Natural Language Processing

Lecture 03

Dirk Hovy

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@dirk_hovy

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Today's Goals

- Understand the difference between **sparse** and **dense** representations
- Learn about **bag of words** (BOW) representations
- Learn about **word2vec** and **doc2vec**

Ham or Spam?

From: offr4u@rsph.com
Subject: Unique wealth offerings
To: dirk.hovy@unibocconi.it

Greetings dear friend

We have an amazing offer 4U: Click here to get access to a free consultation for serious wealth benefits! Urgent: offer expires soon.
Works guaranteed! Triple your income.

Ham or Spam?

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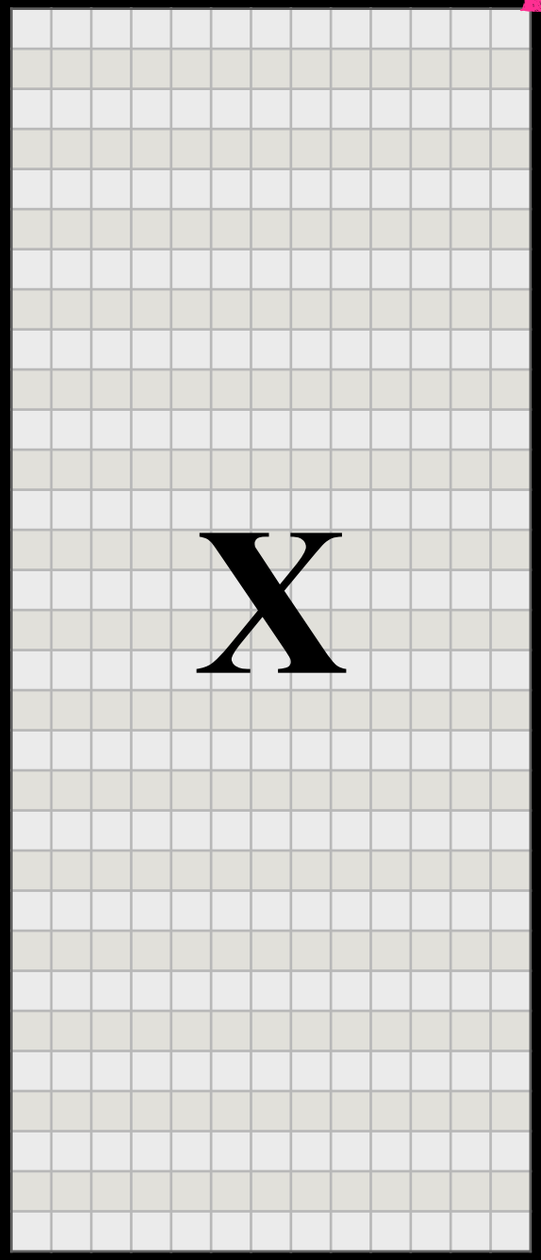
Spam terms:

- 4U
- click
- amazing
- free
- guarantee
- offer
- urgent
- dear friend
- income
- serious

Terminology

DATA MATRIX



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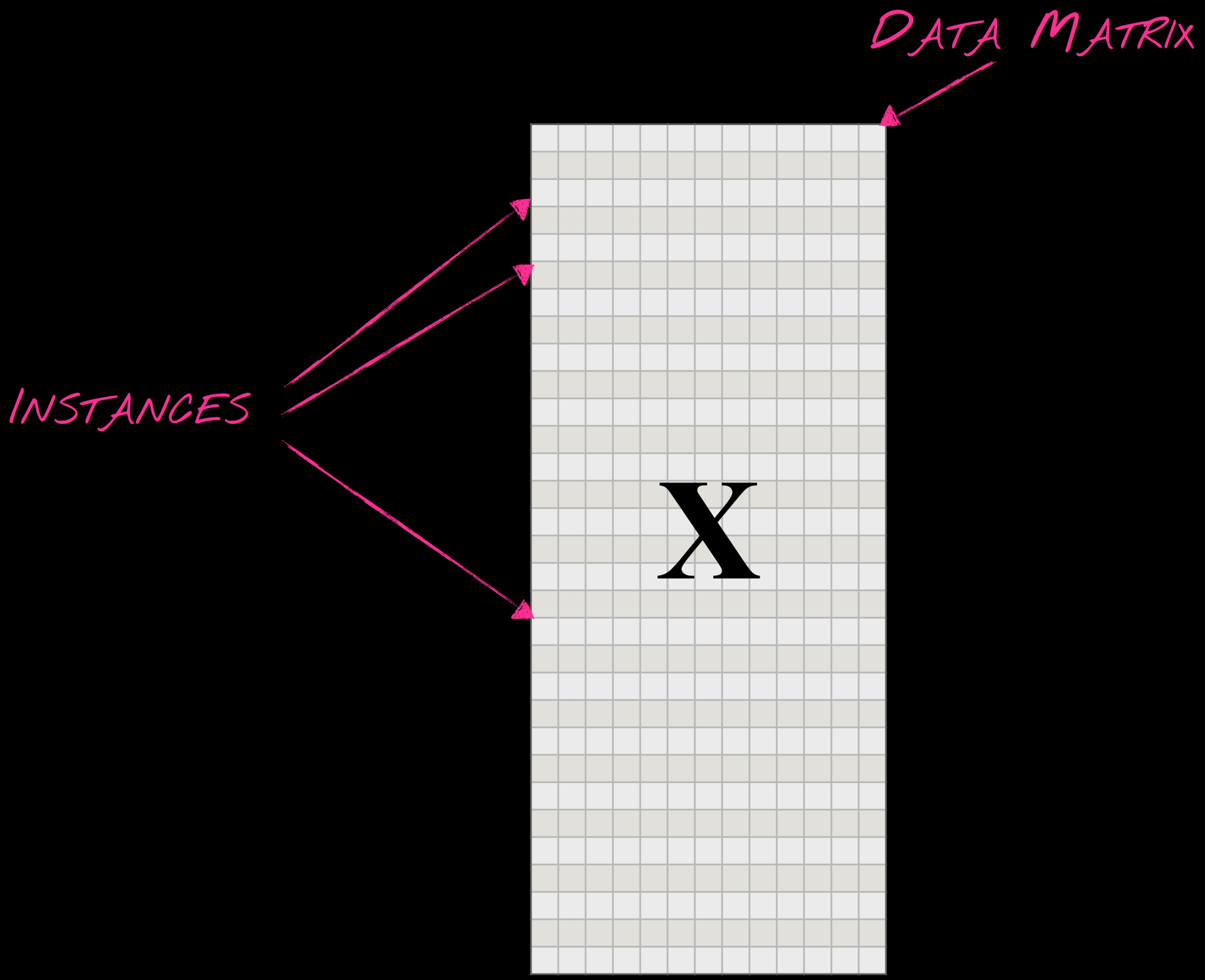

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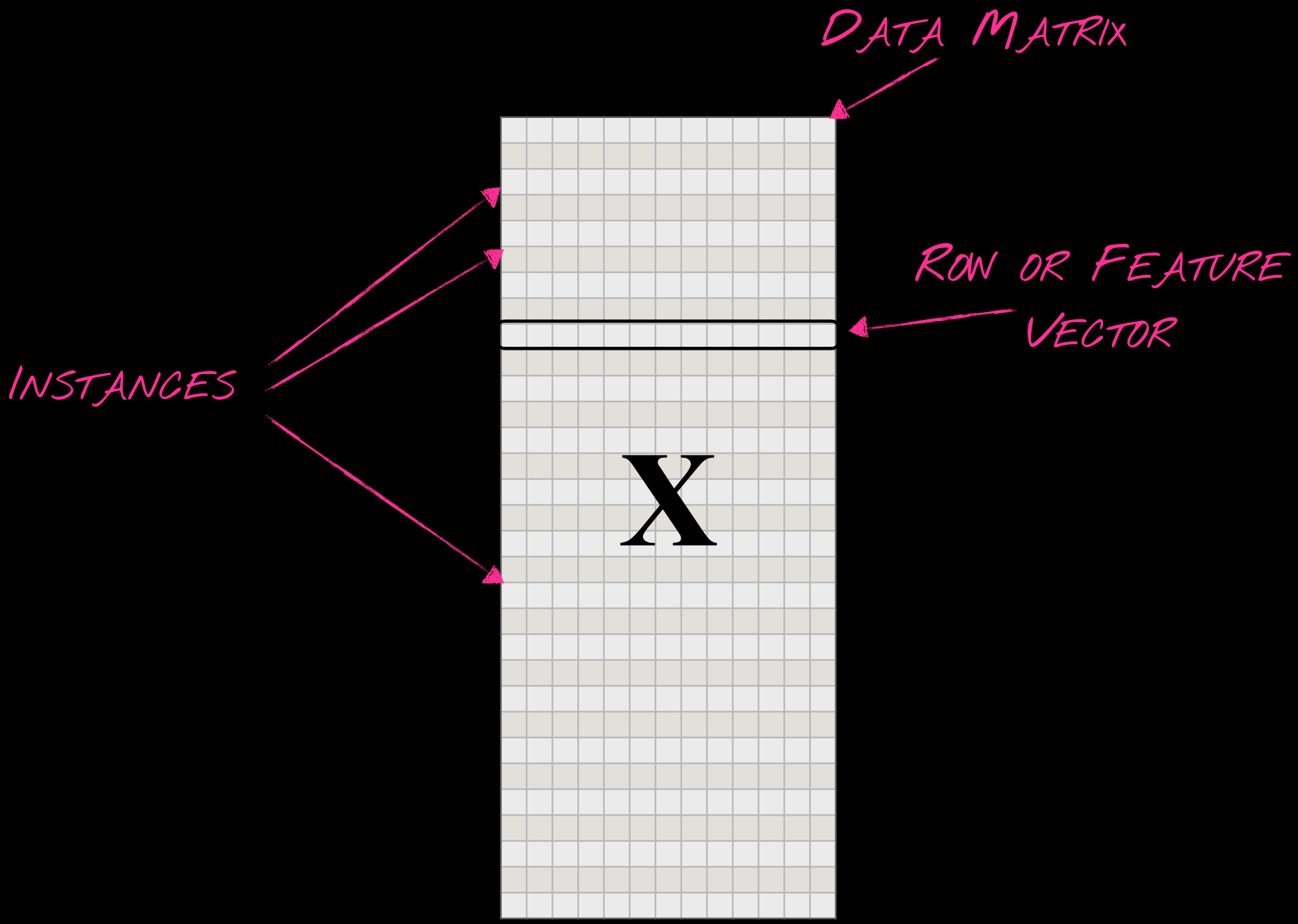

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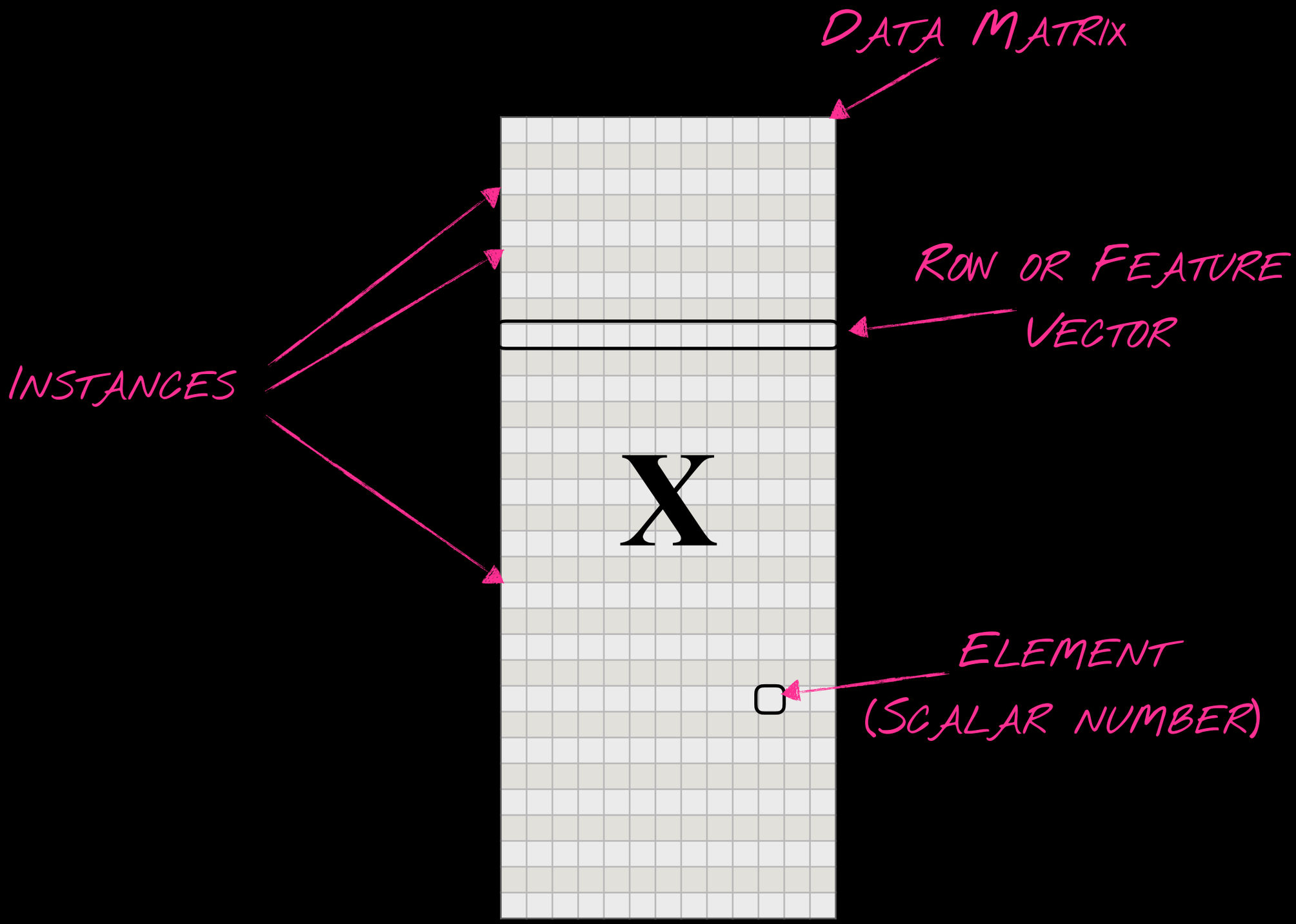

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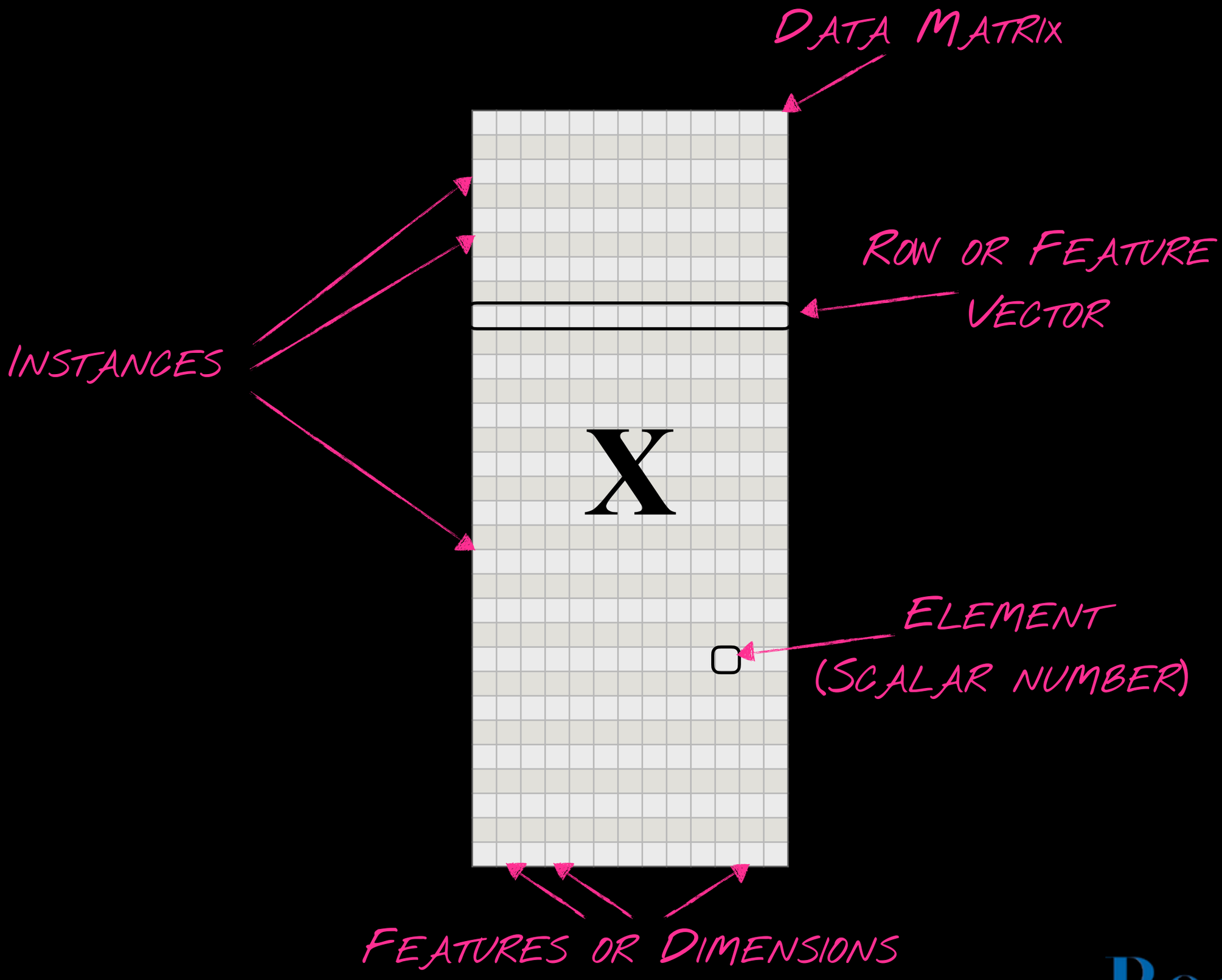

