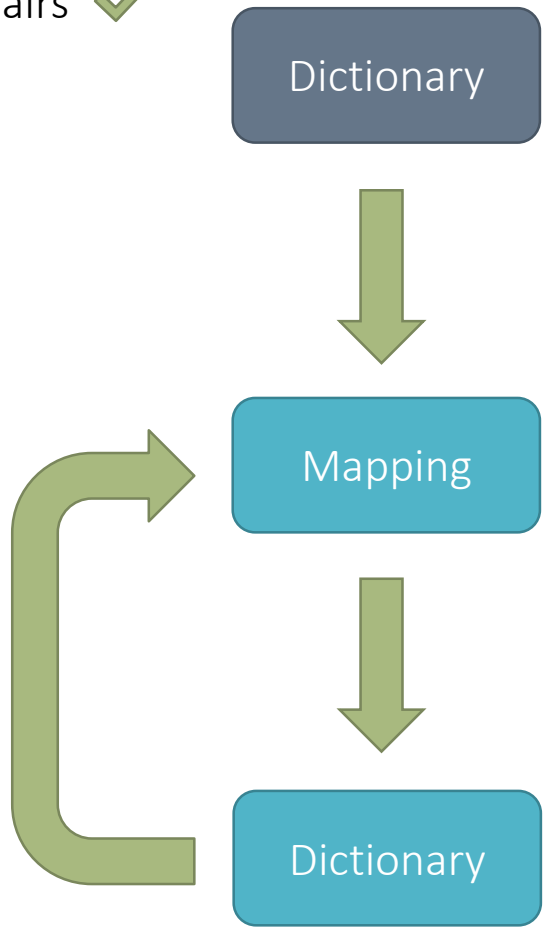
- 25 word pairs

$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$



Artetxe et al. (ACL 2017)

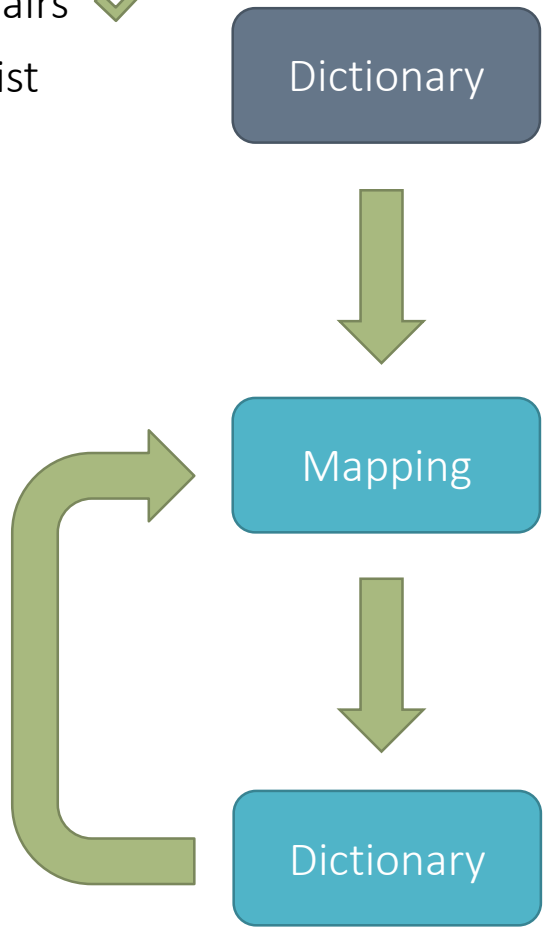
- 25 word pairs ✓



$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

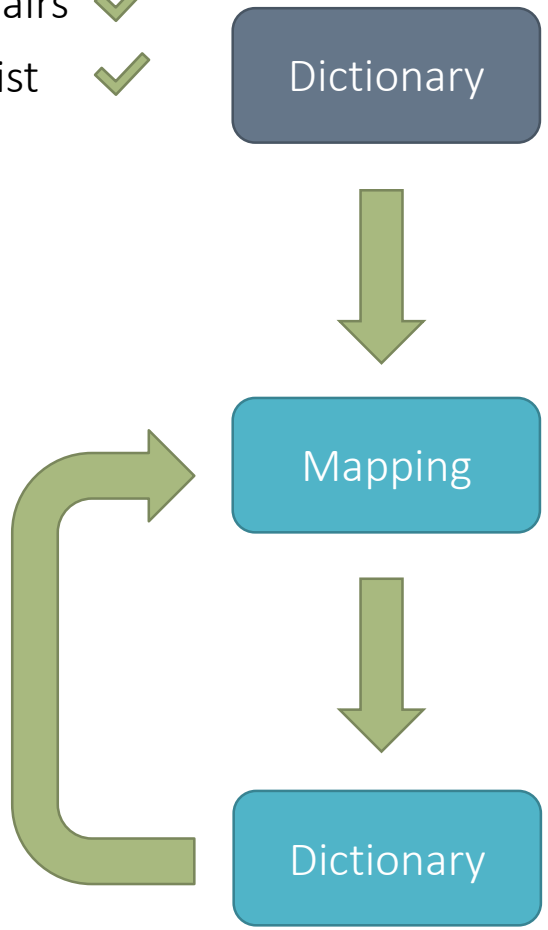
- 25 word pairs ✓
- Numeral list



$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

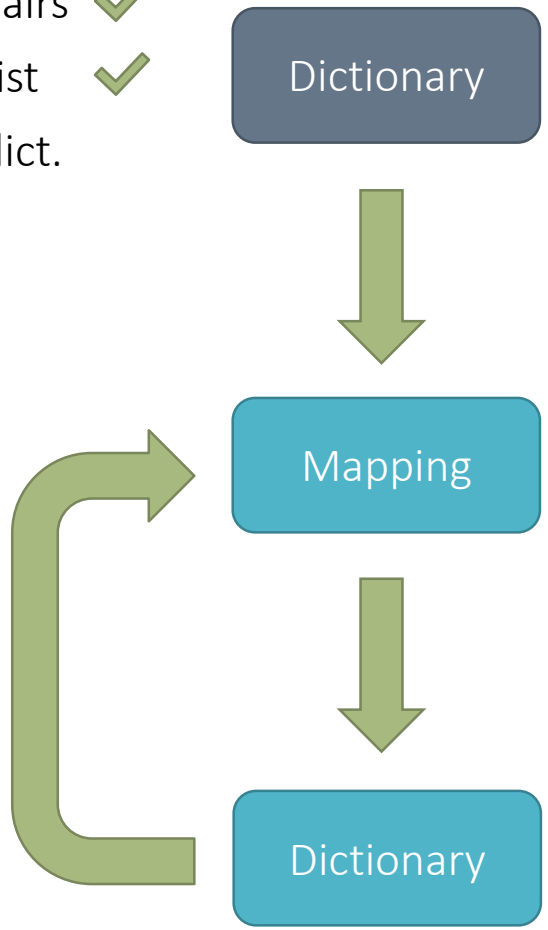
- 25 word pairs ✓
- Numeral list ✓



$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

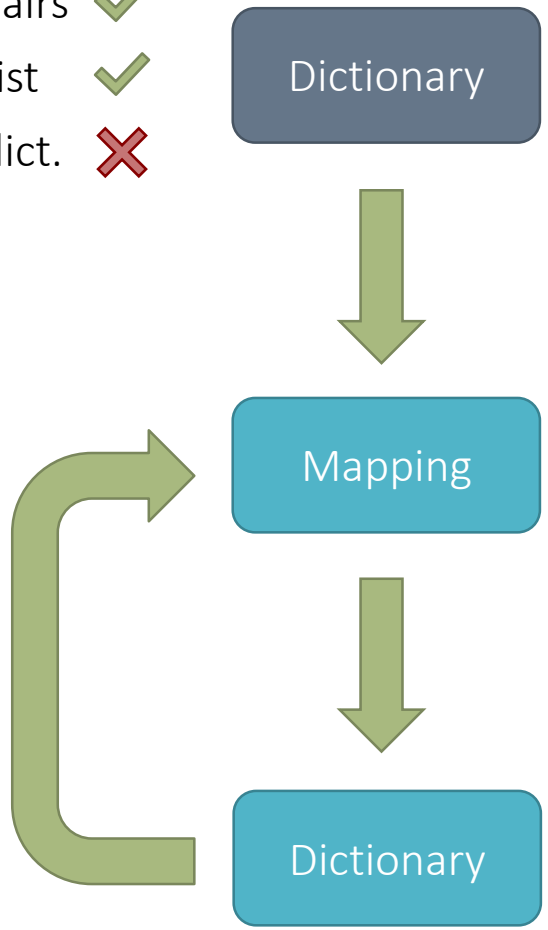
- 25 word pairs ✓
- Numeral list ✓
- Random dict.



$$W^* = \arg\min_{W \in O(n)} \sum_i \min_j \left\| X_{i*} W - Z_{j*} \right\|^2$$

Artetxe et al. (ACL 2017)

- 25 word pairs ✓
- Numeral list ✓
- Random dict. ✗



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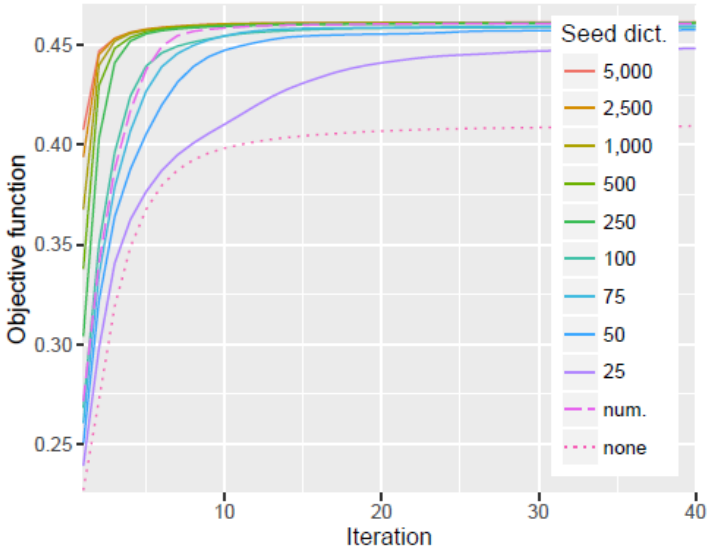
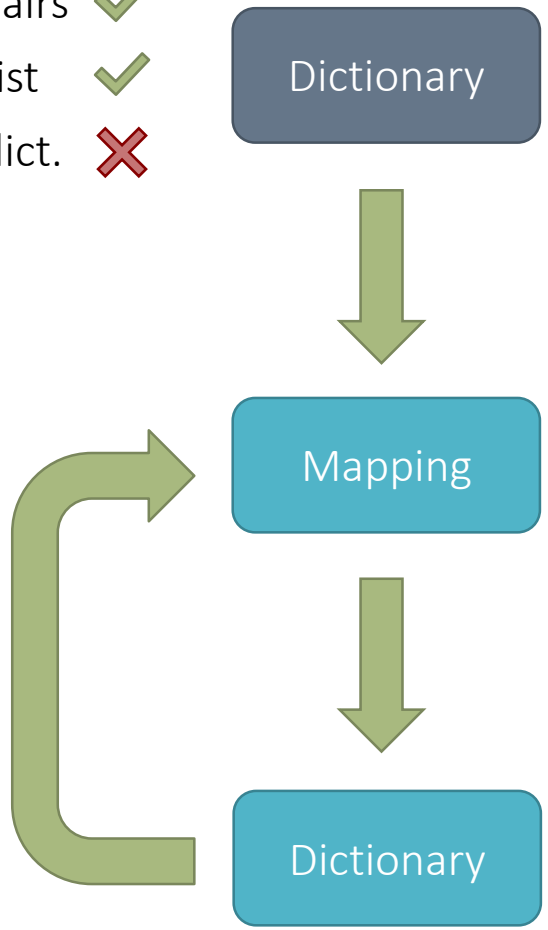
Artetxe et al. (ACL 2017)