Discrete Representations

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Bags of words (BOW)

COUNT WORDS

```
{
   'shakespeare': 6,
   'in': 20,
   'love': 6,
   'is': ...
}
```

shakespeare	in	...	love	beer
6	... 20	0 ...	0 6	0 ... 0

X

VECTORIZE FEATURES

Bags of words (BOW)

COUNT WORDS

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{
   'shakespeare': 6,
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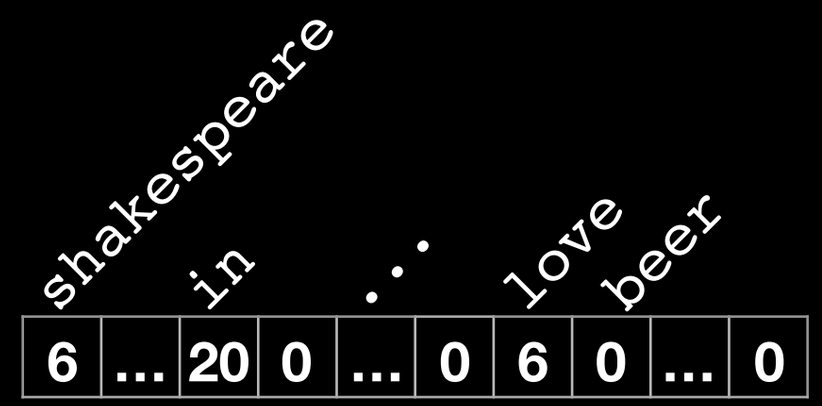

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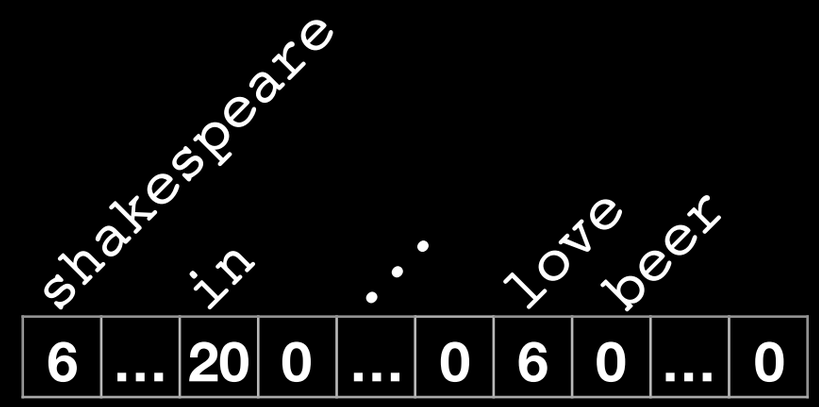

X

VECTORIZE FEATURES

Quiz!

What happens if we allow *every possible word* to constitute a feature?

Quiz!

What happens if we allow *every possible word* to constitute a feature?

Expensive computation, and vectors have too many zeros.

Quiz!

What happens if we allow *<u>every</u> possible word* to constitute a feature?

Expensive computation, and vectors have too many zeros.

Limit to most frequent/informative words!

Counting Trouble

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Counting Trouble

…And a Man named Zipf

Bocconi

Counting Trouble

…And a Man named Zipf

Bocconi

Counting Trouble

…And a Man named Zipf

Bocconi

Counting Trouble

…And a Man named Zipf

50000
40000
30000
20000
10000
0

50%

THE OTHER 50%...

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N-grams

"As Gregor Samsa awoke one morning from uneasy dreams, he found himself transformed in his bed into a gigantic insect-like creature."

N-grams

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Unigrams `As, Gregor, Samsa, awoke, one, morning, from, uneasy, dreams, ...`

N-grams

"As Gregor Samsa awoke one morning from uneasy dreams, he found himself transformed in his bed into a gigantic insect-like creature."

Unigrams `As, Gregor, Samsa, awoke, one, morning, from, uneasy, dreams, ...`

Bigrams `As_Gregor, Gregor_Samsa, Samsa_awoke, awoke_one, one_morning, ...`

N-grams

"As Gregor Samsa awoke one morning from uneasy dreams, he found himself transformed in his bed into a gigantic insect-like creature."

Unigrams `As, Gregor, Samsa, awoke, one, morning, from, uneasy, dreams, ...`

Bigrams `As_Gregor, Gregor_Samsa, Samsa_awoke, awoke_one, one_morning, ...`

Trigrams `As_Gregor_Samsa, Gregor_Samsa_awoke, Samsa_awoke_one, awoke_one_morning, ...`

N-grams

"As Gregor Samsa awoke one morning from uneasy dreams, he found himself transformed in his bed into a gigantic insect-like creature."

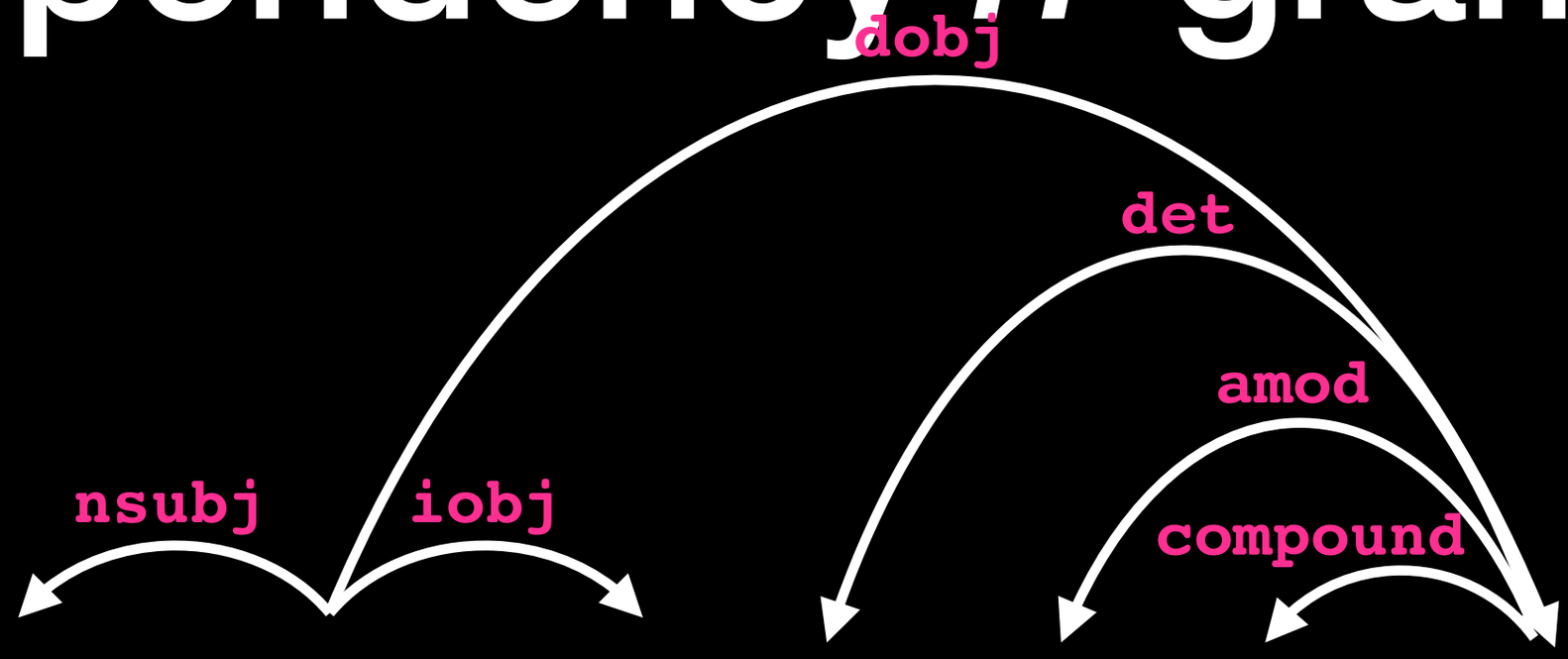
Unigrams `As, Gregor, Samsa, awoke, one, morning, from, uneasy, dreams, ...`

Bigrams `As_Gregor, Gregor_Samsa, Samsa_awoke, awoke_one, one_morning, ...`

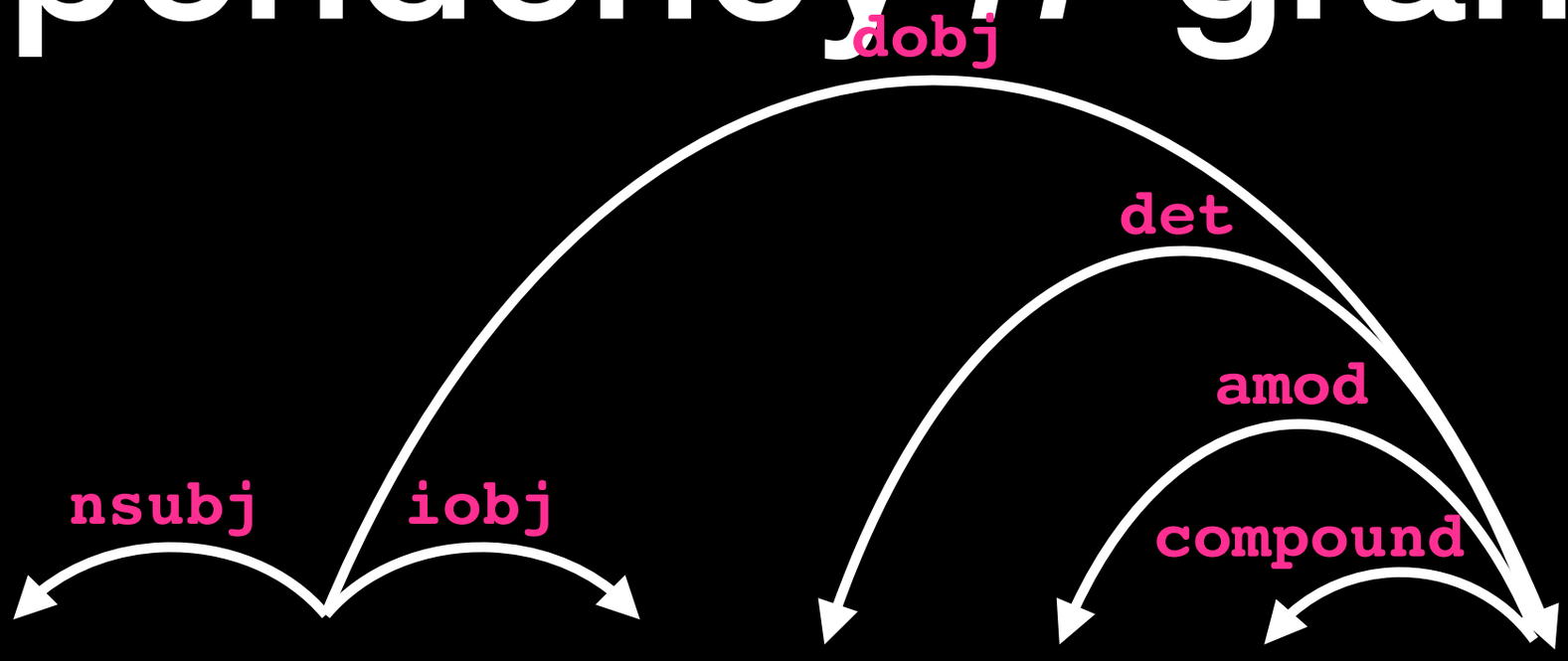
Trigrams `As_Gregor_Samsa, Gregor_Samsa_awoke, Samsa_awoke_one, awoke_one_morning, ...`

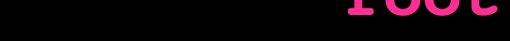
4-grams `As_Gregor_Samsa_awoke, Gregor_Samsa_awoke_one, Samsa_awoke_one_morning, ...`

Dependency *n*-grams



Dependency *n*-grams





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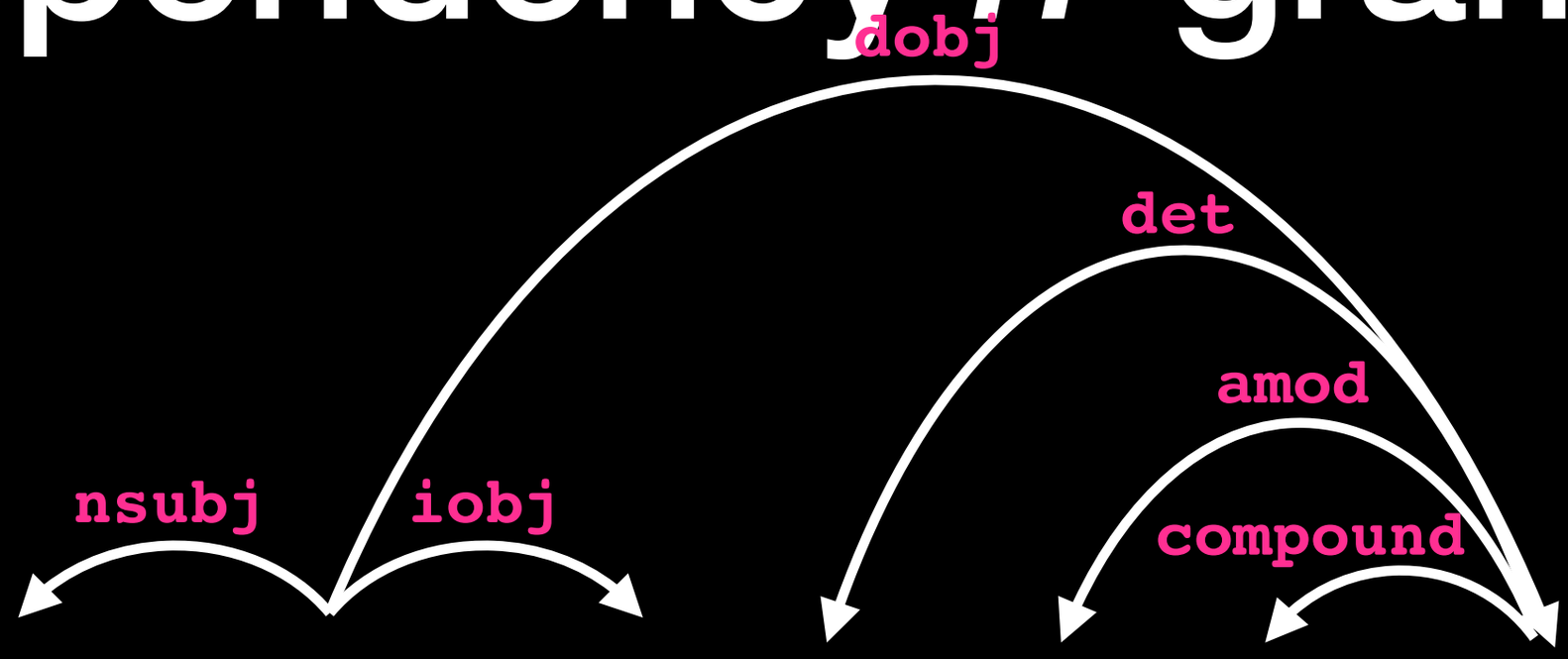
Dependency *n*-grams



root

Nancy gave
Don gave

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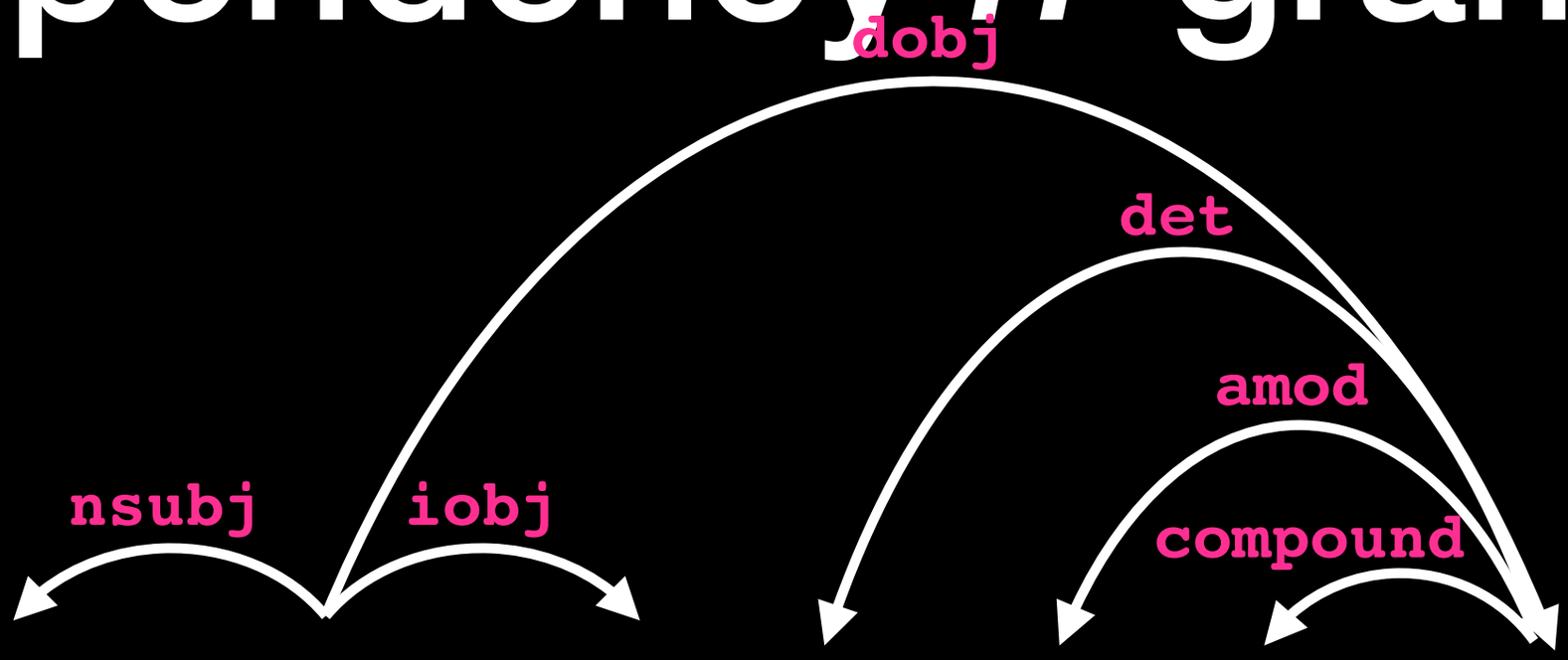
Dependency *n*-grams



root

Nancy gave
Don gave
Mac gave

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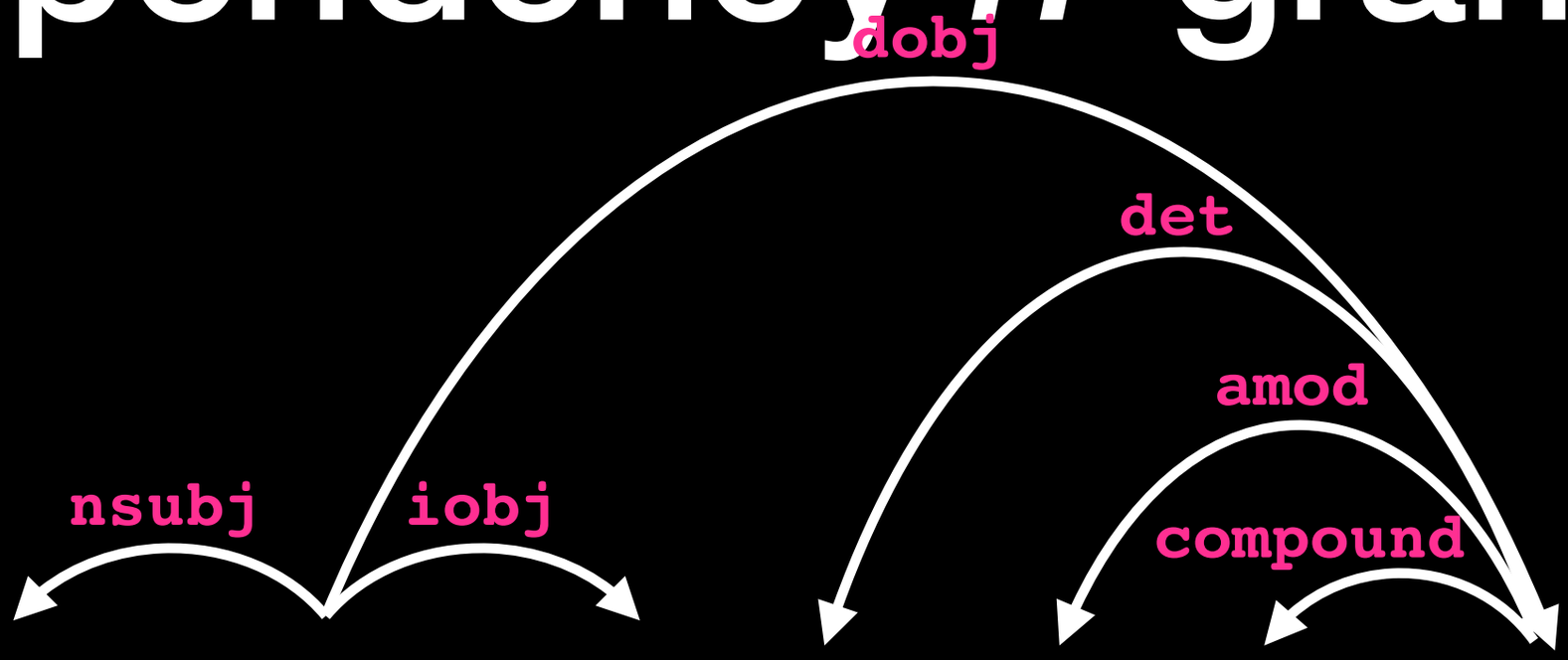
Dependency *n*-grams

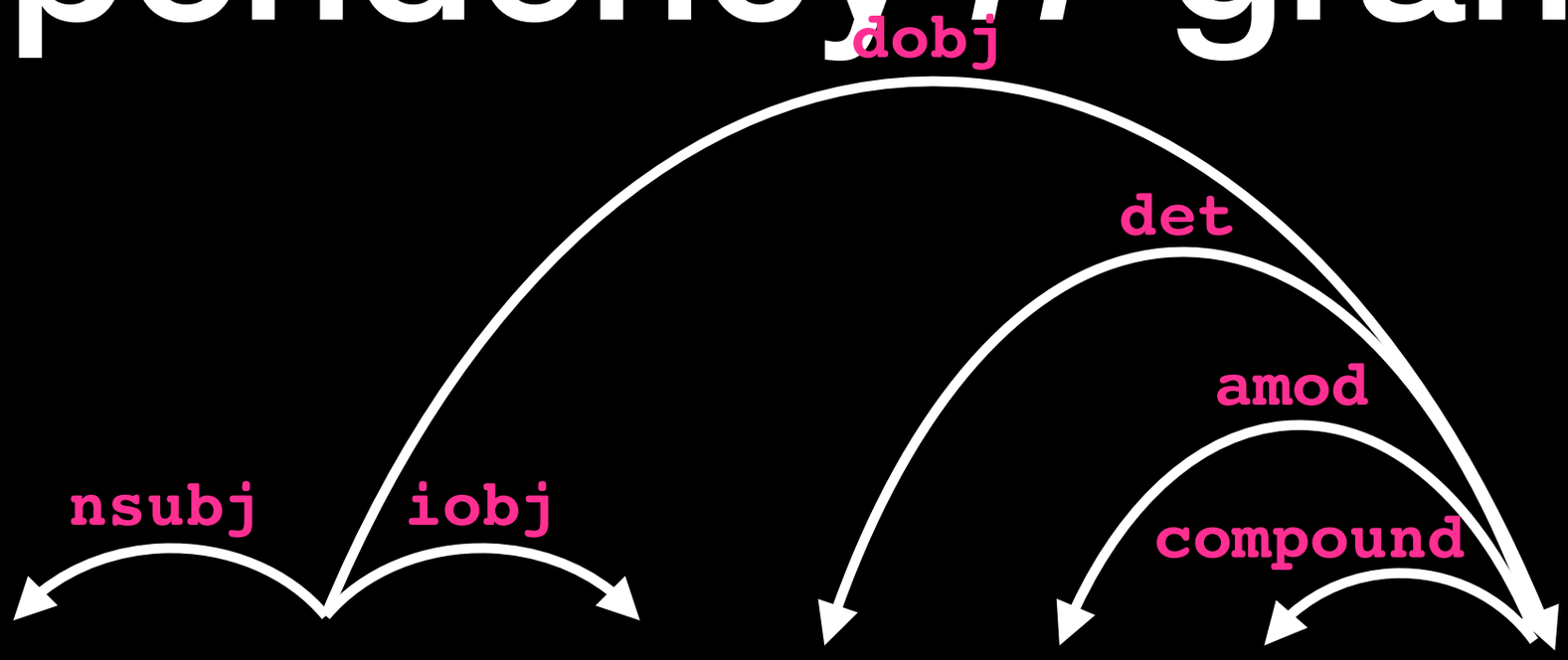


root

Nancy gave
Don gave
Mac gave
a Mac

Bocconi

Dependency *n*-grams

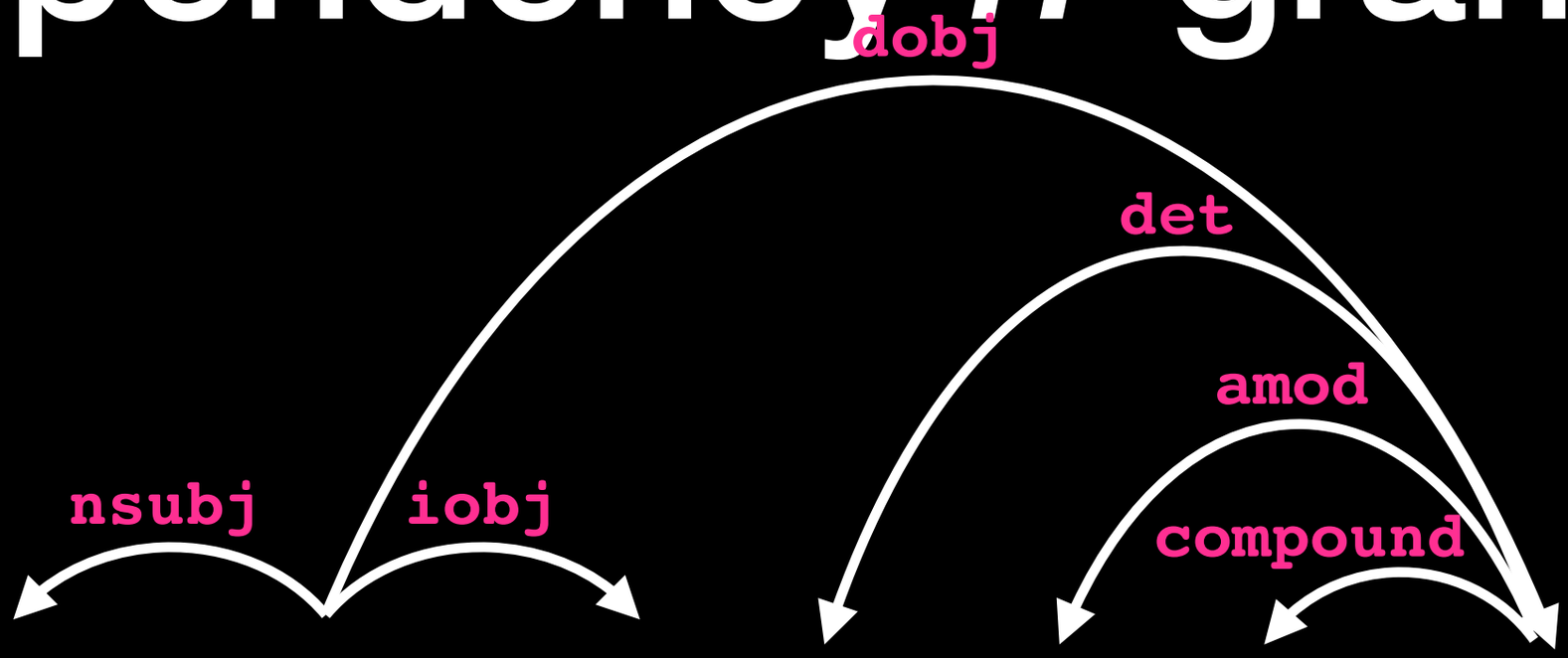


root

Nancy gave
Don gave
Mac gave
a Mac
cold Mac

Bocconi

Dependency *n*-grams



root

Nancy gave
Don gave
Mac gave
a Mac
cold Mac
Big Mac

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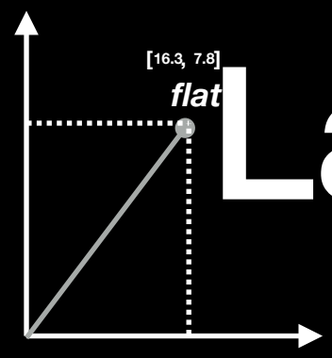
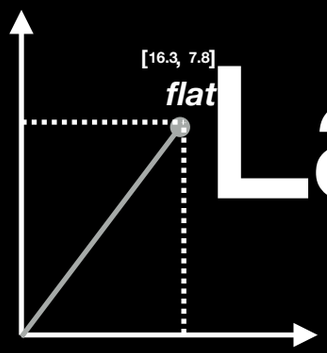


Latent Semantic Analysis



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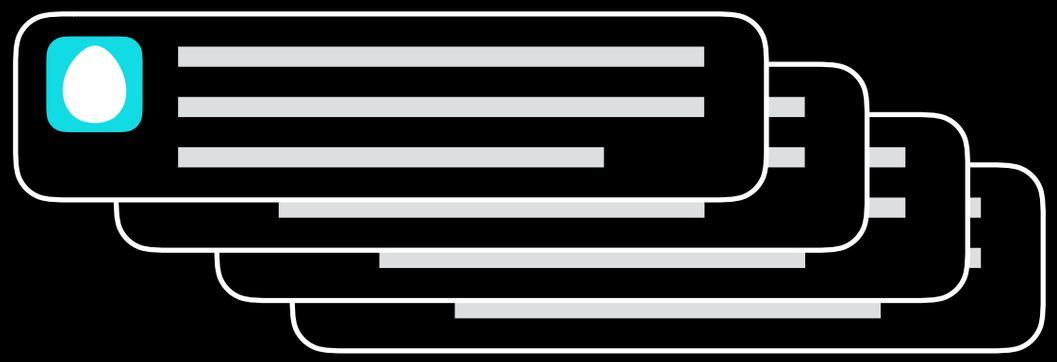
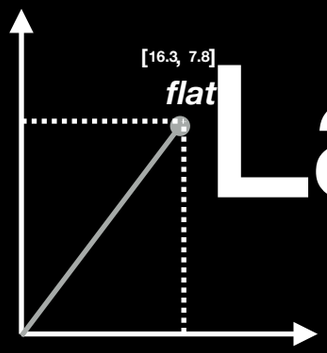
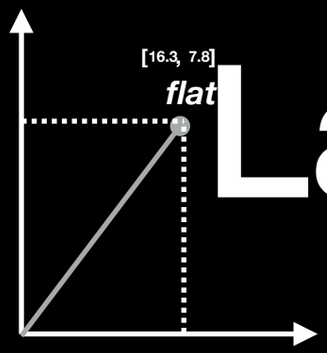




Latent Semantic Analysis

	rent	location	fairy	rainbow	prince	sleep
flat	87	73	14	11	7	45
apartment	83	87	12	23	11	32
unicorn	27	46	79	92	54	16
toad	4	37	73	55	67	73
bed	34	42	21	15	62	97