- 25 word pairs ✓
- Numeral list ✓
- Random dict. ✗



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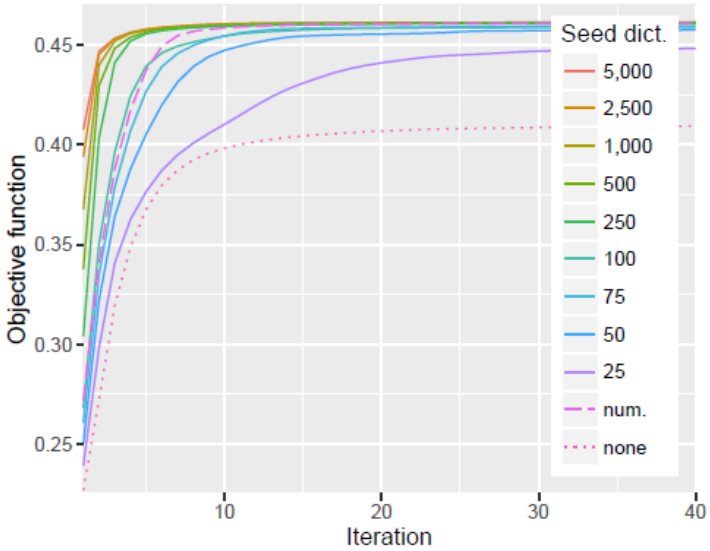
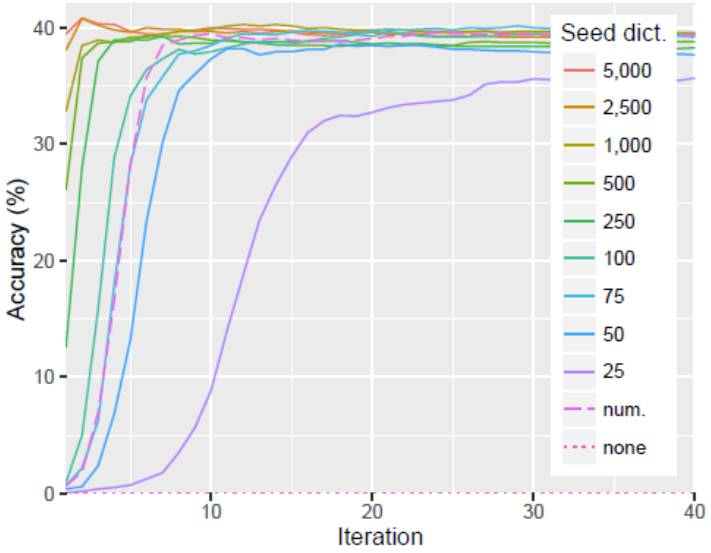
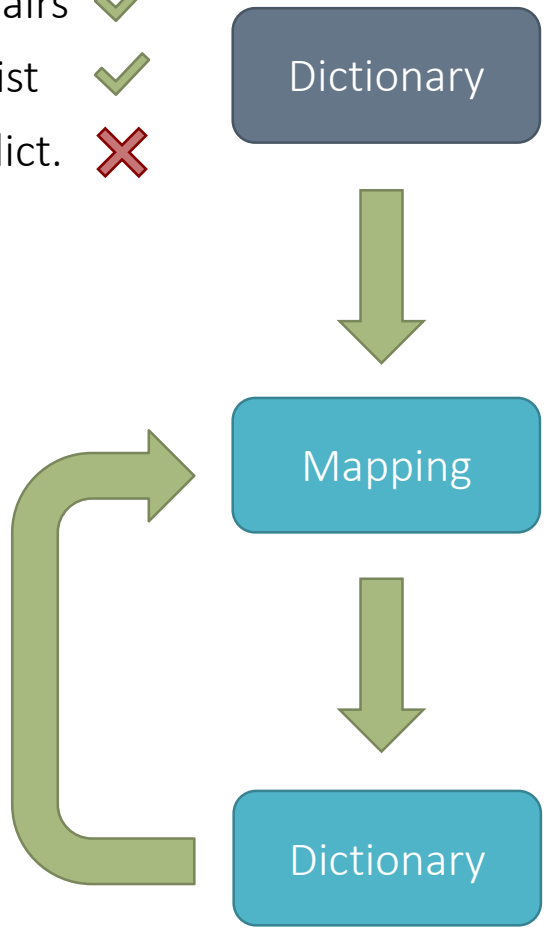
Artetxe et al. (ACL 2017)