Latent Semantic Analysis

CONTEXTS

	rent	location	fairy	rainbow	prince	sleep
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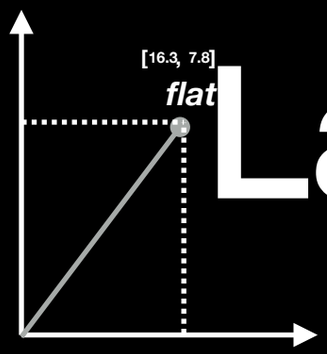

Latent Semantic Analysis

CONTEXTS

TARGETS

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toad	4	37	73	55	67	73
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Dense Distributed Representations

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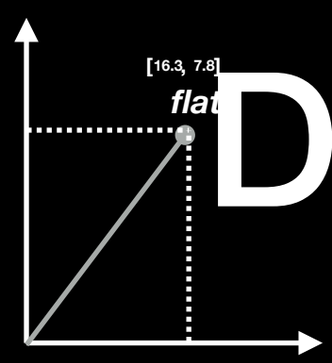


Distributional Hypothesis

"You shall know the meaning of a word by the company it keeps"

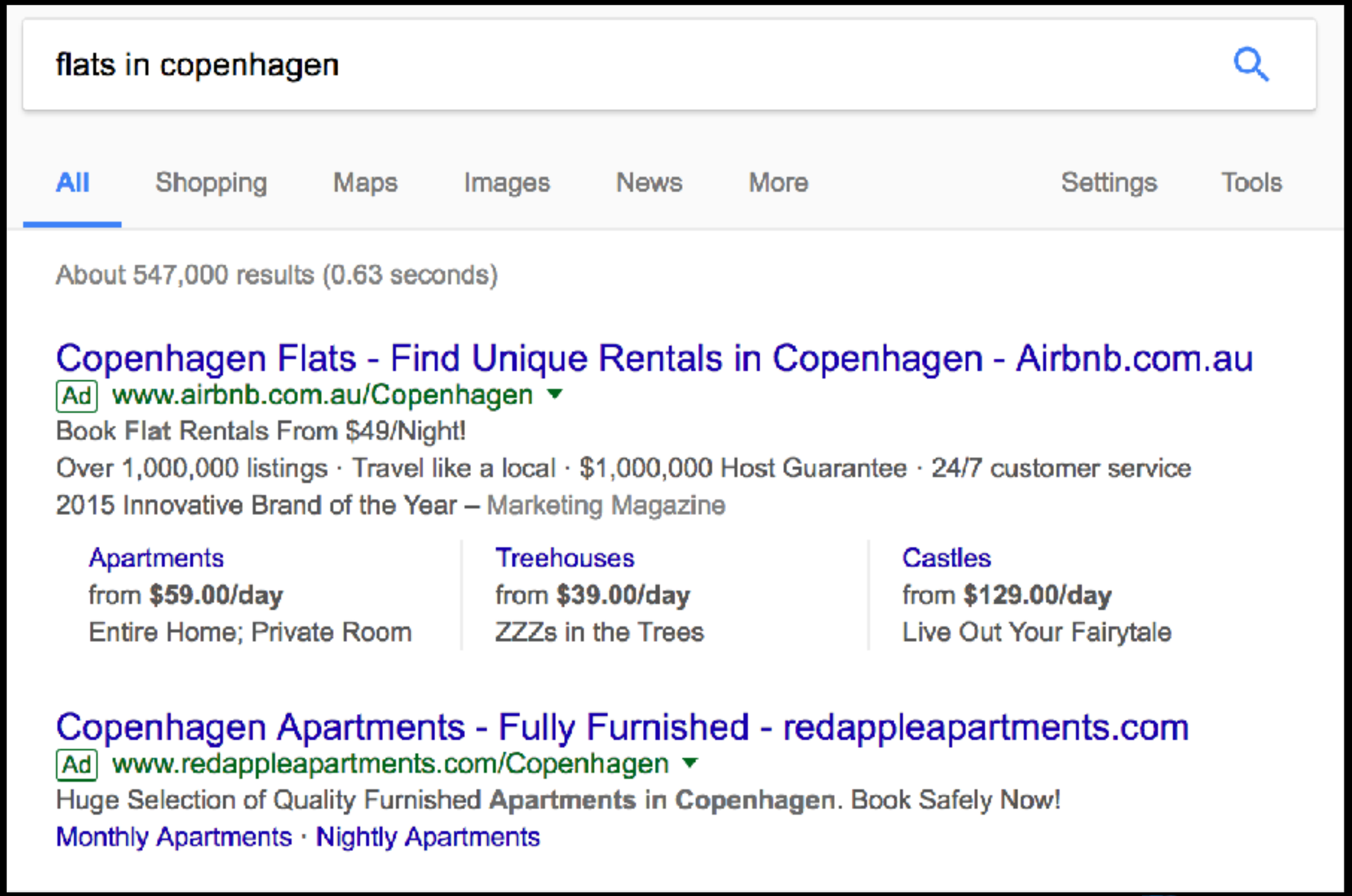
Firth (1957)

Similar words have similar **contexts**

Represent **words** as **vectors**/points in space

Similar words have similar vectors

An Example


flats in copenhagen
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Shopping
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Book Flat Rentals From $49/Night!
Over 1,000,000 listings · Travel like a local · $1,000,000 Host Guarantee · 24/7 customer service
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Monthly Apartments · Nightly Apartments

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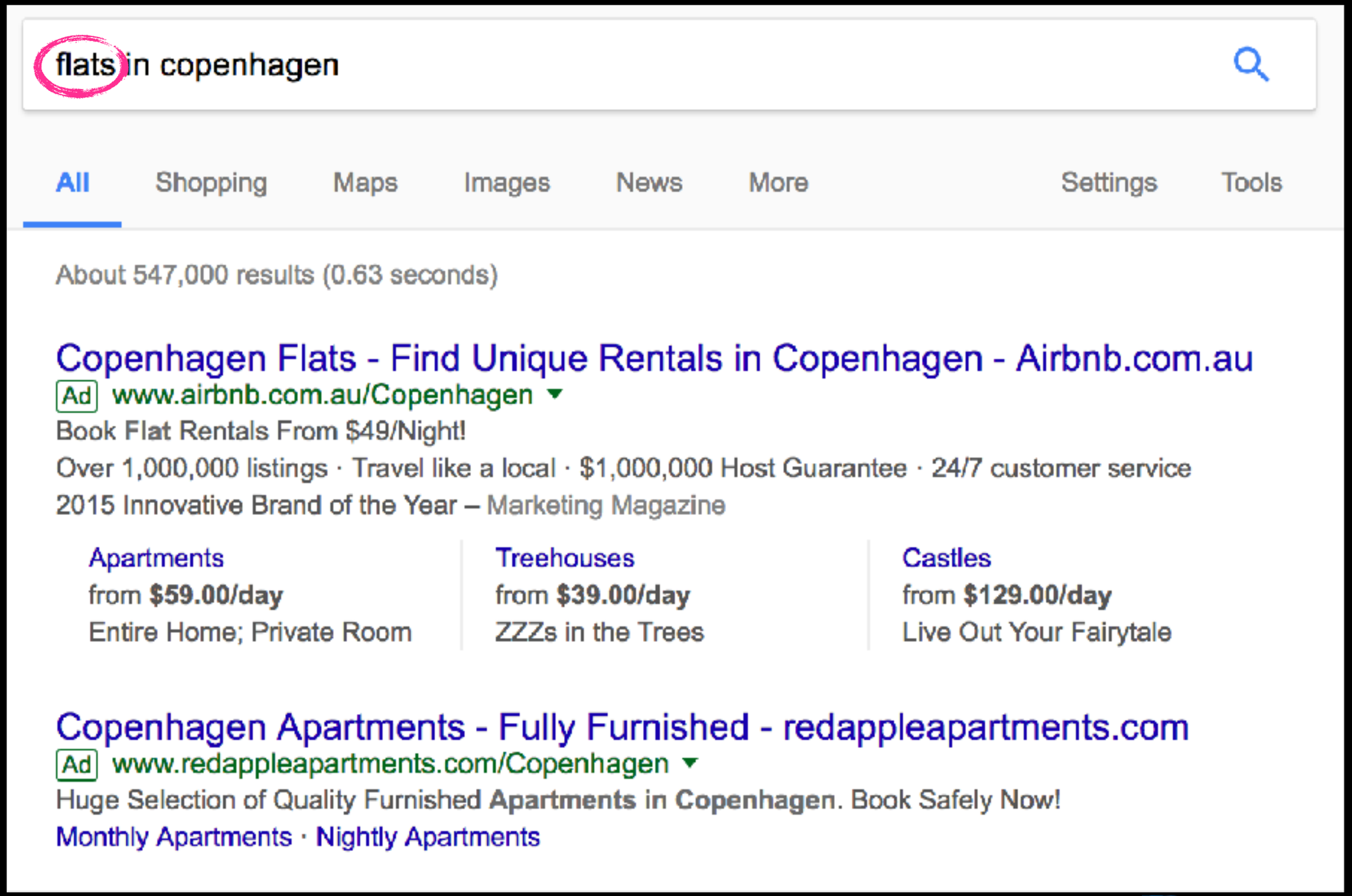
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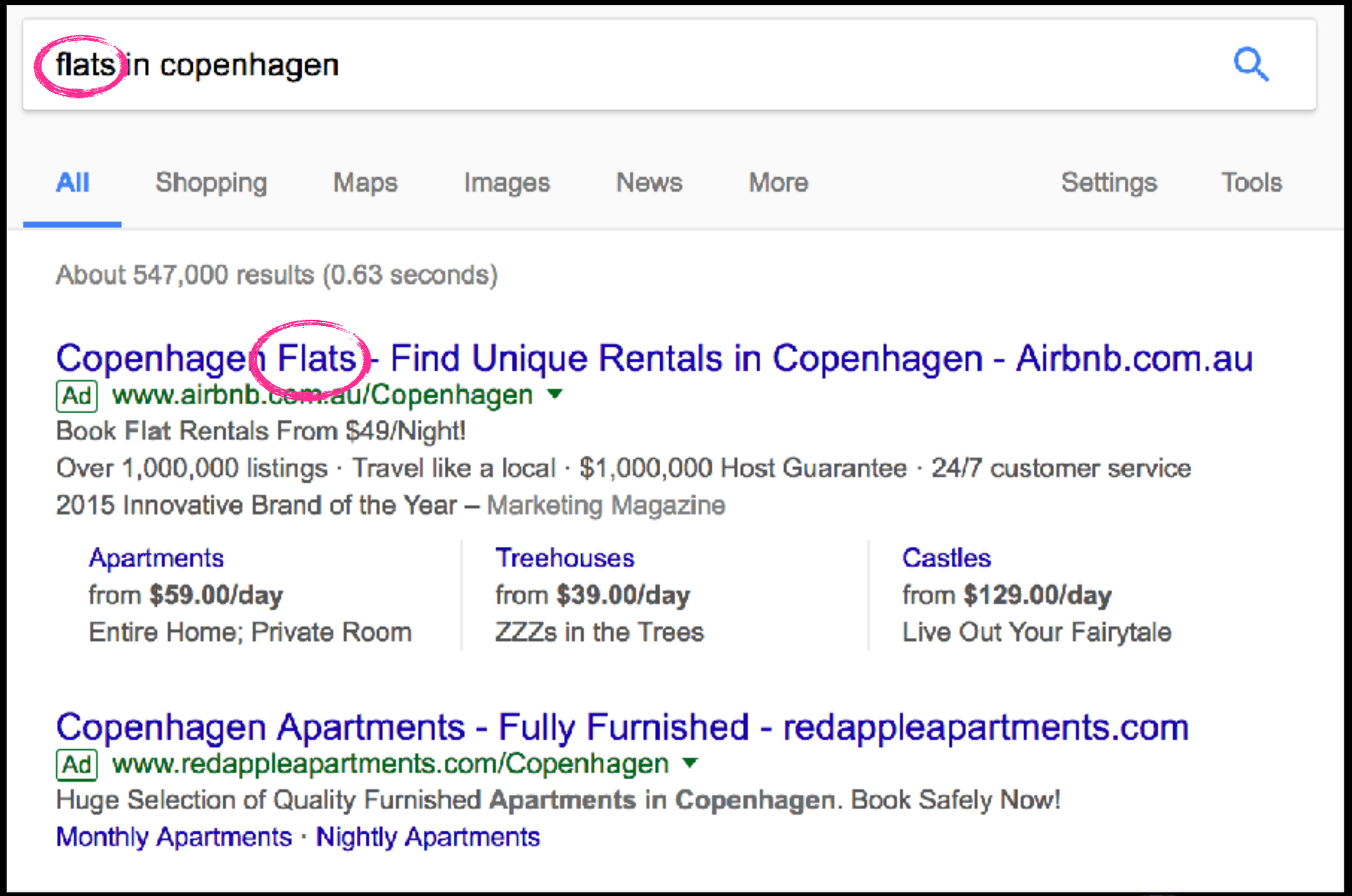
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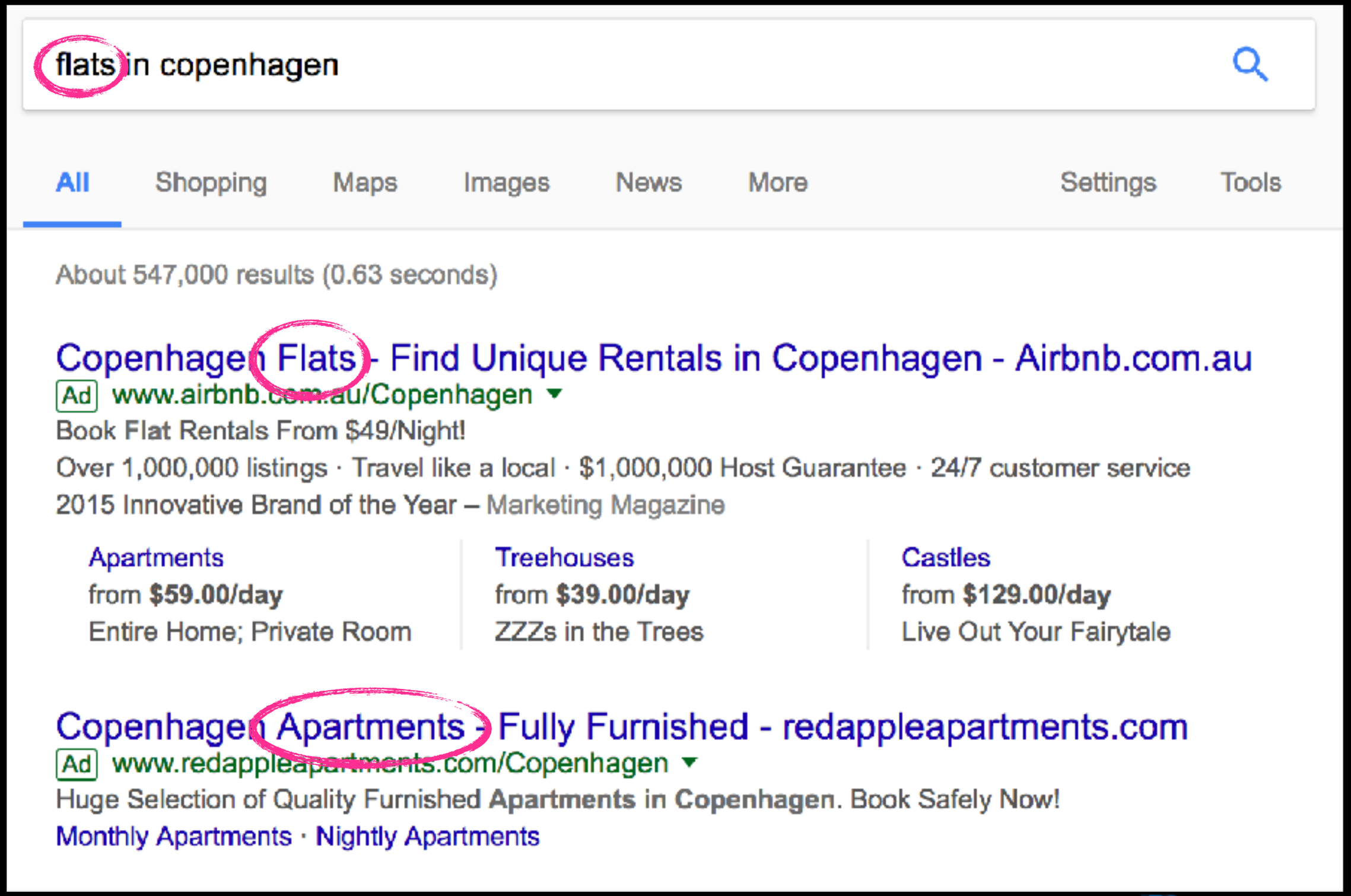
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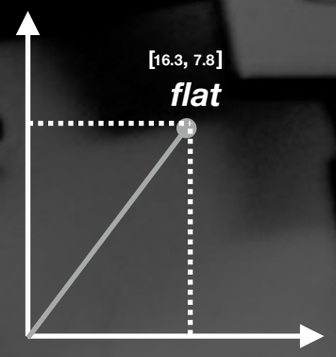
Part 1