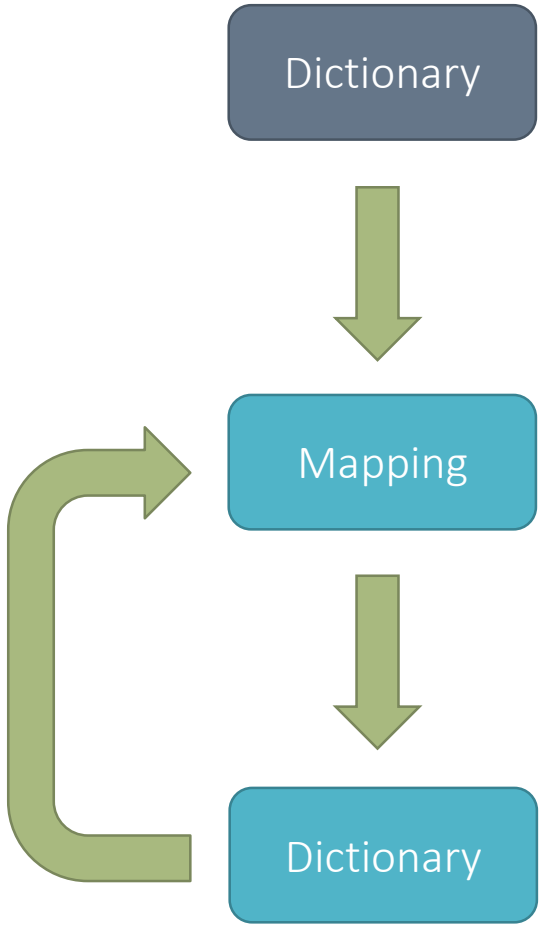




- 25 word pairs ✓
- Numeral list ✓
- Random dict. ✗

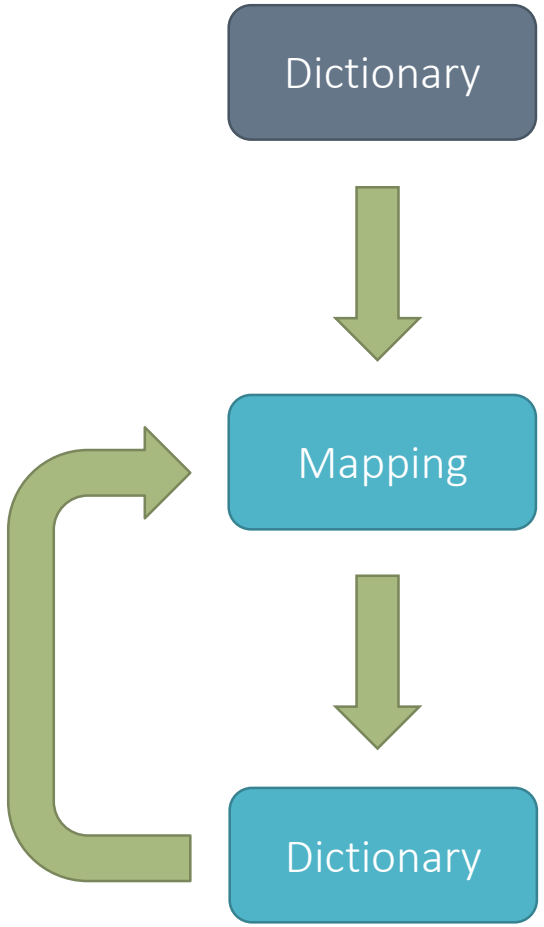


Proposed method



Proposed method

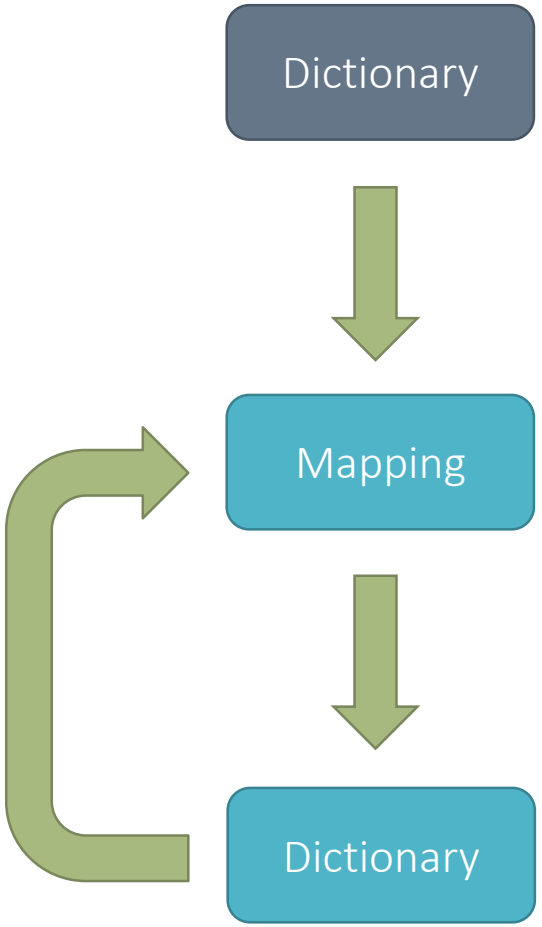
1) Fully unsupervised initialization



Proposed method

1) Fully unsupervised initialization

2) Robust self-learning

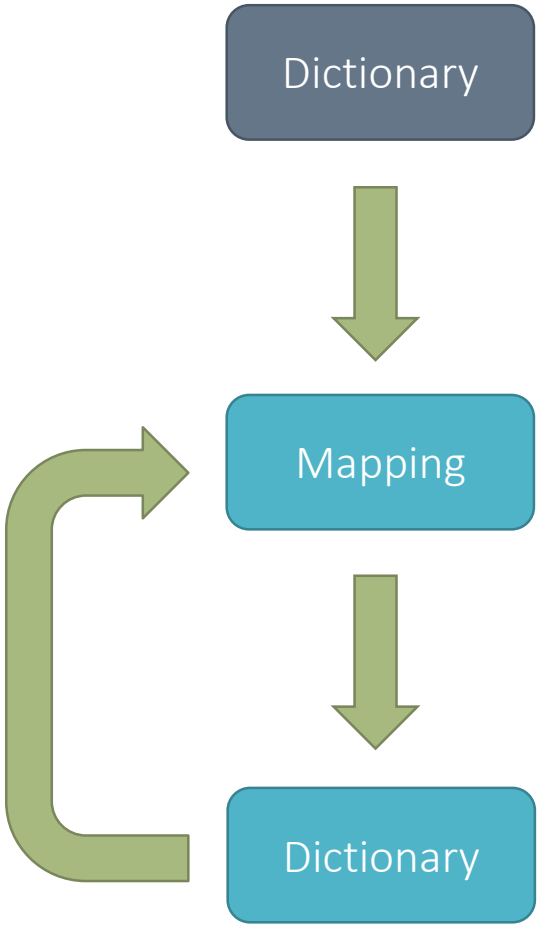


Proposed method

1) Fully unsupervised initialization

Intra-lingual similarity distribution

2) Robust self-learning

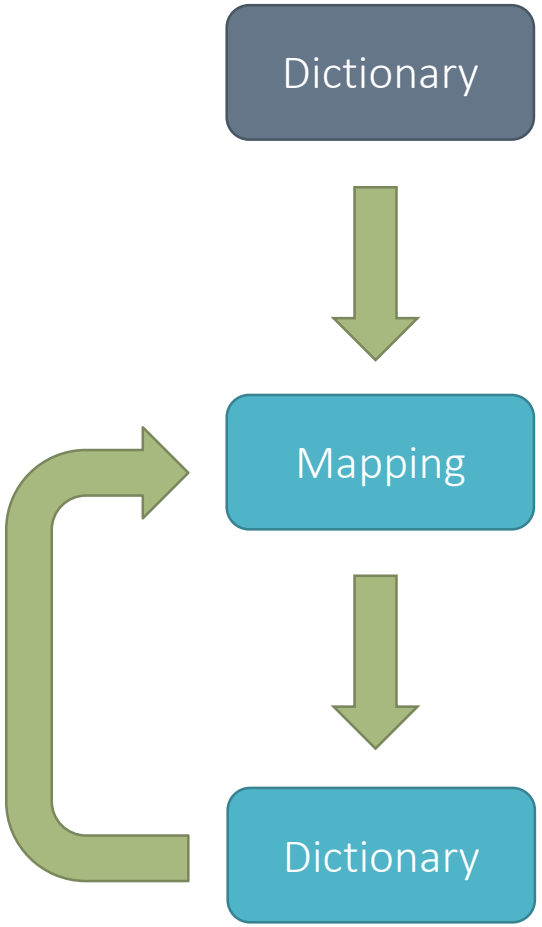


Proposed method

1) Fully unsupervised initialization

English

Intra-lingual similarity distribution



2) Robust self-learning

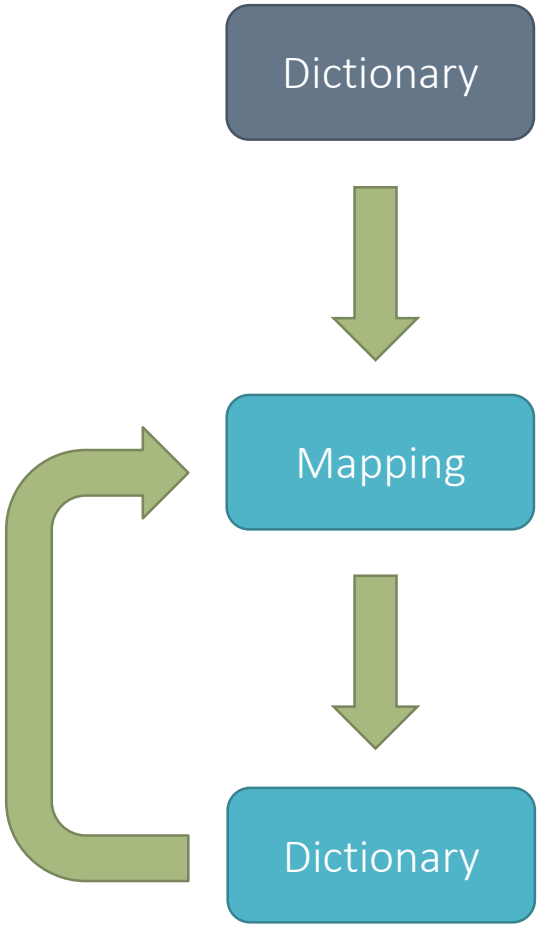
Proposed method

1) Fully unsupervised initialization

English

two

Intra-lingual similarity distribution



2) Robust self-learning

Proposed method

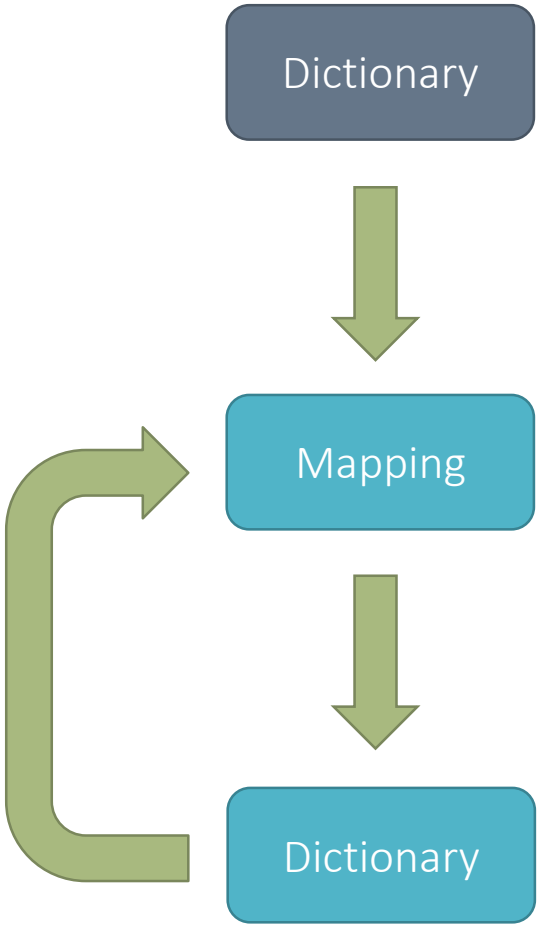
1) Fully unsupervised initialization

English