Representing Words as Vectors



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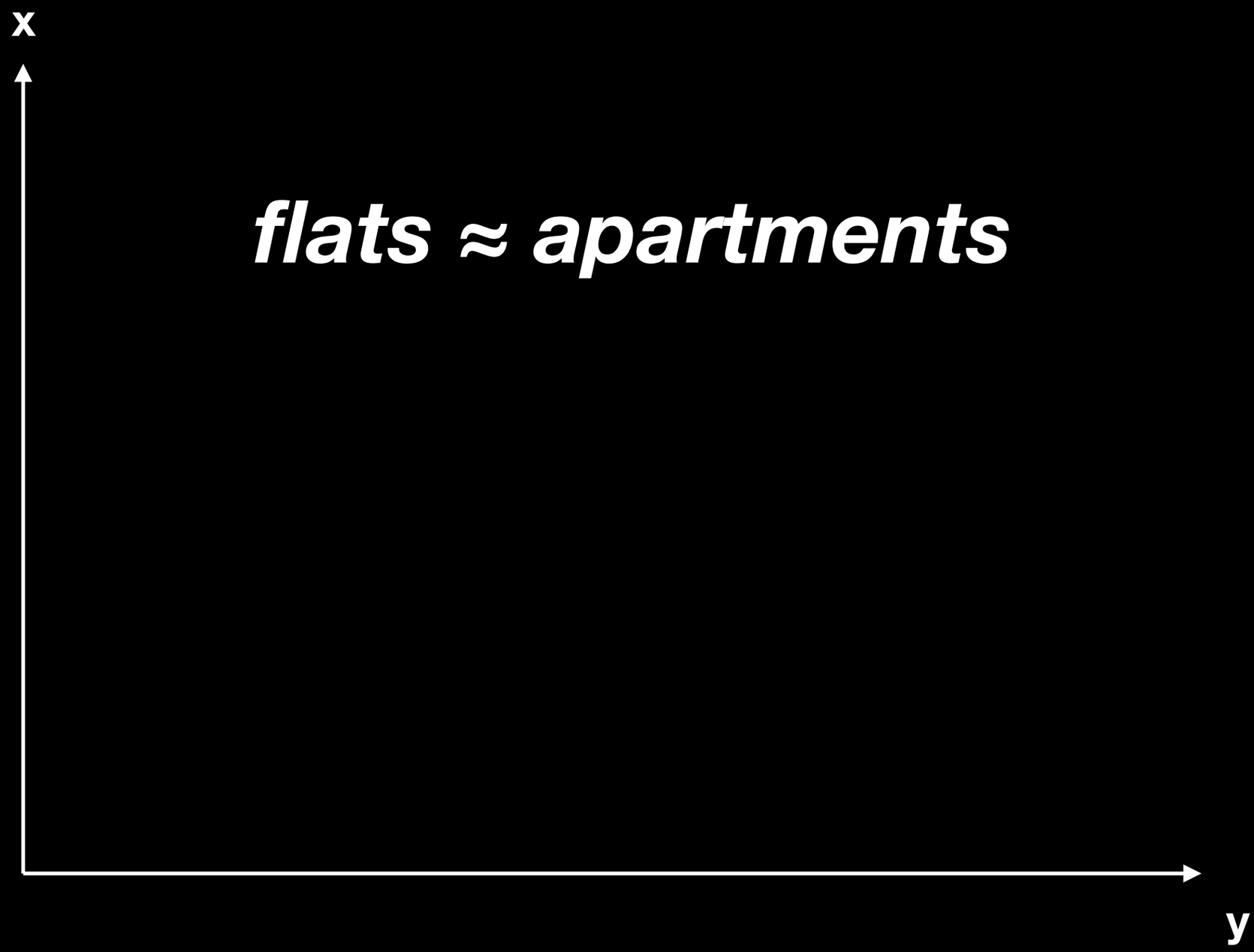
Semantic Similarity

flats ≈ apartments

Semantic Similarity



flats ≈ apartments

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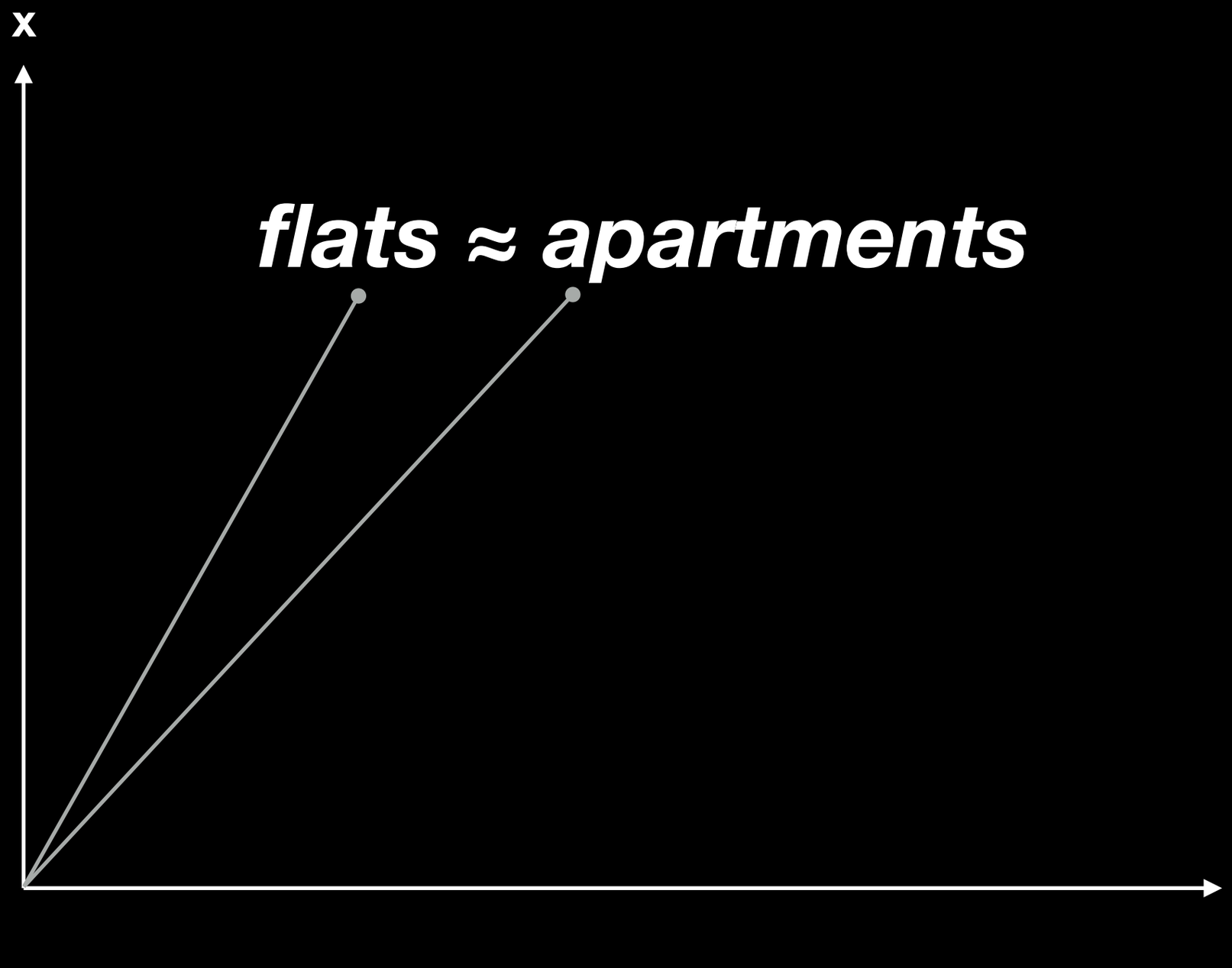

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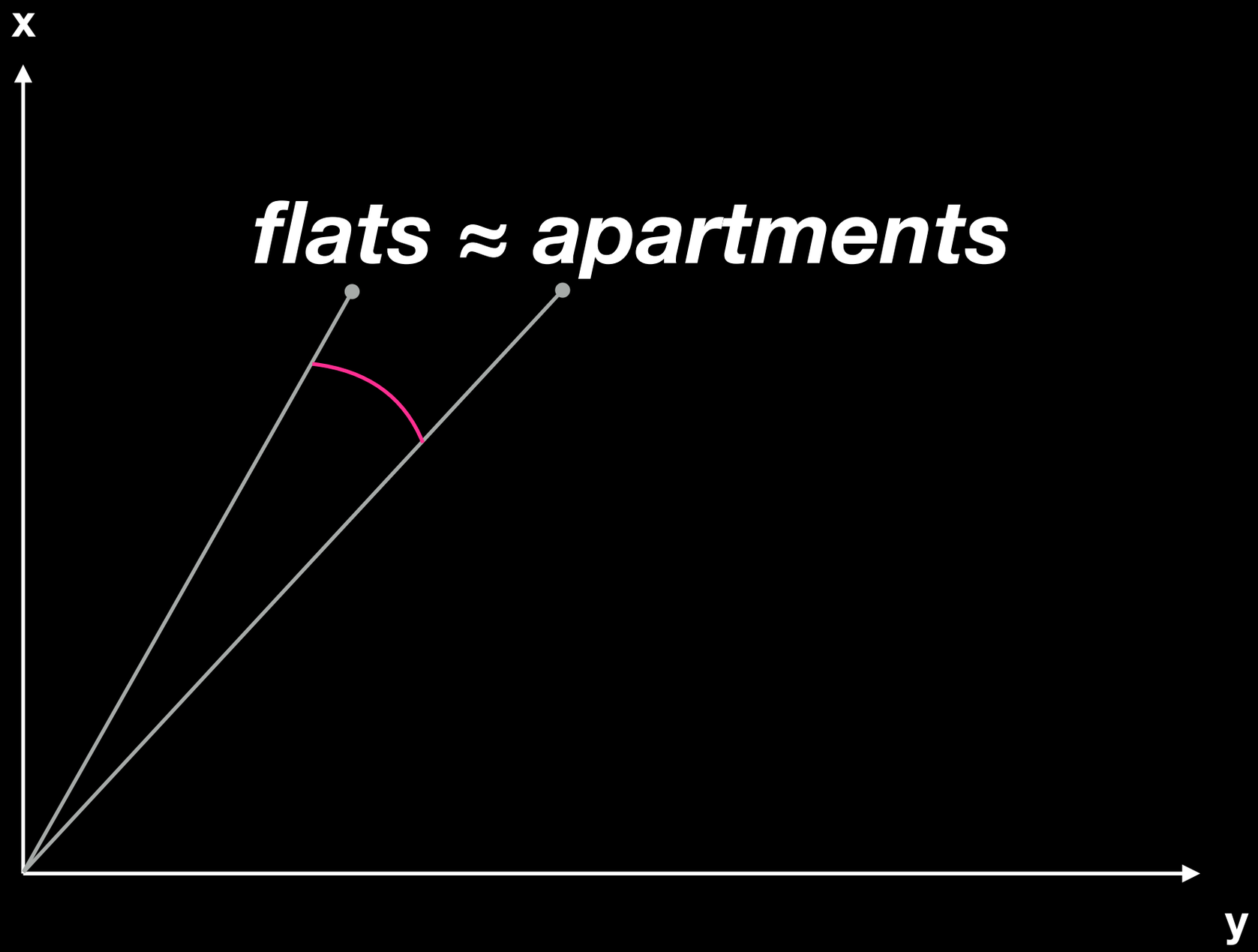

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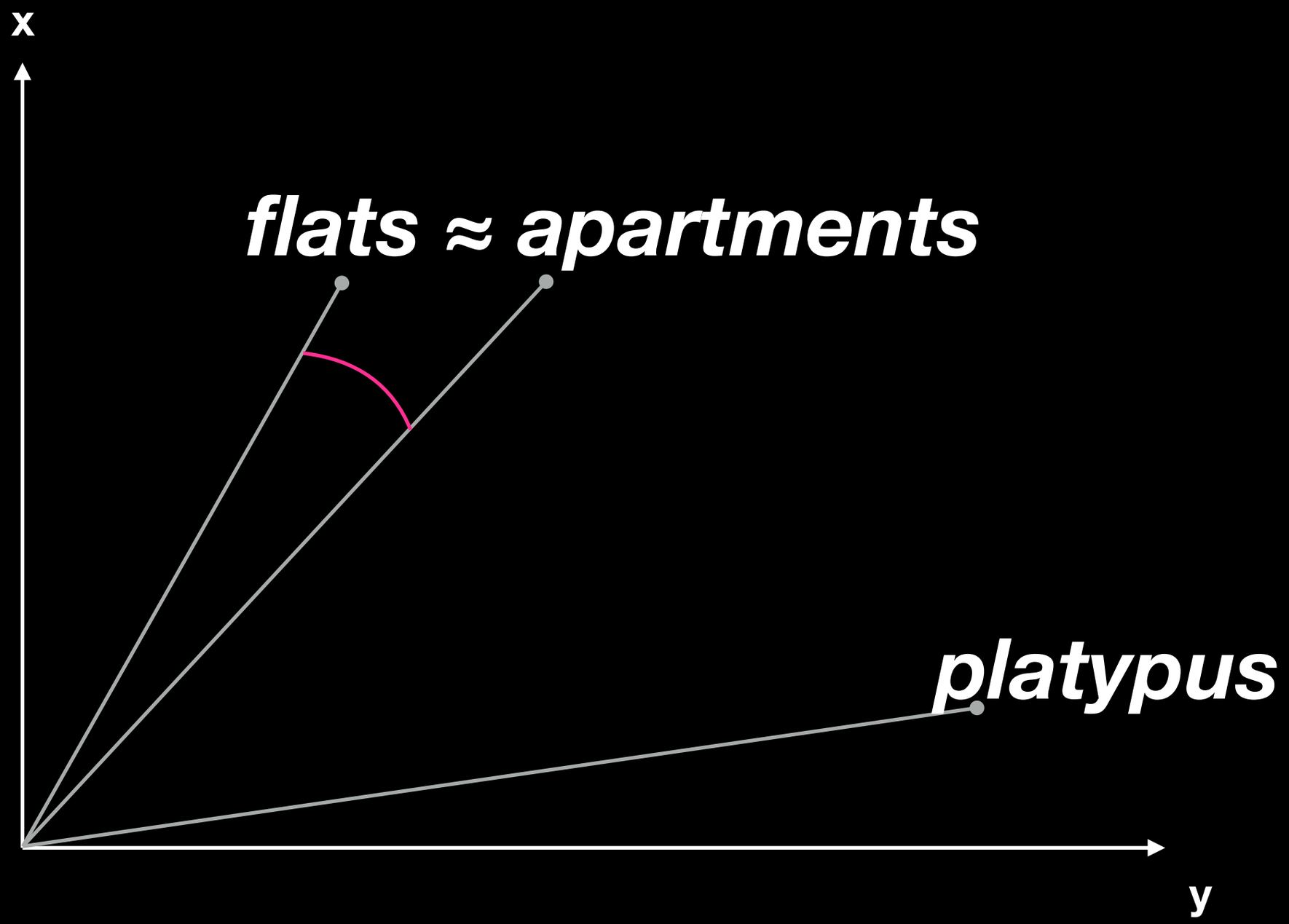