```
for x in vocab:
   sim("two", x)
```

two

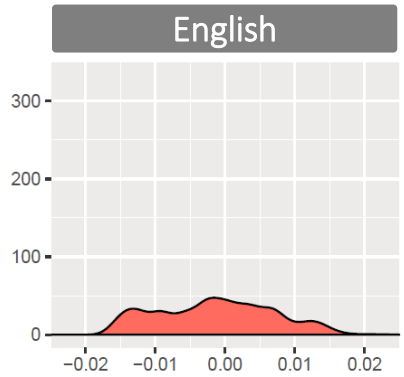
Intra-lingual similarity distribution



2) Robust self-learning

Proposed method

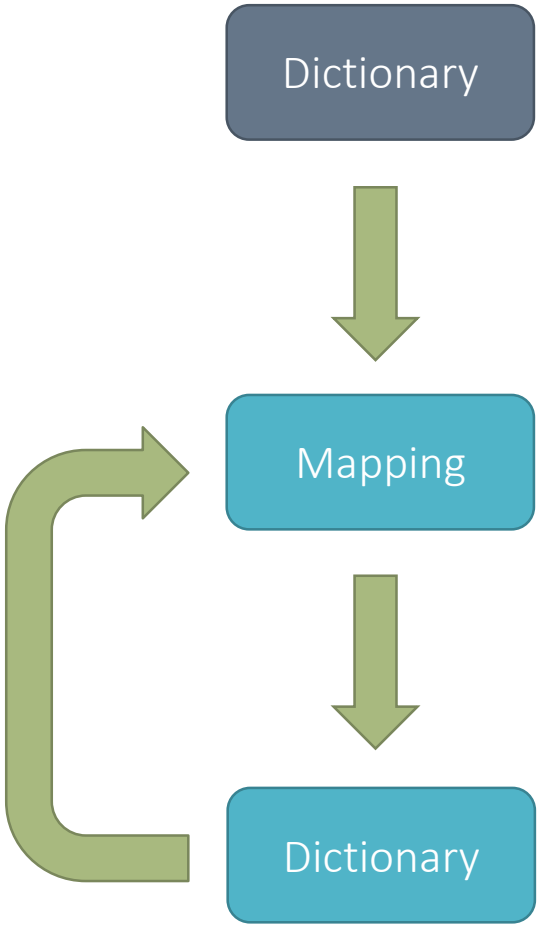
1) Fully unsupervised initialization



two

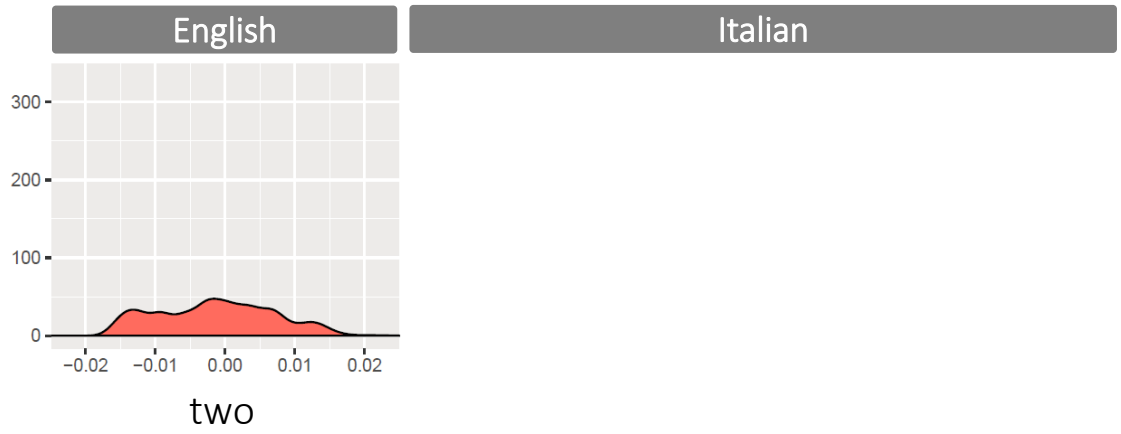
Intra-lingual similarity distribution

2) Robust self-learning



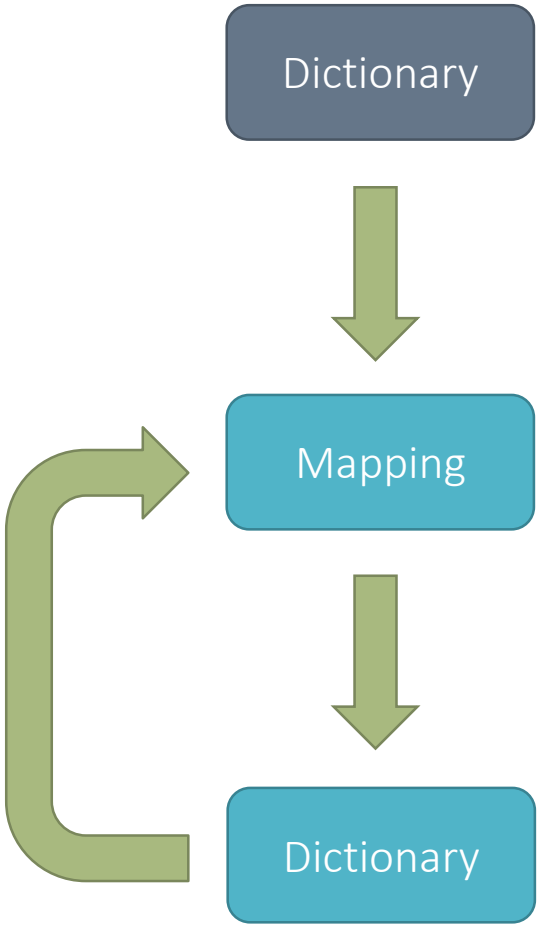
Proposed method

1) Fully unsupervised initialization



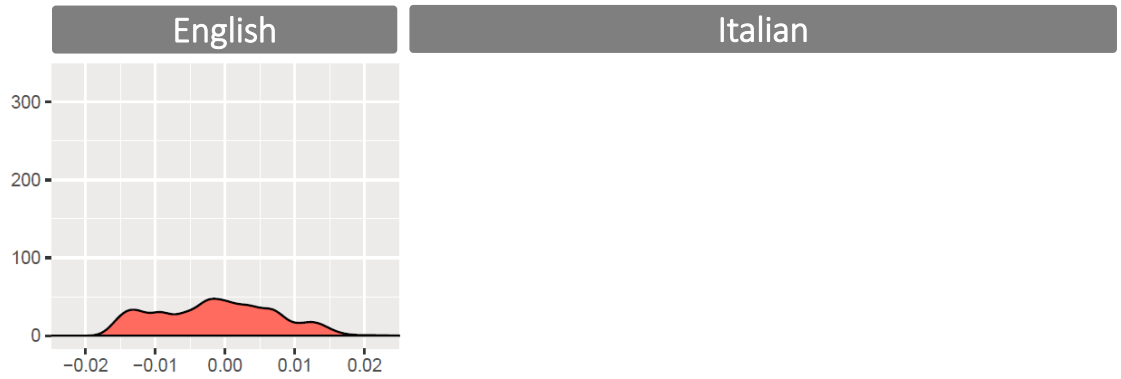
Intra-lingual similarity distribution

2) Robust self-learning



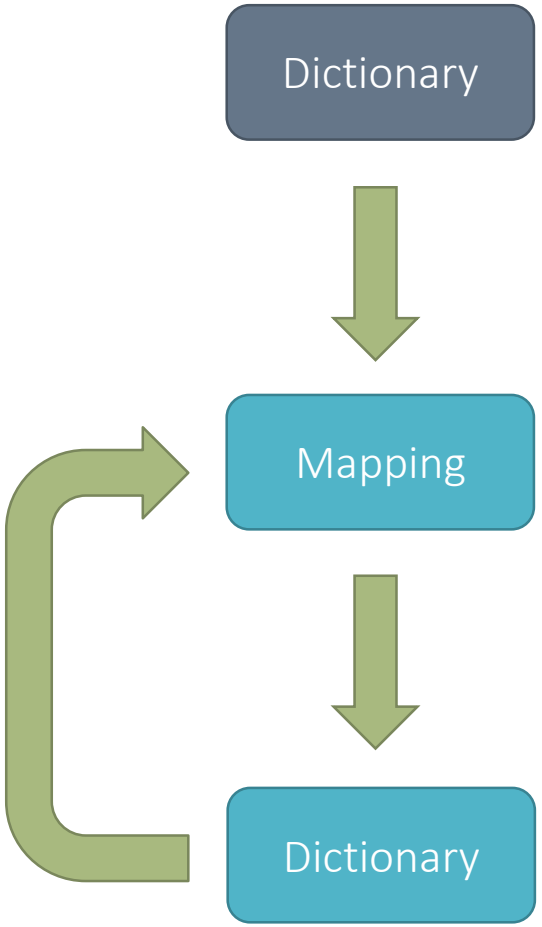
Proposed method

1) Fully unsupervised initialization



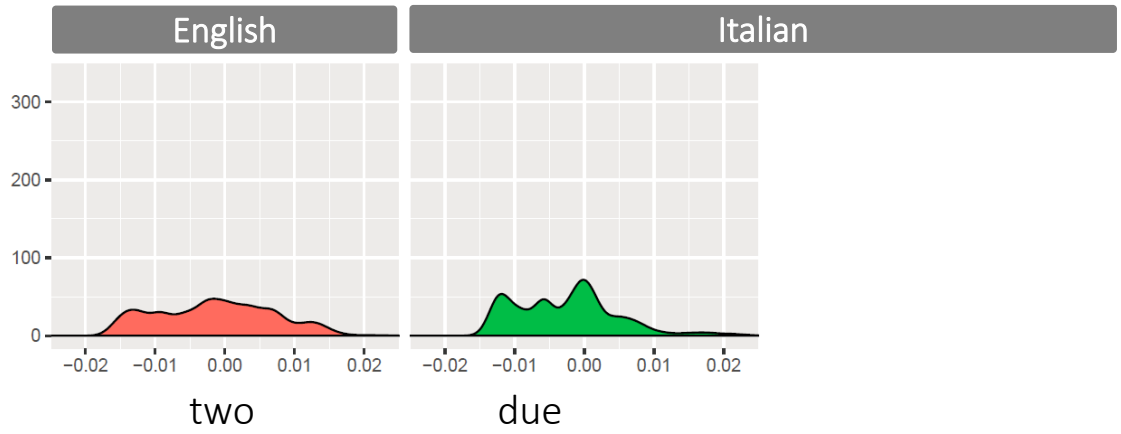
Intra-lingual similarity distribution

2) Robust self-learning



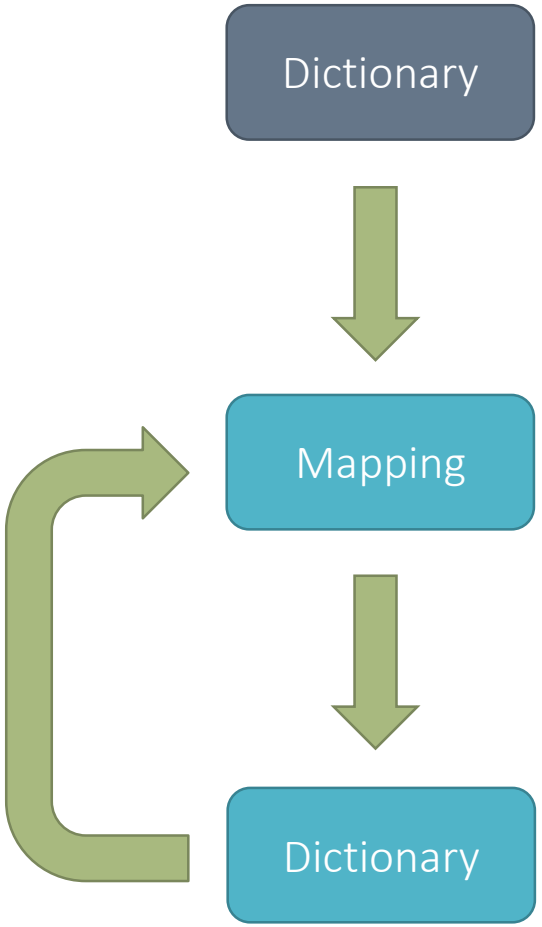
Proposed method

1) Fully unsupervised initialization



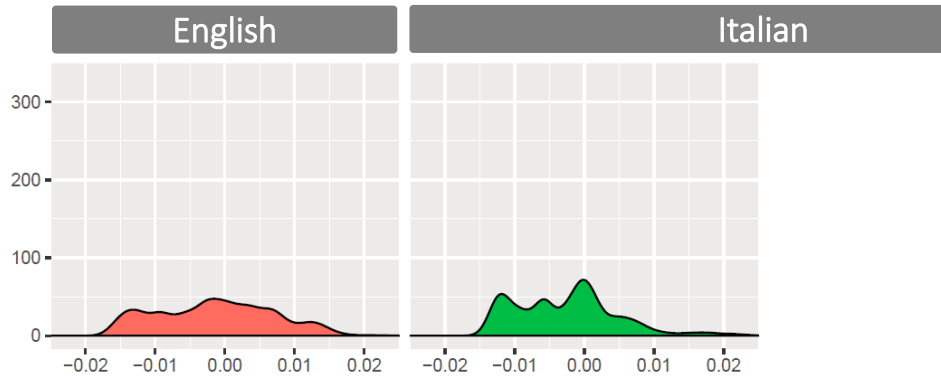
Intra-lingual similarity distribution

2) Robust self-learning



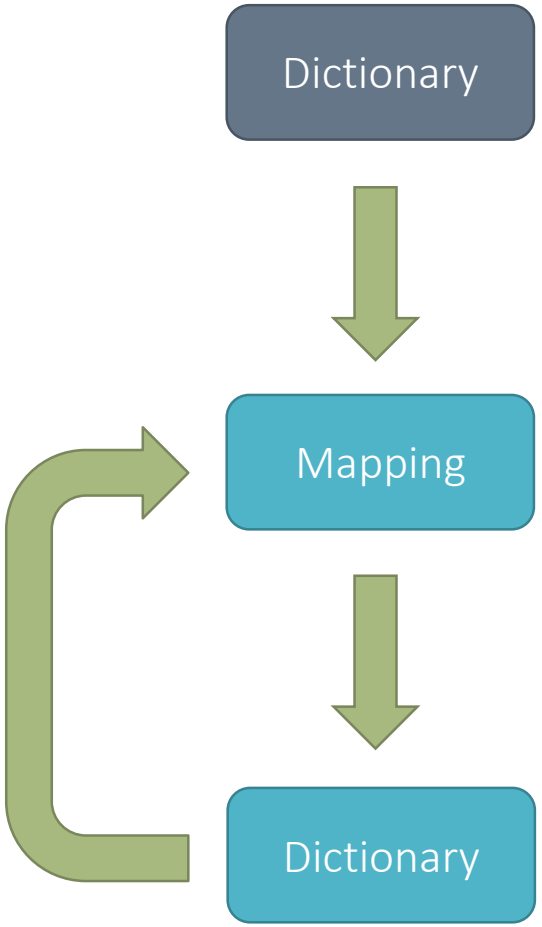
Proposed method

1) Fully unsupervised initialization



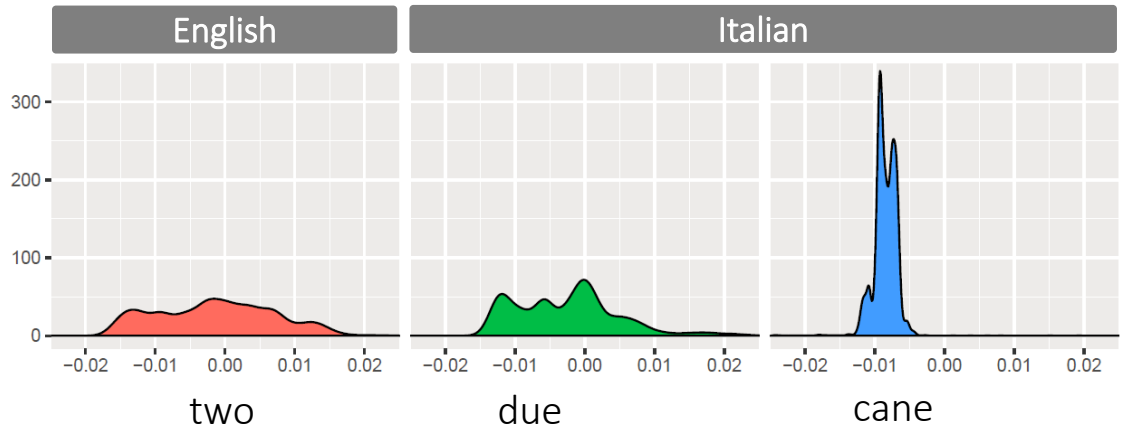
Intra-lingual similarity distribution

2) Robust self-learning



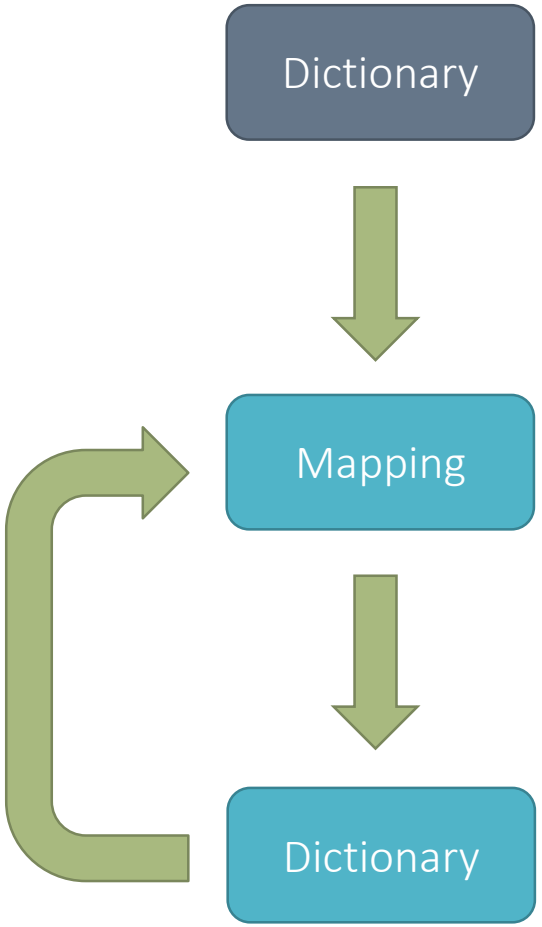
Proposed method

1) Fully unsupervised initialization



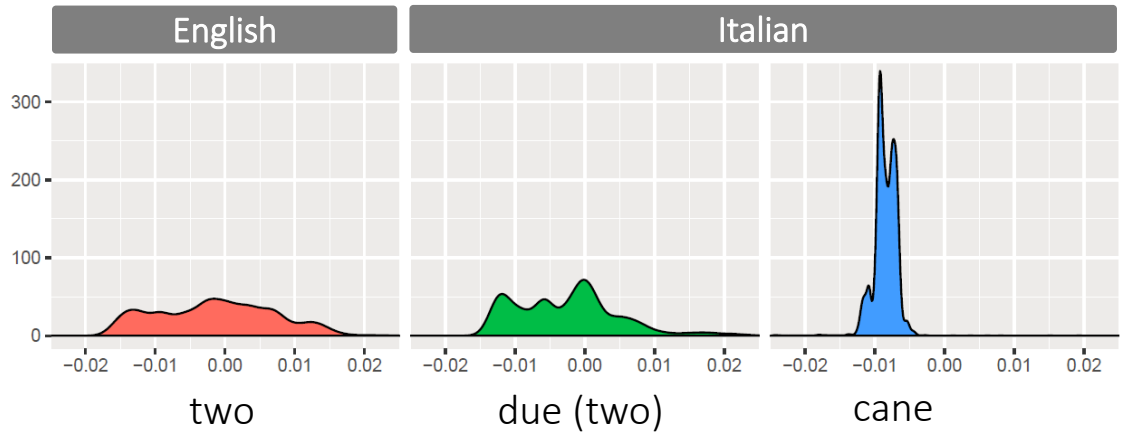
Intra-lingual similarity distribution

2) Robust self-learning



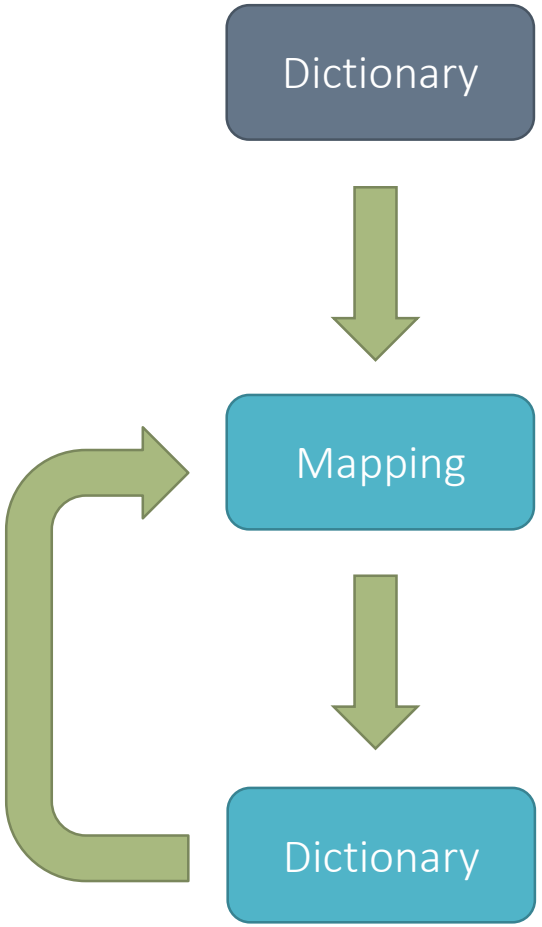
Proposed method

1) Fully unsupervised initialization



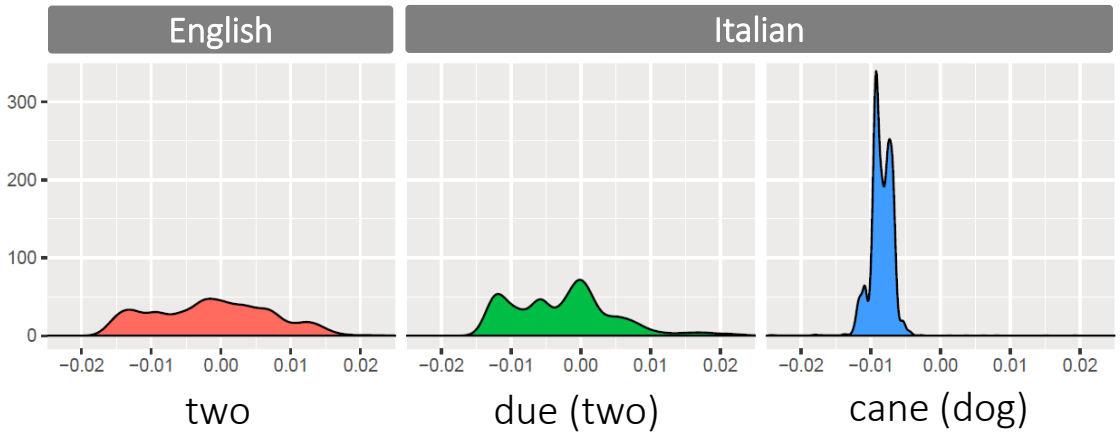
Intra-lingual similarity distribution

2) Robust self-learning



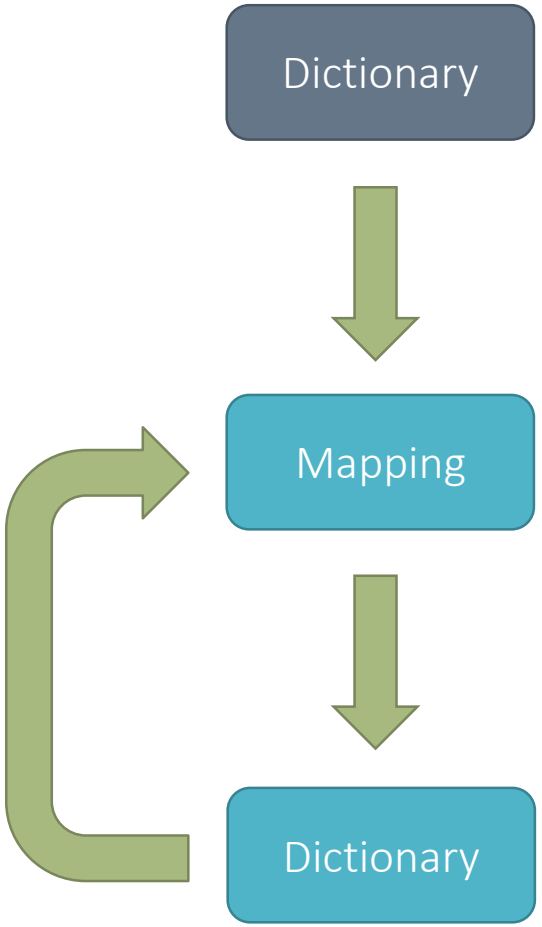
Proposed method

1) Fully unsupervised initialization



Intra-lingual similarity distribution

2) Robust self-learning



Proposed method

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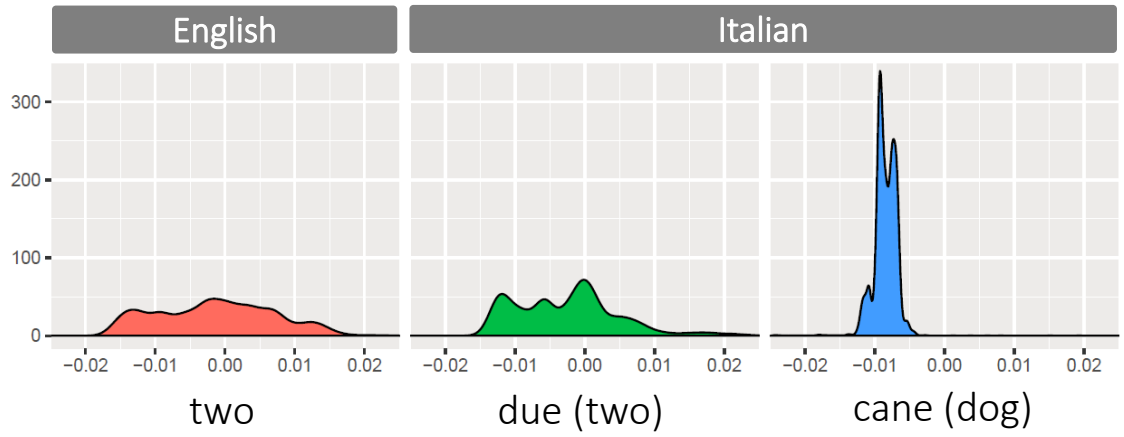
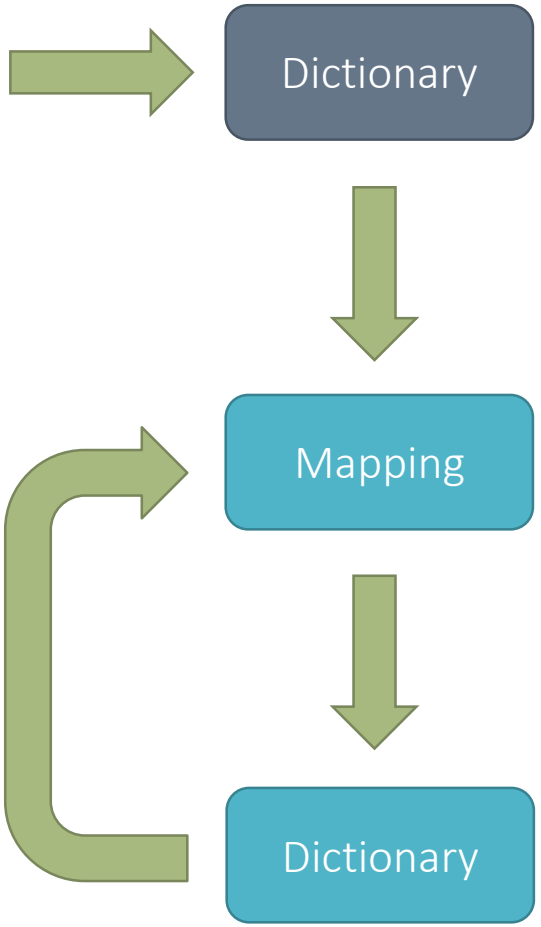