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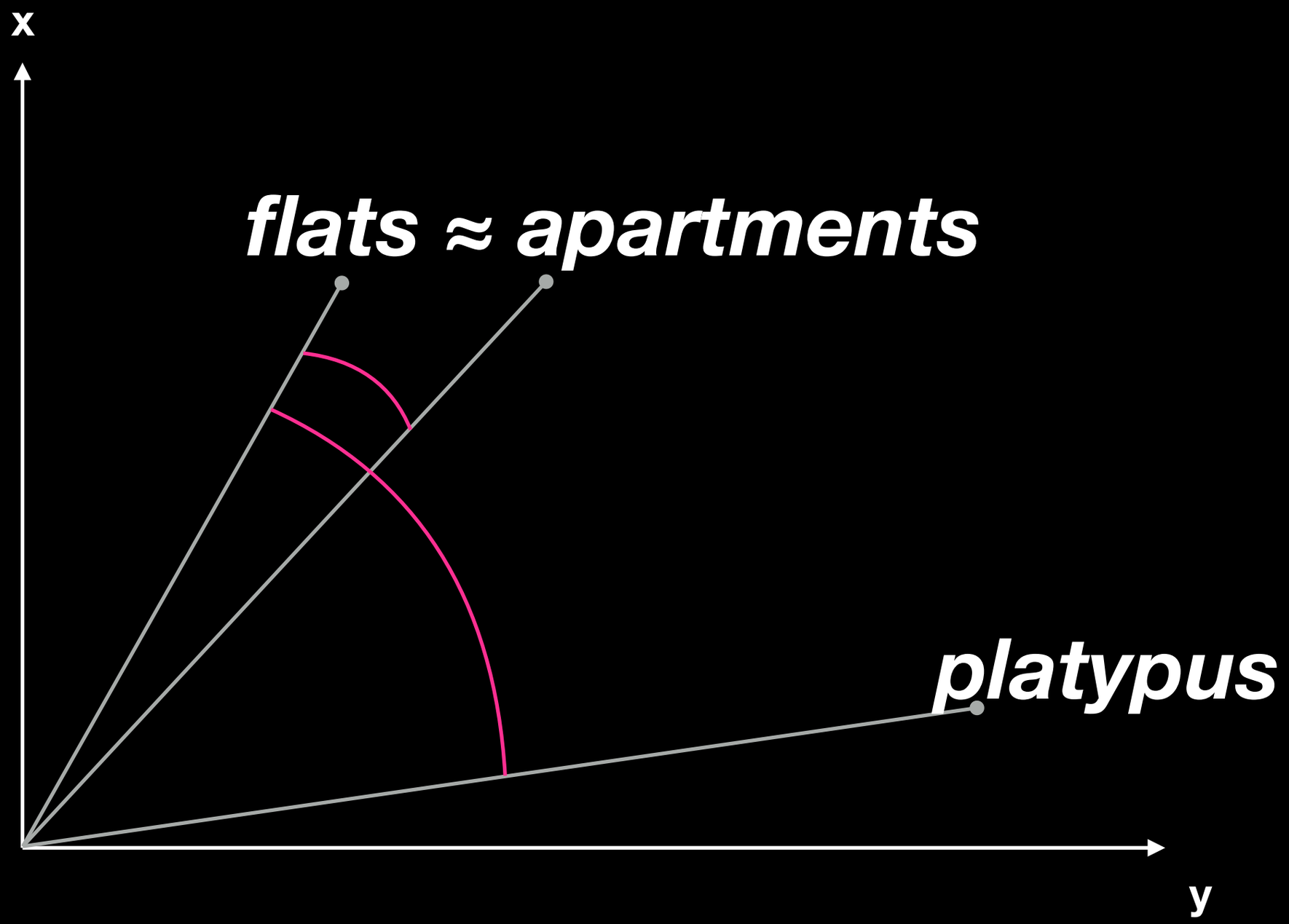

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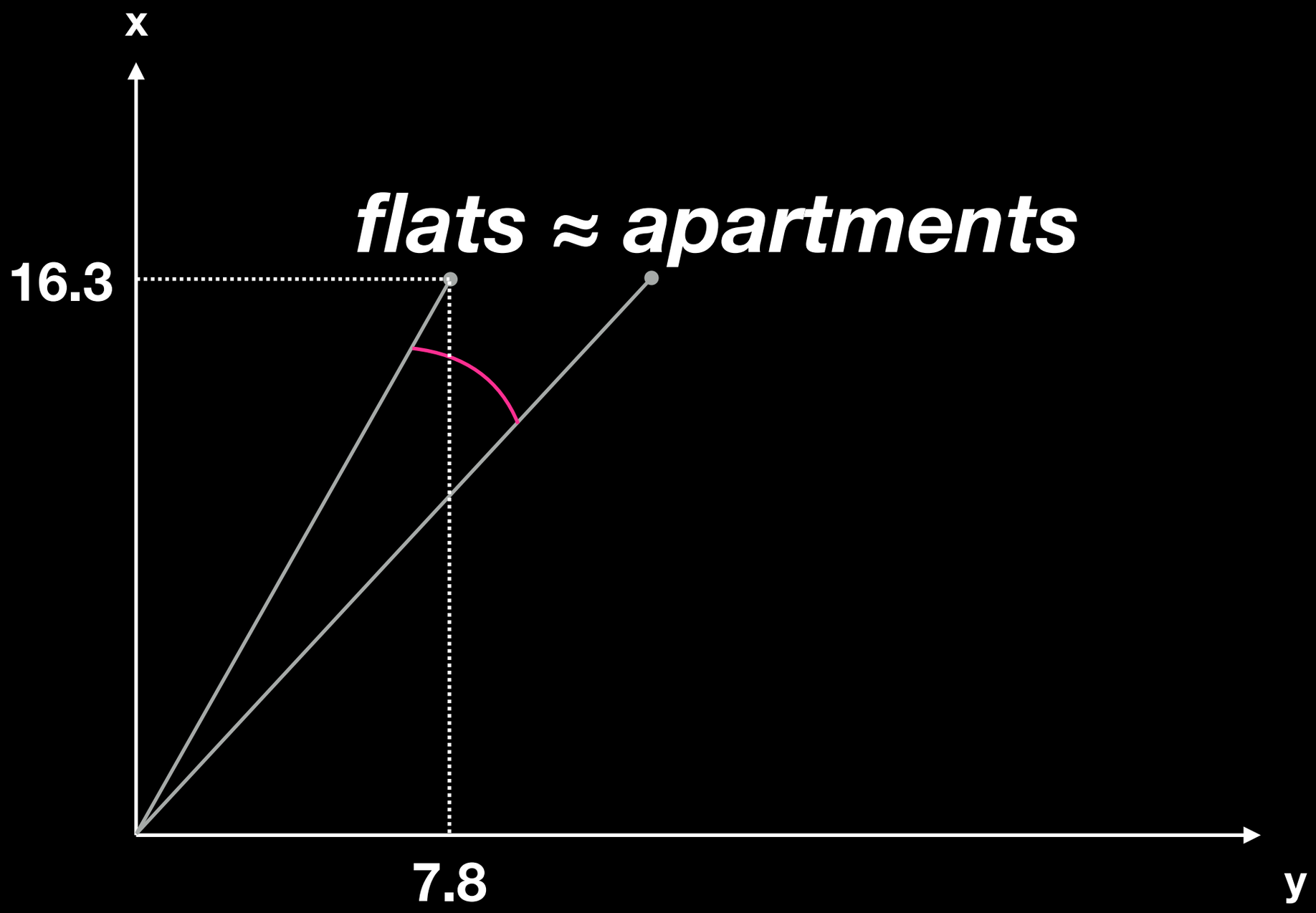
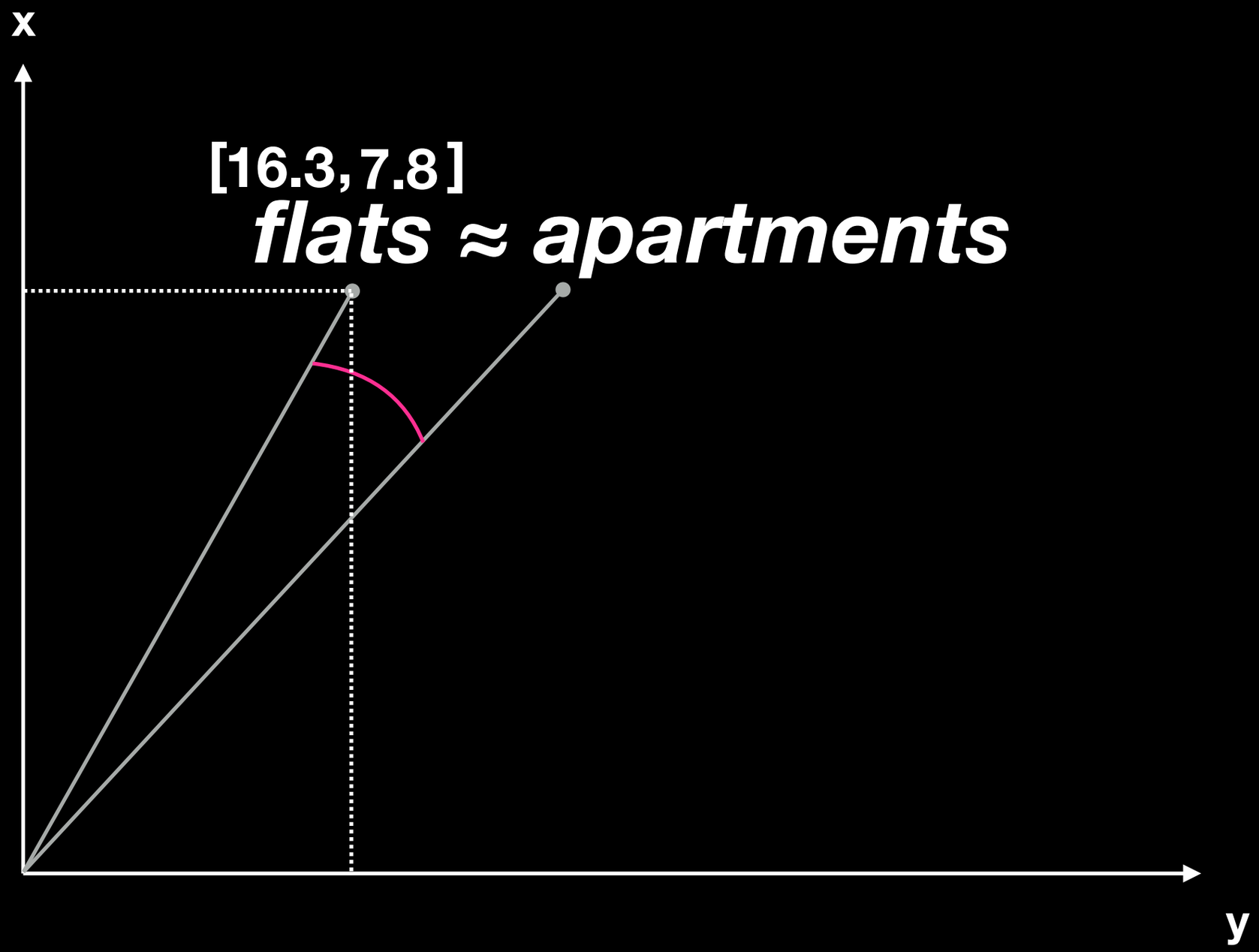
Semantic Similarity



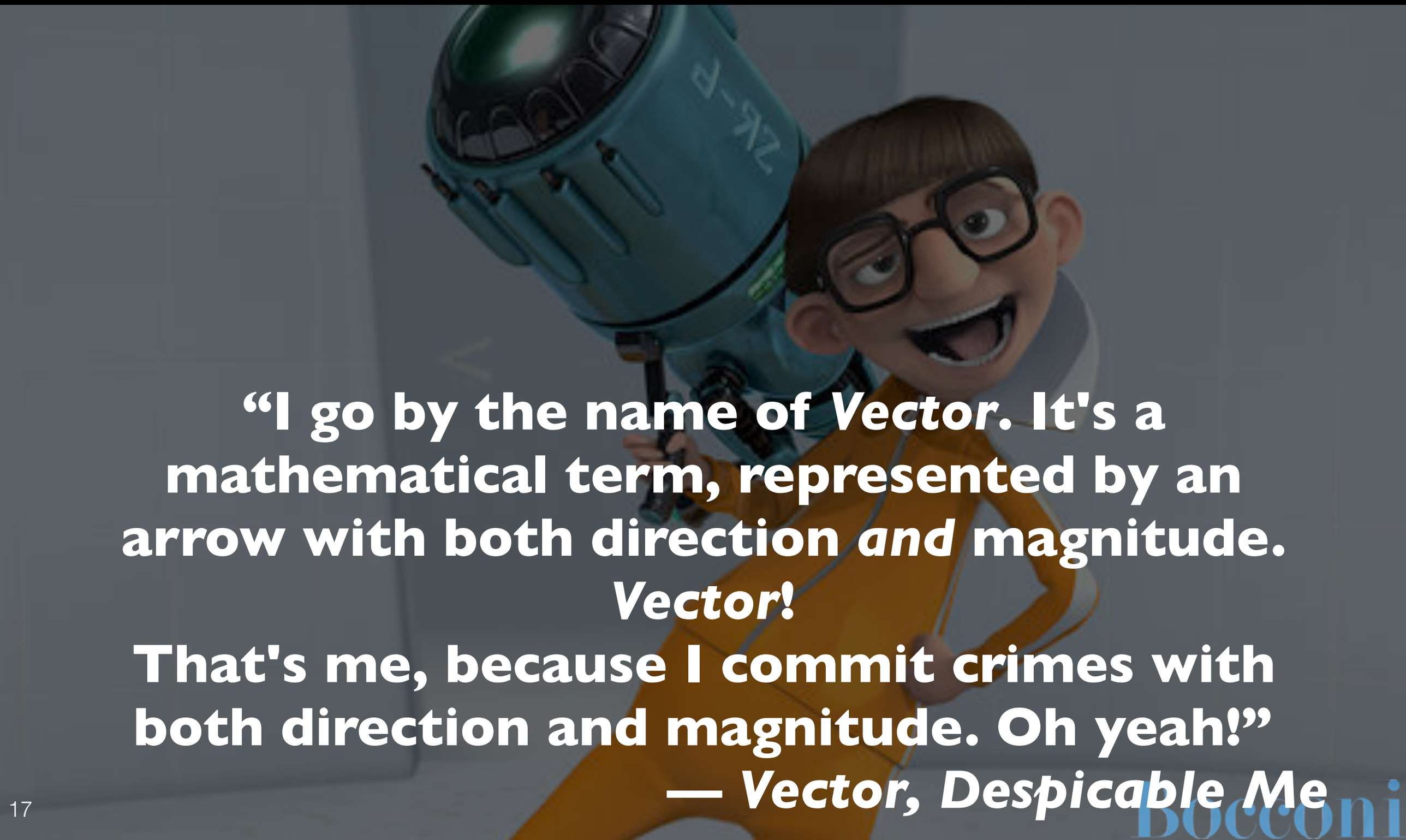
Bocconi

Semantic Similarity

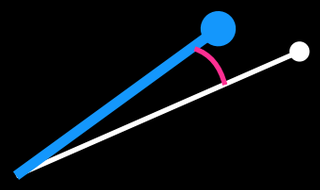


Bocconi

Vectors!