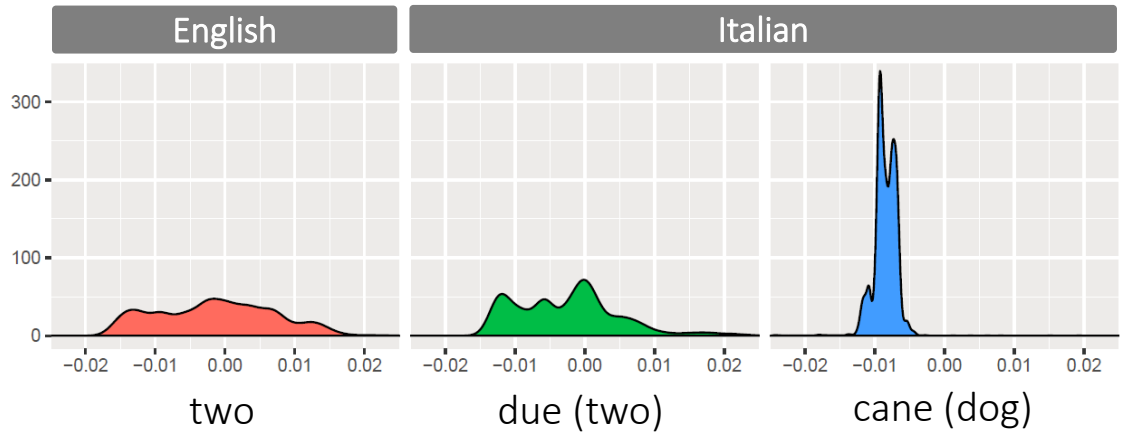
Intra-lingual similarity distribution



2) Robust self-learning

Proposed method

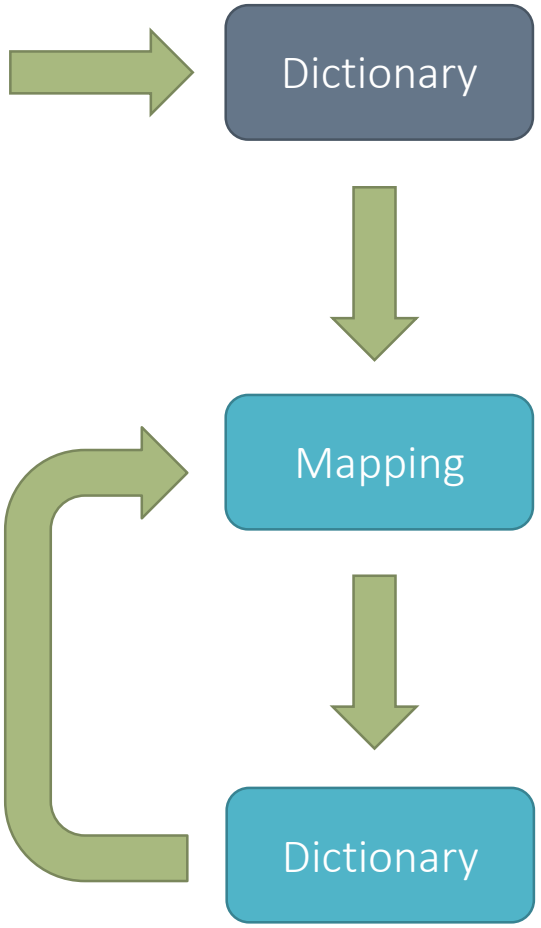
1) Fully unsupervised initialization



Intra-lingual similarity distribution

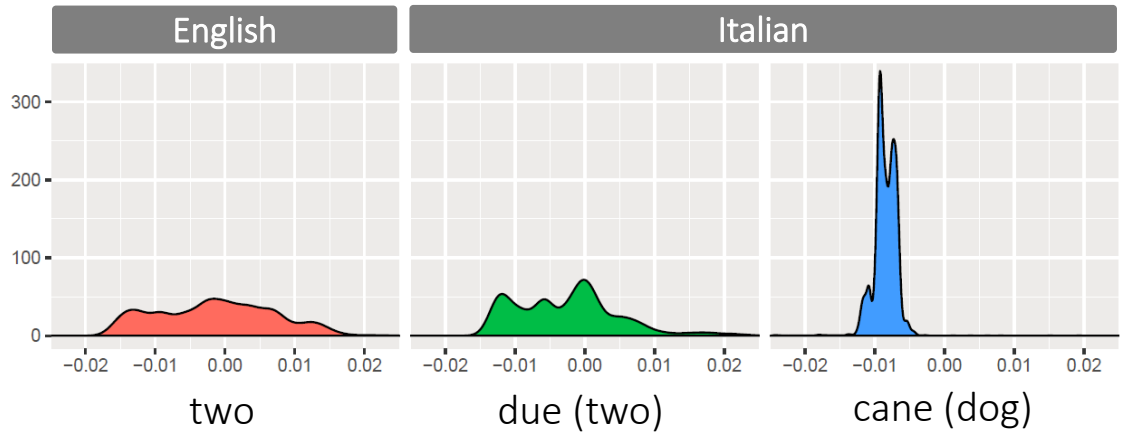
$$X' = \text{sorted}\left(\sqrt{XX^T}\right)$$

2) Robust self-learning



Proposed method

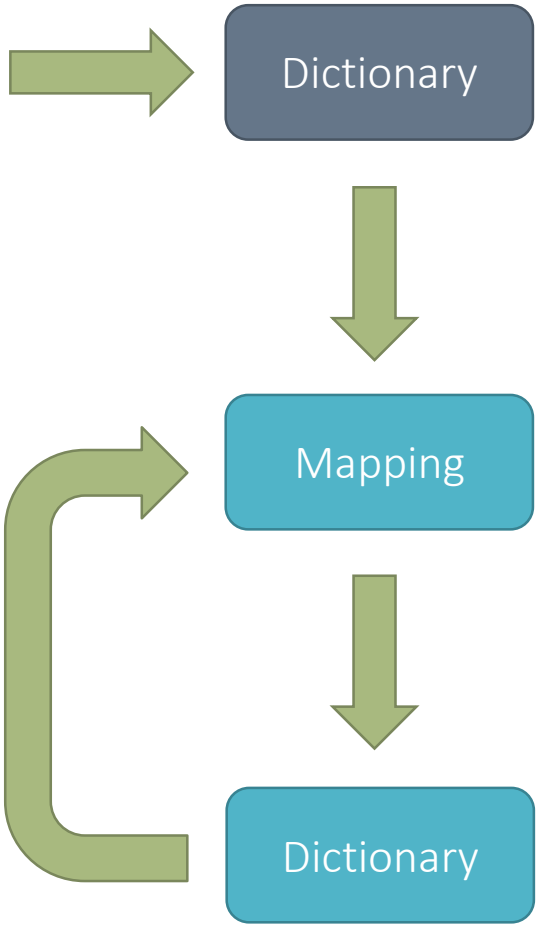
1) Fully unsupervised initialization



Intra-lingual similarity distribution

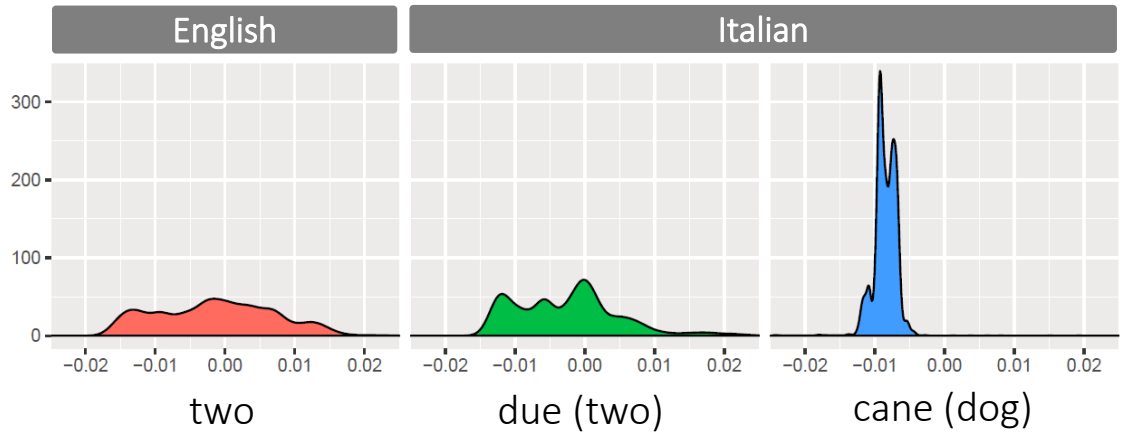
$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$

2) Robust self-learning



Proposed method

1) Fully unsupervised initialization

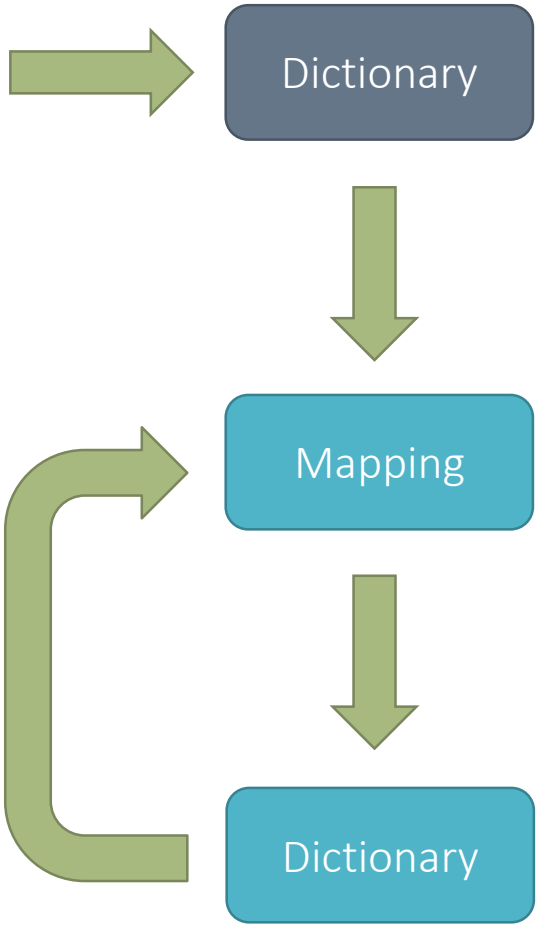


Intra-lingual similarity distribution

$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$

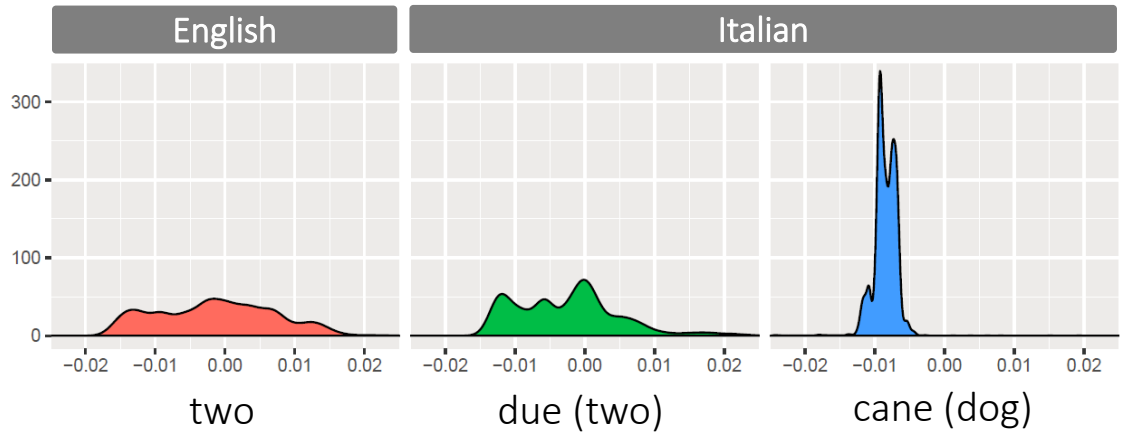
2) Robust self-learning

- Stochastic dictionary induction



Proposed method

1) Fully unsupervised initialization

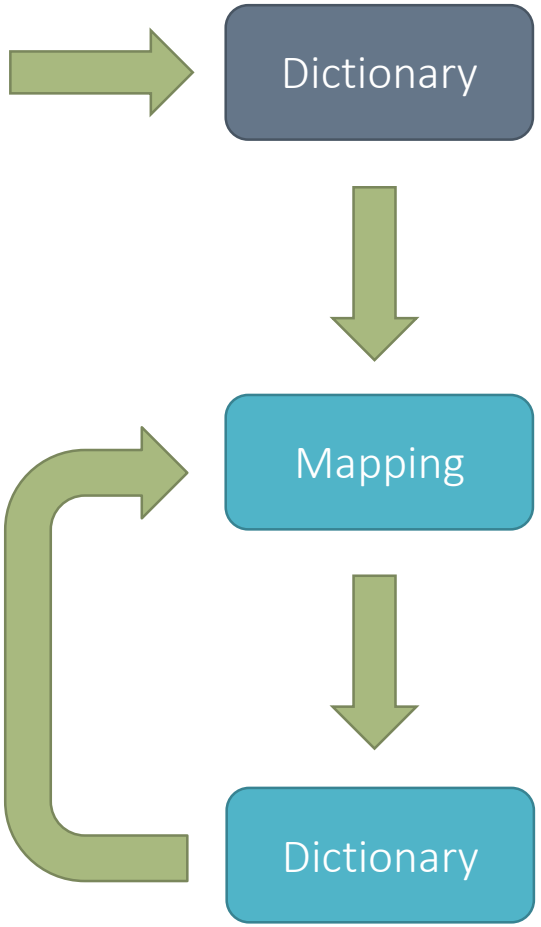


Intra-lingual similarity distribution

$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$

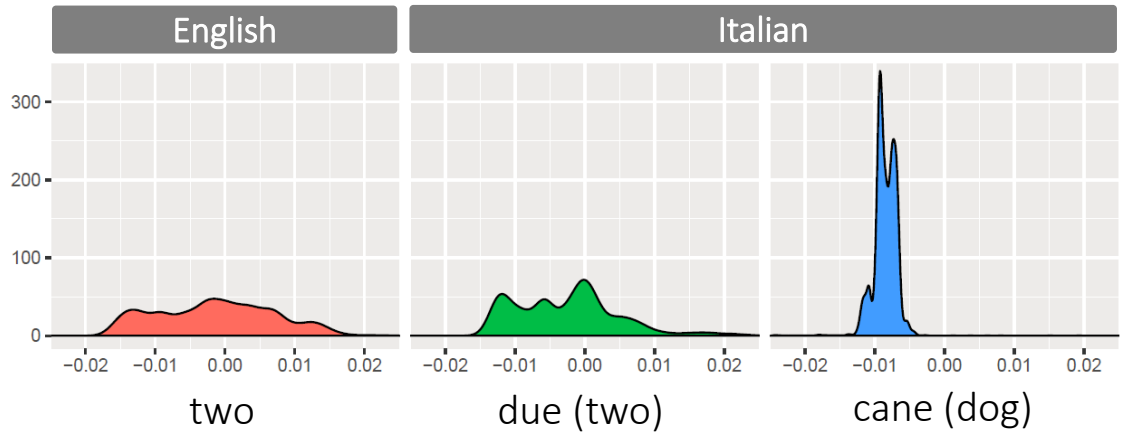
2) Robust self-learning

- Stochastic dictionary induction
- Frequency-based vocabulary cutoff



Proposed method

1) Fully unsupervised initialization

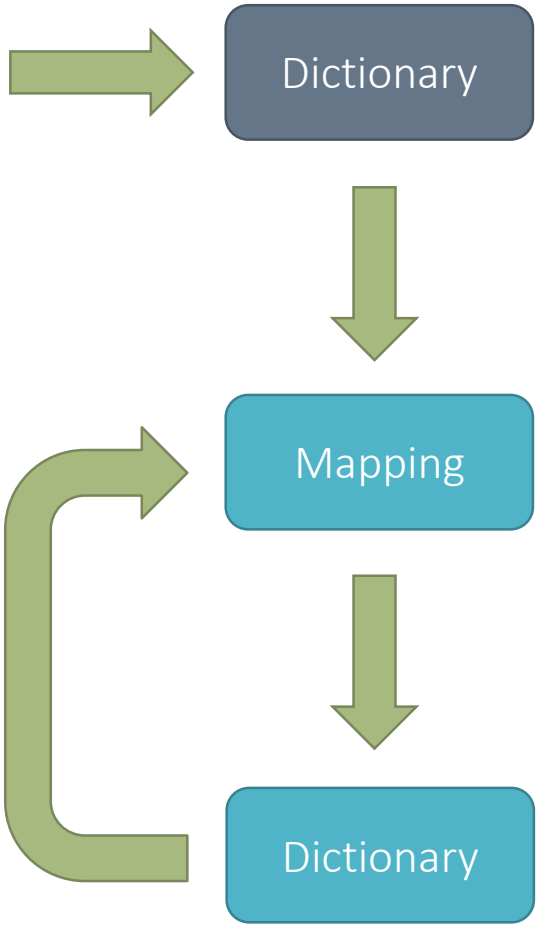


Intra-lingual similarity distribution

$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$

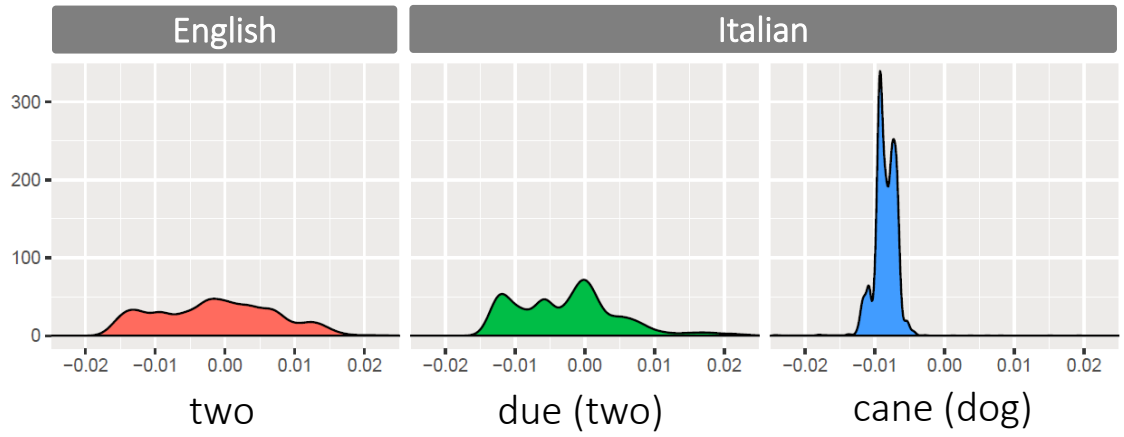
2) Robust self-learning

- Stochastic dictionary induction
- Frequency-based vocabulary cutoff
- CSLS retrieval (Conneau et al., 2018)



Proposed method

1) Fully unsupervised initialization

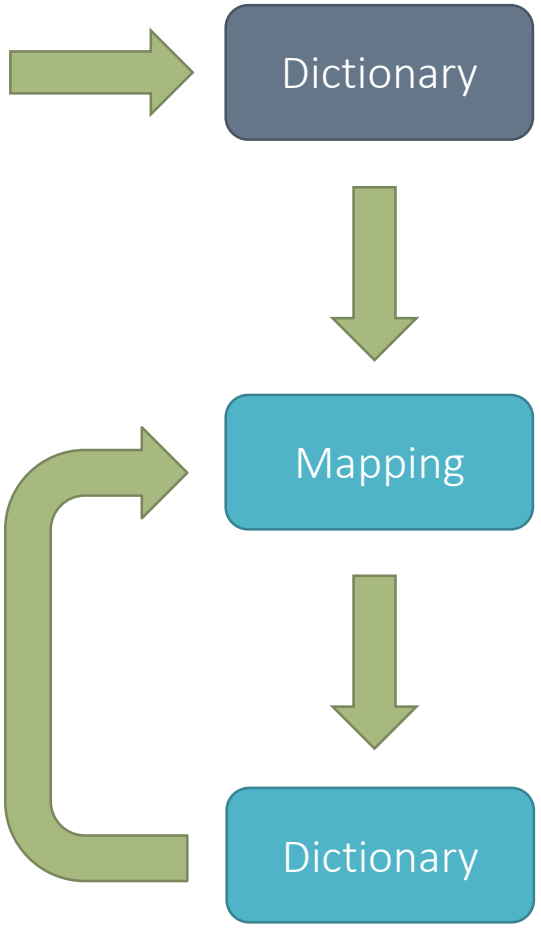


Intra-lingual similarity distribution

$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$

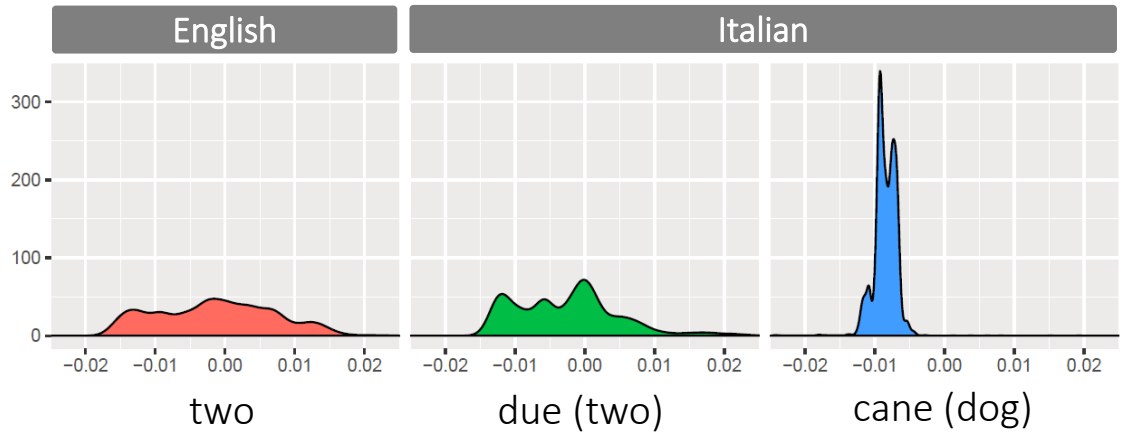
2) Robust self-learning

- Stochastic dictionary induction
- Frequency-based vocabulary cutoff
- CSLS retrieval (Conneau et al., 2018)
- Bidirectional dictionary induction



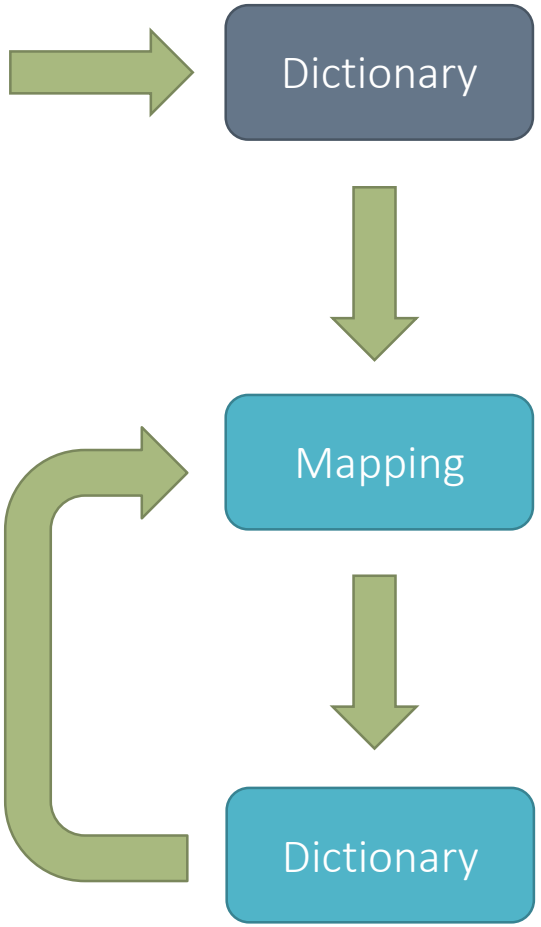
Proposed method

1) Fully unsupervised initialization



Intra-lingual similarity distribution

$$X' = \text{sorted}\left(\sqrt{XX^T}\right) \quad Z' = \text{sorted}\left(\sqrt{ZZ^T}\right)$$



2) Robust self-learning

- Stochastic dictionary induction
- Frequency-based vocabulary cutoff
- CSLS retrieval (Conneau et al., 2018)
- Bidirectional dictionary induction
- Final symmetric re-weighting (Artetxe et al., 2018)

Experiments

Experiments

- Bilingual lexicon extraction

Experiments

- Bilingual lexicon extraction

Method

Experiments

- Bilingual lexicon extraction

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$

Experiments

- Bilingual lexicon extraction

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper

Experiments

- Bilingual lexicon extraction

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method

  ⇒ *Best/average accuracy*

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

Method	ES-EN	IT-EN	TR-EN
Zhang et al. (2017), $\lambda = 1$			
Zhang et al. (2017), $\lambda = 10$			
Conneau et al. (2018), code			
Conneau et al. (2018), paper			
Proposed method			

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

Method	ES-EN	IT-EN	TR-EN
Zhang et al. (2017), $\lambda = 1$	71.43	60.38	0.00
Zhang et al. (2017), $\lambda = 10$	70.24	57.64	21.07
Conneau et al. (2018), code	76.18	**67.32**	32.64
Conneau et al. (2018), paper	76.15	67.21	29.79
Proposed method	**76.43**	66.96	**36.10**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