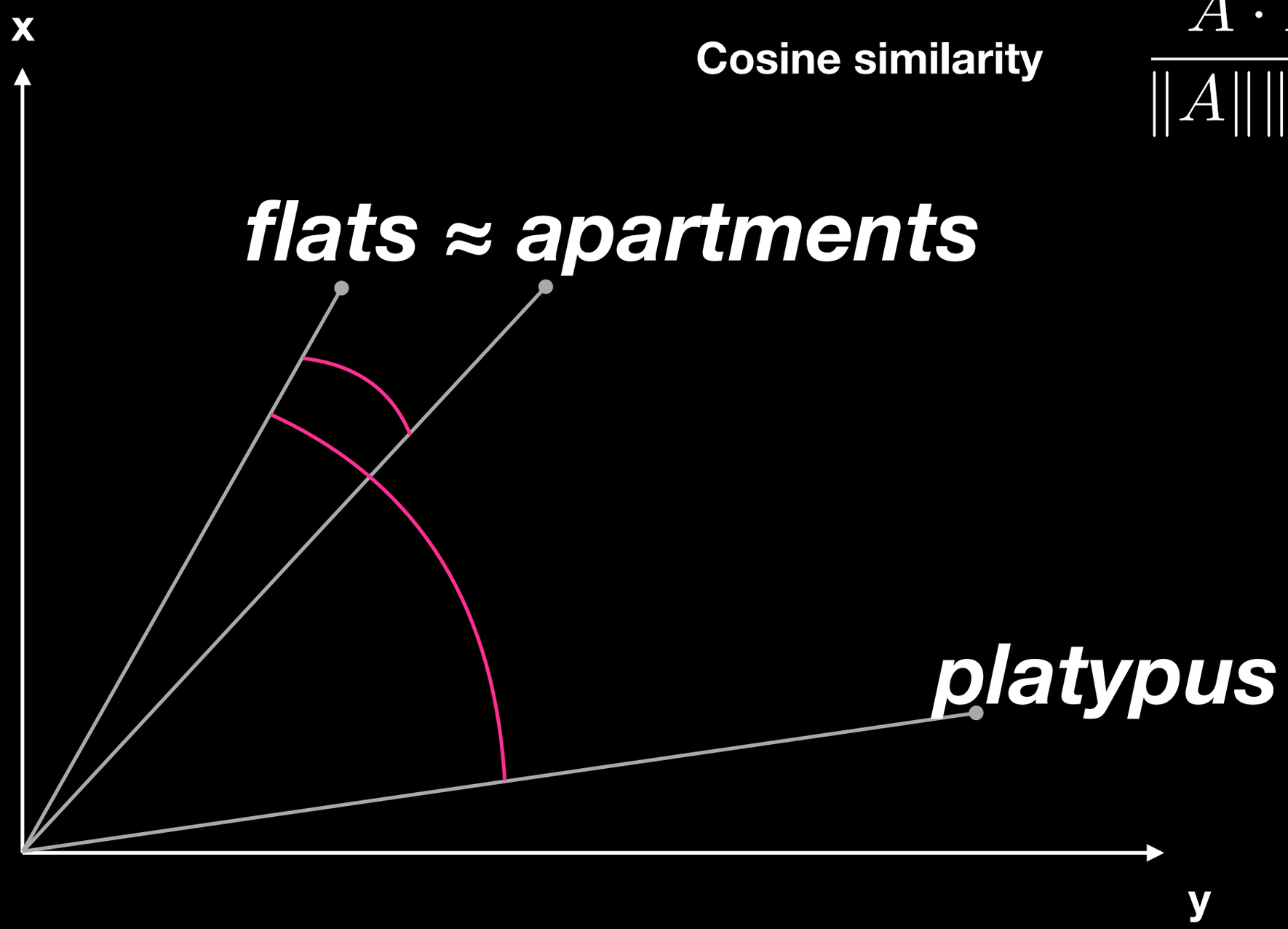
“I go by the name of *Vector*. It's a mathematical term, represented by an arrow with both direction *and* magnitude. *Vector*!
That's me, because I commit crimes with both direction and magnitude. Oh yeah!”
— *Vector, Despicable Me*



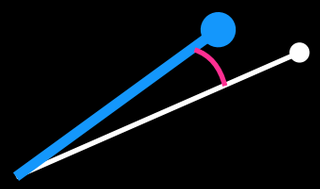
Similarity Measures

Cosine similarity

$$\frac{A \cdot B}{\|A\| \|B\|}$$



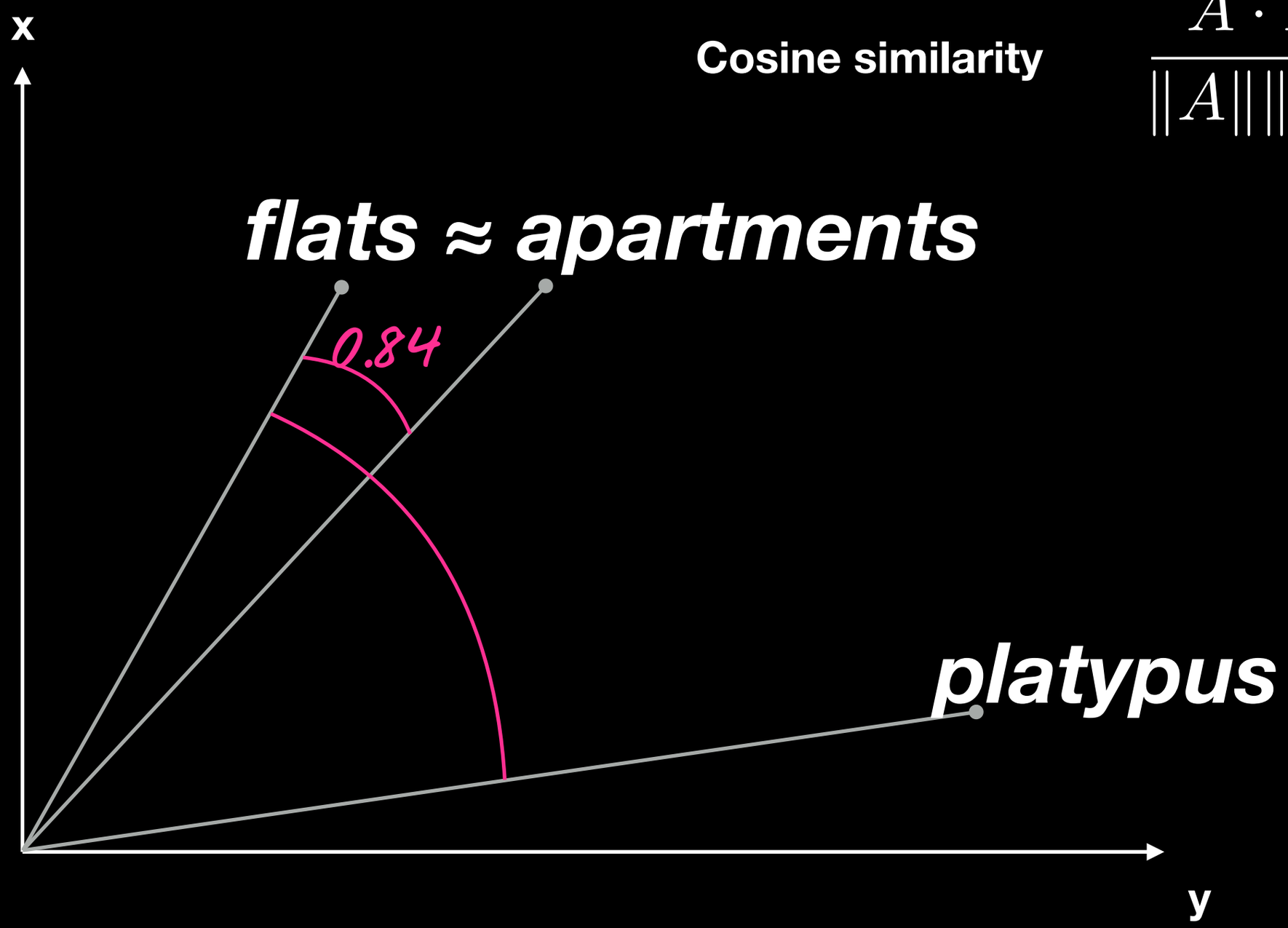
Bocconi



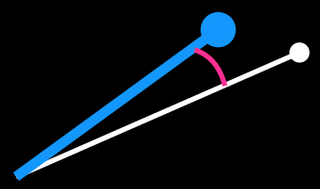
Similarity Measures

Cosine similarity

$$\frac{A \cdot B}{\|A\| \|B\|}$$



Bocconi



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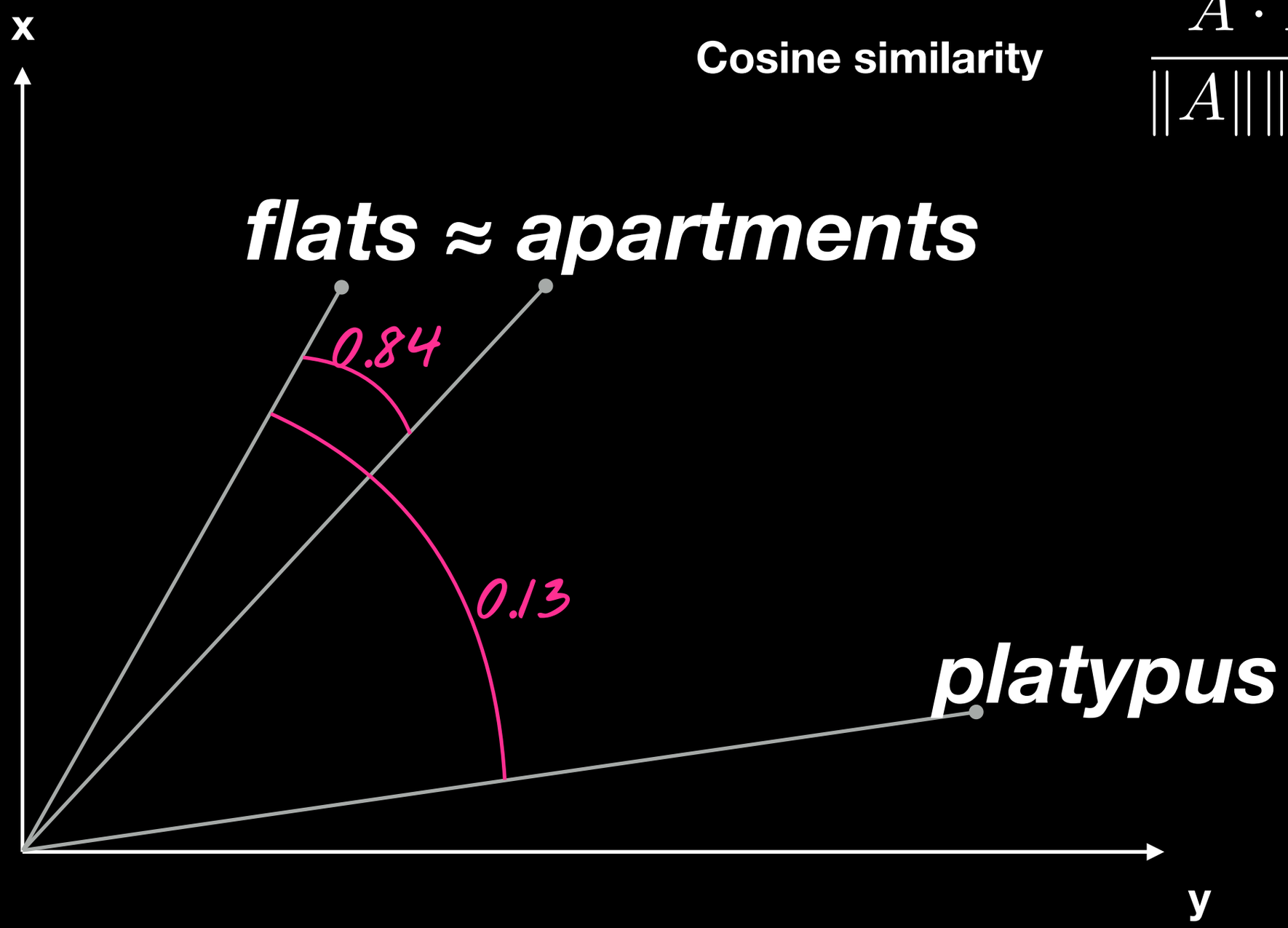
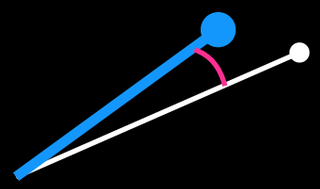
Cosine similarity