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Experiments

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- 10 runs for each method
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- 10 runs for each method
  - ⇒ *Best/average accuracy*
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Proposed method	**76.43**	66.96	**36.10**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

Method	ES-EN	IT-EN	TR-EN
Zhang et al. (2017), $\lambda = 1$	68.18	56.45	0.00
Zhang et al. (2017), $\lambda = 10$	66.37	52.60	17.95
Conneau et al. (2018), code	75.82	**67.00**	14.34
Conneau et al. (2018), paper	75.81	60.22	16.48
Proposed method	**76.28**	66.92	**35.93**

Average accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)

Method	ES-EN	IT-EN	TR-EN
Zhang et al. (2017), $\lambda = 1$	10	10	0
Zhang et al. (2017), $\lambda = 10$	10	10	10
Conneau et al. (2018), code	10	10	5
Conneau et al. (2018), paper	10	9	7
Proposed method	10	10	10

Number of successful runs

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method
Zhang et al. (2017), $\lambda = 1$
Zhang et al. (2017), $\lambda = 10$
Conneau et al. (2018), code
Conneau et al. (2018), paper
Proposed method

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$				
Zhang et al. (2017), $\lambda = 10$				
Conneau et al. (2018), code				
Conneau et al. (2018), paper				
Proposed method				

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0.00	0.00	0.00	0.00
Zhang et al. (2017), $\lambda = 10$	0.00	0.00	0.01	0.01
Conneau et al. (2018), code	45.40	47.27	1.62	36.20
Conneau et al. (2018), paper	45.27	0.07	0.07	35.47
Proposed method	**48.53**	**48.47**	**33.50**	**37.60**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0.00	0.00	0.00	0.00
Zhang et al. (2017), $\lambda = 10$	0.00	0.00	0.01	0.01
Conneau et al. (2018), code	45.40	47.27	1.62	36.20
Conneau et al. (2018), paper	45.27	0.07	0.07	35.47
Proposed method	**48.53**	**48.47**	**33.50**	**37.60**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0.00	0.00	0.00	0.00
Zhang et al. (2017), $\lambda = 10$	0.00	0.00	0.01	0.01
Conneau et al. (2018), code	45.40	47.27	1.62	36.20
Conneau et al. (2018), paper	45.27	0.07	0.07	35.47
Proposed method	**48.53**	**48.47**	**33.50**	**37.60**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0.00	0.00	0.00	0.00
Zhang et al. (2017), $\lambda = 10$	0.00	0.00	0.01	0.01
Conneau et al. (2018), code	45.40	47.27	1.62	36.20
Conneau et al. (2018), paper	45.27	0.07	0.07	35.47
Proposed method	**48.53**	**48.47**	**33.50**	**37.60**

Best accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0.00	0.00	0.00	0.00
Zhang et al. (2017), $\lambda = 10$	0.00	0.00	0.01	0.01
Conneau et al. (2018), code	13.55	42.15	0.38	21.23
Conneau et al. (2018), paper	9.10	0.01	0.01	7.09
Proposed method	**48.13**	**48.19**	**32.63**	**37.33**

Average accuracy (%)

Experiments

- Bilingual lexicon extraction
- 10 runs for each method
  - ⇒ *Best/average accuracy*
  - ⇒ *Successful runs (>5% accuracy)*
- (Easy) dataset by Zhang et al. (2017)
- (Hard) dataset by Dinu et al. (2016) + extensions

Method	EN-IT	EN-DE	EN-FI	EN-ES
Zhang et al. (2017), $\lambda = 1$	0	0	0	0
Zhang et al. (2017), $\lambda = 10$	0	0	0	0
Conneau et al. (2018), code	3	9	0	6
Conneau et al. (2018), paper	2	0	0	2
Proposed method	10	10	10	10

Number of successful runs

Experiments

Supervision	Method

Experiments

Supervision	Method
	Mikolov et al. (2013)
	Faruqui and Dyer (2014)
	Shigeto et al. (2015)
	Dinu et al. (2015)
	Lazaridou et al. (2015)
5k dict.	Xing et al. (2015)
	Zhang et al. (2016)
	Artetxe et al. (2016)
	Artetxe et al. (2017)
	Smith et al. (2017)
	Artetxe et al. (2018)

Experiments

Supervision	Method
5k dict.	Mikolov et al. (2013)
	Faruqui and Dyer (2014)
	Shigeto et al. (2015)
	Dinu et al. (2015)
	Lazaridou et al. (2015)
	Xing et al. (2015)
	Zhang et al. (2016)
	Artetxe et al. (2016)
	Artetxe et al. (2017)
	Smith et al. (2017)
	Artetxe et al. (2018)
25 dict.	Artetxe et al. (2017)
Init. heurist.	Smith et al. (2017), cognates
	Artetxe et al. (2017), num.

Experiments

Supervision	Method
5k dict.	Mikolov et al. (2013)
	Faruqui and Dyer (2014)
	Shigeto et al. (2015)
	Dinu et al. (2015)
	Lazaridou et al. (2015)
	Xing et al. (2015)
	Zhang et al. (2016)
	Artetxe et al. (2016)
	Artetxe et al. (2017)
	Smith et al. (2017)
	Artetxe et al. (2018)
25 dict.	Artetxe et al. (2017)
Init. heurist.	Smith et al. (2017), cognates
	Artetxe et al. (2017), num.
None	Zhang et al. (2017), $\lambda = 1$
	Zhang et al. (2017), $\lambda = 10$
	Conneau et al. (2018), code‡
	Conneau et al. (2018), paper‡
	Proposed method

Experiments

Supervision	Method	EN-IT	EN-DE	EN-FI	EN-ES
5k dict.	Mikolov et al. (2013)				
	Faruqui and Dyer (2014)				
	Shigeto et al. (2015)				
	Dinu et al. (2015)				
	Lazaridou et al. (2015)				
	Xing et al. (2015)				
	Zhang et al. (2016)				
	Artetxe et al. (2016)				
	Artetxe et al. (2017)				
	Smith et al. (2017)				
	Artetxe et al. (2018)				
25 dict.	Artetxe et al. (2017)				
Init. heurist.	Smith et al. (2017), cognates				
	Artetxe et al. (2017), num.				
None	Zhang et al. (2017), $\lambda = 1$				
	Zhang et al. (2017), $\lambda = 10$				
	Conneau et al. (2018), code‡				
	Conneau et al. (2018), paper‡				
	Proposed method				

Experiments

Supervision	Method	EN-IT	EN-DE	EN-FI	EN-ES
5k dict.	Mikolov et al. (2013)	34.93†	35.00†	25.91†	27.73†
	Faruqui and Dyer (2014)	38.40*	37.13*	27.60*	26.80*
	Shigeto et al. (2015)	41.53†	43.07†	31.04†	33.73†
	Dinu et al. (2015)	37.7	38.93*	29.14*	30.40*
	Lazaridou et al. (2015)	40.2	-	-	-
	Xing et al. (2015)	36.87†	41.27†	28.23†	31.20†
	Zhang et al. (2016)	36.73†	40.80†	28.16†	31.07†
	Artetxe et al. (2016)	39.27	41.87*	30.62*	31.40*
	Artetxe et al. (2017)	39.67	40.87	28.72	-
	Smith et al. (2017)	43.1	43.33†	29.42†	35.13†
	Artetxe et al. (2018)	45.27	44.13	**32.94**	36.60
25 dict.	Artetxe et al. (2017)	37.27	39.60	28.16	-
Init. heurist.	Smith et al. (2017), cognates	39.9	-	-	-
	Artetxe et al. (2017), num.	39.40	40.27	26.47	-
None	Zhang et al. (2017), $\lambda = 1$	0.00*	0.00*	0.00*	0.00*
	Zhang et al. (2017), $\lambda = 10$	0.00*	0.00*	0.01*	0.01*
	Conneau et al. (2018), code‡	45.15*	46.83*	0.38*	35.38*
	Conneau et al. (2018), paper‡	45.1	0.01*	0.01*	35.44*
	Proposed method	**48.13**	**48.19**	32.63	**37.33**

Experiments

Supervision	Method	EN-IT	EN-DE	EN-FI	EN-ES
5k dict.	Mikolov et al. (2013)	34.93†	35.00†	25.91†	27.73†
	Faruqui and Dyer (2014)	38.40*	37.13*	27.60*	26.80*
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None	Zhang et al. (2017), $\lambda = 1$	0.00*	0.00*	0.00*	0.00*
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	Artetxe et al. (2017), num.	39.40	40.27	26.47	-
None	Zhang et al. (2017), $\lambda = 1$	0.00*	0.00*	0.00*	0.00*
	Zhang et al. (2017), $\lambda = 10$	0.00*	0.00*	0.01*	0.01*
	Conneau et al. (2018), code‡	45.15*	46.83*	0.38*	35.38*
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Experiments

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	Xing et al. (2015)	36.87†	41.27†	28.23†	31.20†
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	Artetxe et al. (2017)	39.67	40.87	28.72	-
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Init. heurist.	Smith et al. (2017), cognates	39.9	-	-	-
	Artetxe et al. (2017), num.	39.40	40.27	26.47	-
None	Zhang et al. (2017), $\lambda = 1$	0.00*	0.00*	0.00*	0.00*
	Zhang et al. (2017), $\lambda = 10$	0.00*	0.00*	0.01*	0.01*
	Conneau et al. (2018), code‡	45.15*	46.83*	0.38*	35.38*
	Conneau et al. (2018), paper‡	45.1	0.01*	0.01*	35.44*
	Proposed method	**48.13**	**48.19**	32.63	**37.33**

Experiments

Supervision	Method	EN-IT	EN-DE	EN-FI	EN-ES
5k dict.	Mikolov et al. (2013)	34.93†	35.00†	25.91†	27.73†
	Faruqui and Dyer (2014)	38.40*	37.13*	27.60*	26.80*
	Shigeto et al. (2015)	41.53†	43.07†	31.04†	33.73†
	Dinu et al. (2015)	37.7	38.93*	29.14*	30.40*
	Lazaridou et al. (2015)	40.2	-	-	-
	Xing et al. (2015)	36.87†	41.27†	28.23†	31.20†
	Zhang et al. (2016)	36.73†	40.80†	28.16†	31.07†
	Artetxe et al. (2016)	39.27	41.87*	30.62*	31.40*
	Artetxe et al. (2017)	39.67	40.87	28.72	-
	Smith et al. (2017)	43.1	43.33†	29.42†	35.13†
	Artetxe et al. (2018)	45.27	44.13	**32.94**	36.60
25 dict.	Artetxe et al. (2017)	37.27	39.60	28.16	-
Init. heurist.	Smith et al. (2017), cognates	39.9	-	-	-
	Artetxe et al. (2017), num.	39.40	40.27	26.47	-
None	Zhang et al. (2017), $\lambda = 1$	0.00*	0.00*	0.00*	0.00*
	Zhang et al. (2017), $\lambda = 10$	0.00*	0.00*	0.01*	0.01*
	Conneau et al. (2018), code‡	45.15*	46.83*	0.38*	35.38*
	Conneau et al. (2018), paper‡	45.1	0.01*	0.01*	35.44*
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Conclusions

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  - ⇒ *Fully unsupervised initialization*
  - ⇒ *Robust self-learning*
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- Future work: from bilingual to multilingual

One more thing…

>

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```
> git clone https://github.com/artetxem/vecmap.git
>
```

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> git clone https://github.com/artetxem/vecmap.git
> python3 vecmap/map_embeddings.py
```

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> git clone https://github.com/artetxem/vecmap.git
> python3 vecmap/map_embeddings.py --unsupervised
```

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> python3 vecmap/map_embeddings.py --unsupervised \
  SRC.EMB TRG.EMB
```

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https://github.com/artetxem/vecmap

Thank you!

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