$$\frac{A \cdot B}{\|A\| \|B\|}$$



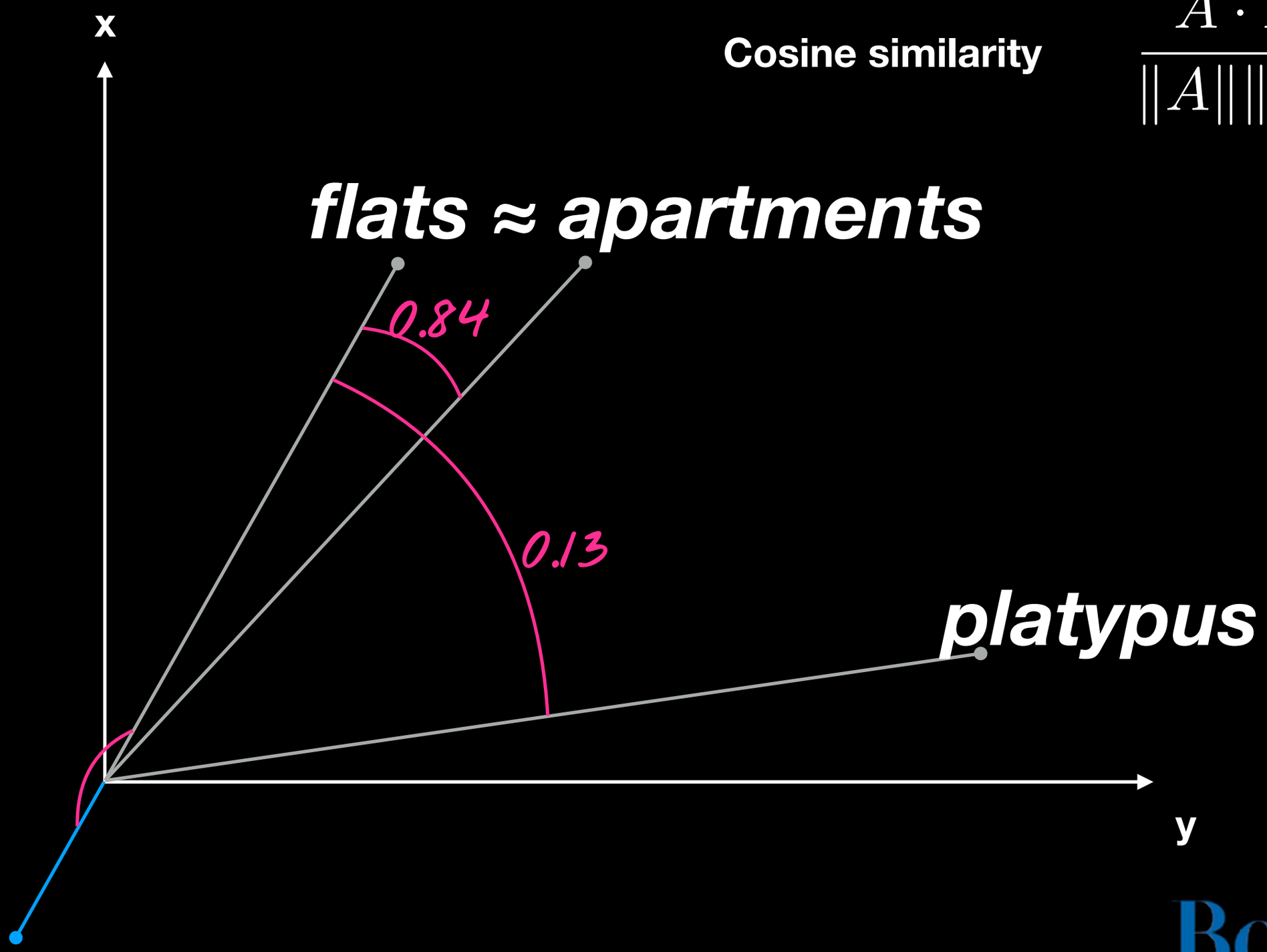
Bocconi



Similarity Measures

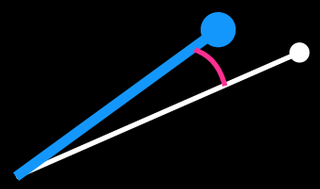
Cosine similarity

$$\frac{A \cdot B}{\|A\| \|B\|}$$



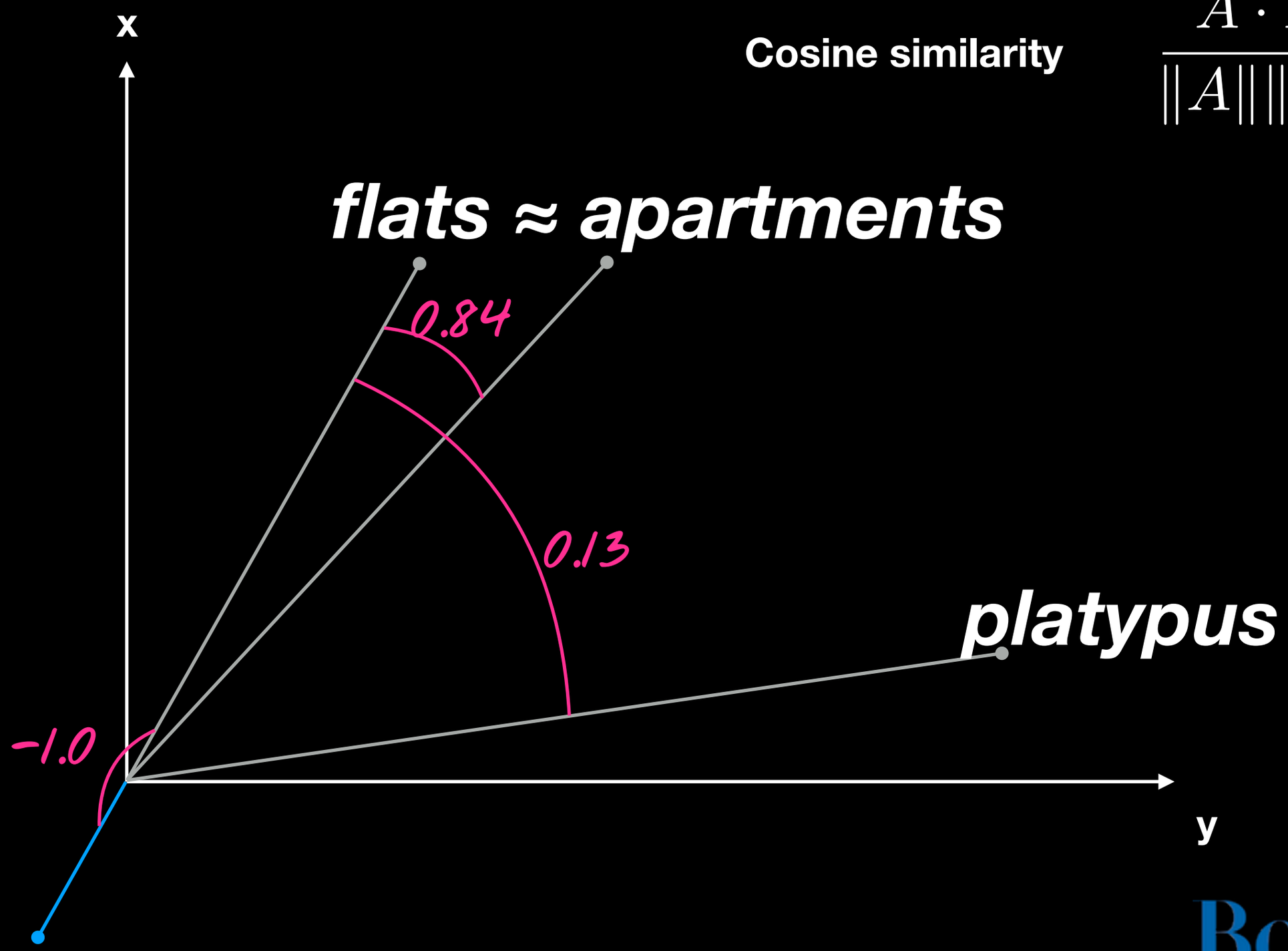
Bocconi

Similarity Measures

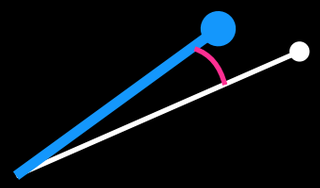


Cosine similarity

$$\frac{A \cdot B}{\|A\| \|B\|}$$



Bocconi

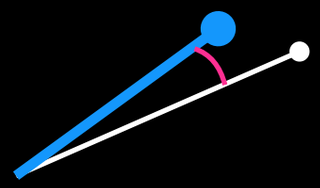


Dot Product

- “combine” vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} =$$



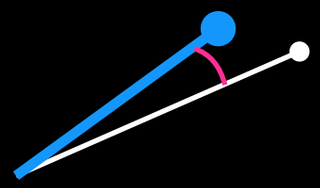
Dot Product

- “combine” vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

MULTIPLY

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} =$$



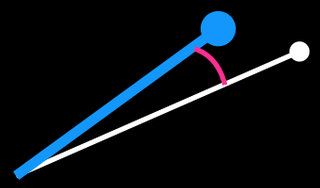
Dot Product

- “combine” vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

MULTIPLY

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} = 1$$



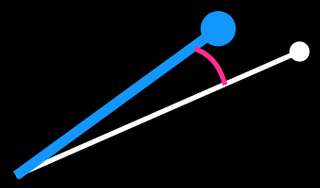
Dot Product

- “combine” vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

MULTIPLY

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} = 1 \quad 3$$



Dot Product

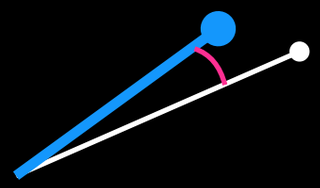
- “combine” vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

SUM

MULTIPLY

$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} = \begin{matrix} 1 \\ 3 \end{matrix}$$



Dot Product

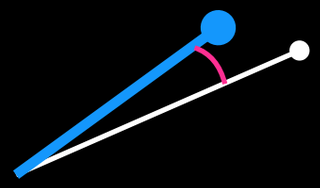
- "combine" vectors to a scalar

$$x \cdot y = \sum_{i=1}^{D} x_i y_i$$

SUM

MULTIPLY

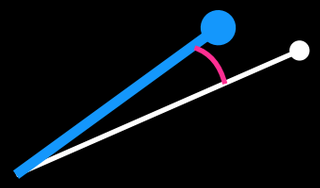
$$\begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 2 \\ 6 \end{bmatrix} = 4$$



Vector Norm

- add up square of each element, take $\sqrt{\ }$

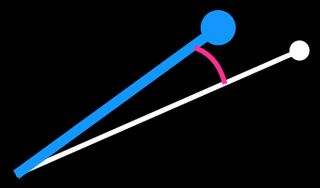
$$\begin{bmatrix} 2 \\ 6 \end{bmatrix}$$



Vector Norm

- add up square of each element, take $\sqrt{\ }$

$$\begin{bmatrix} 2 \\ 6 \end{bmatrix} = \sqrt{2^2 + 6^2}$$

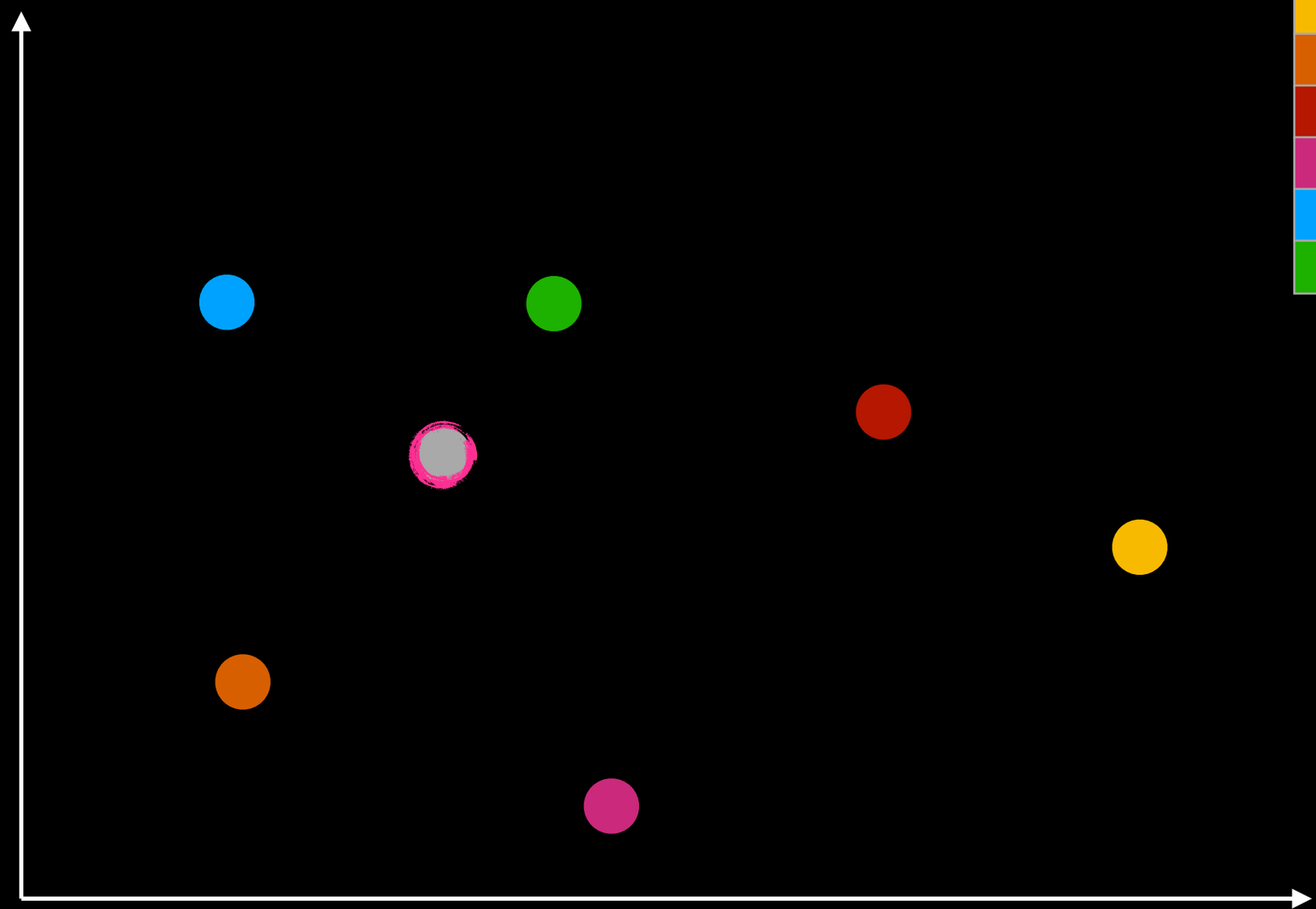


Vector Norm

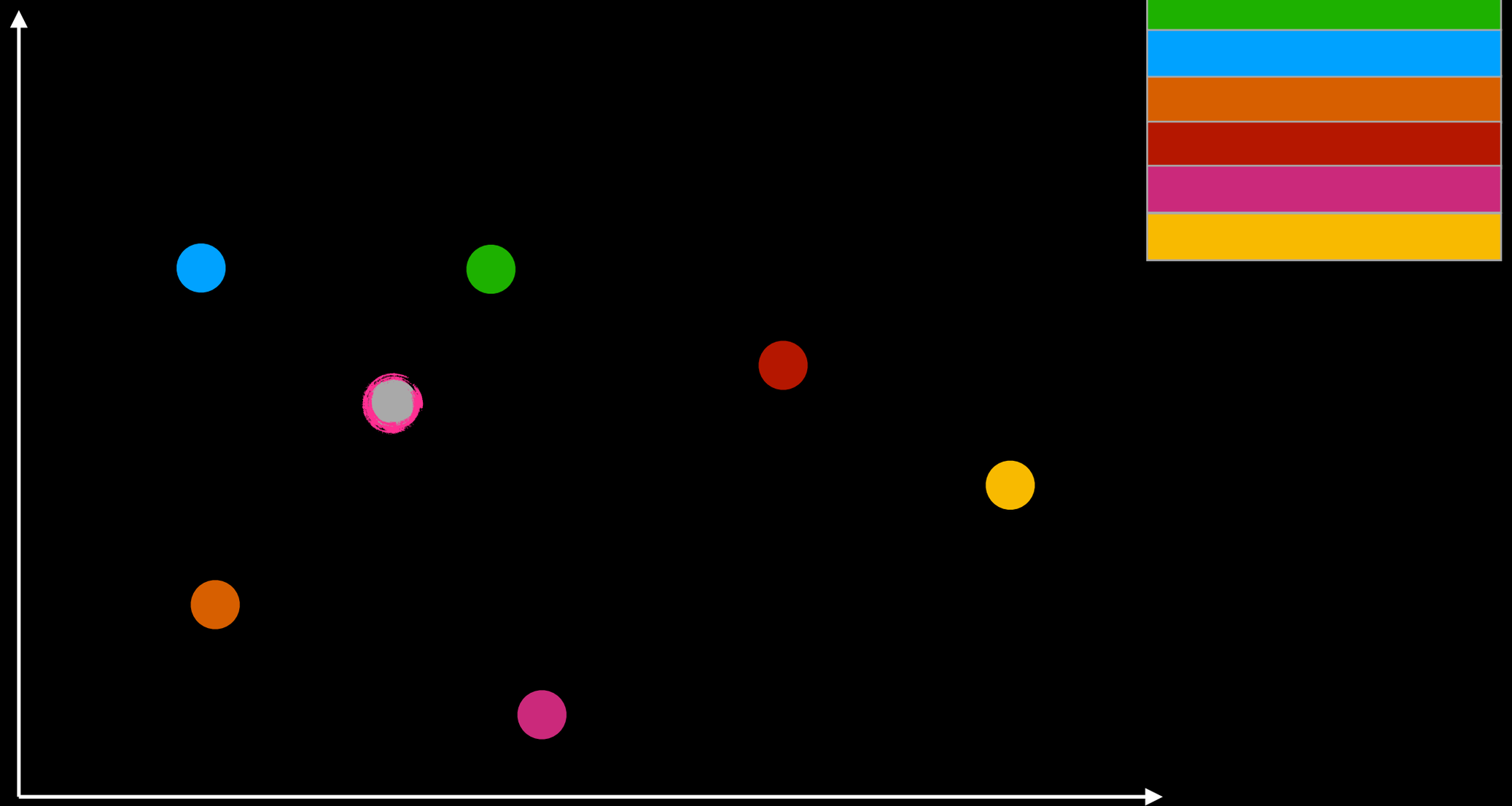
- add up square of each element, take $\sqrt{\ }$

$$\begin{bmatrix} 2 \\ 6 \end{bmatrix} = \sqrt{2^2 + 6^2} = 6.324$$

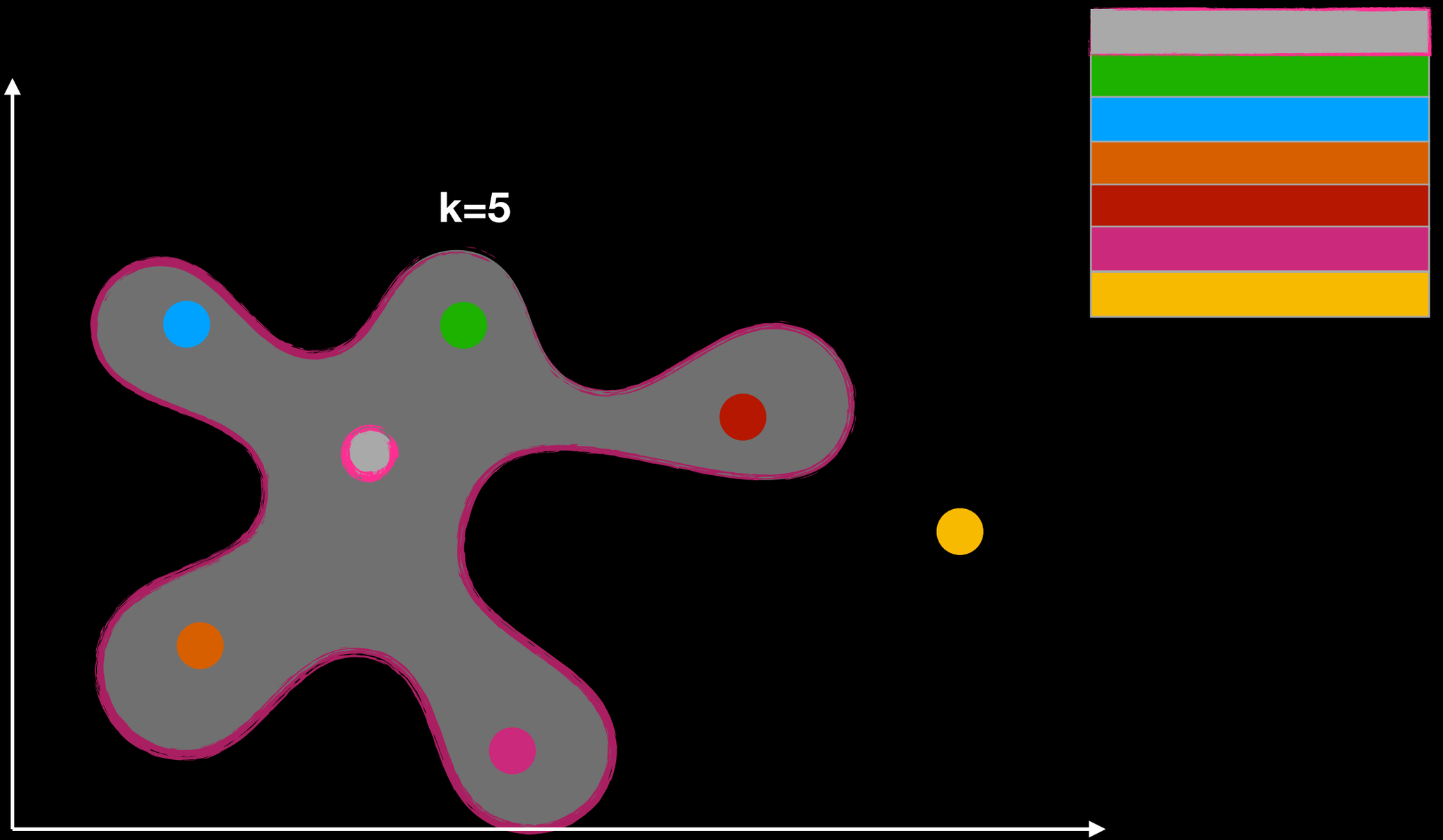
Nearest neighbors



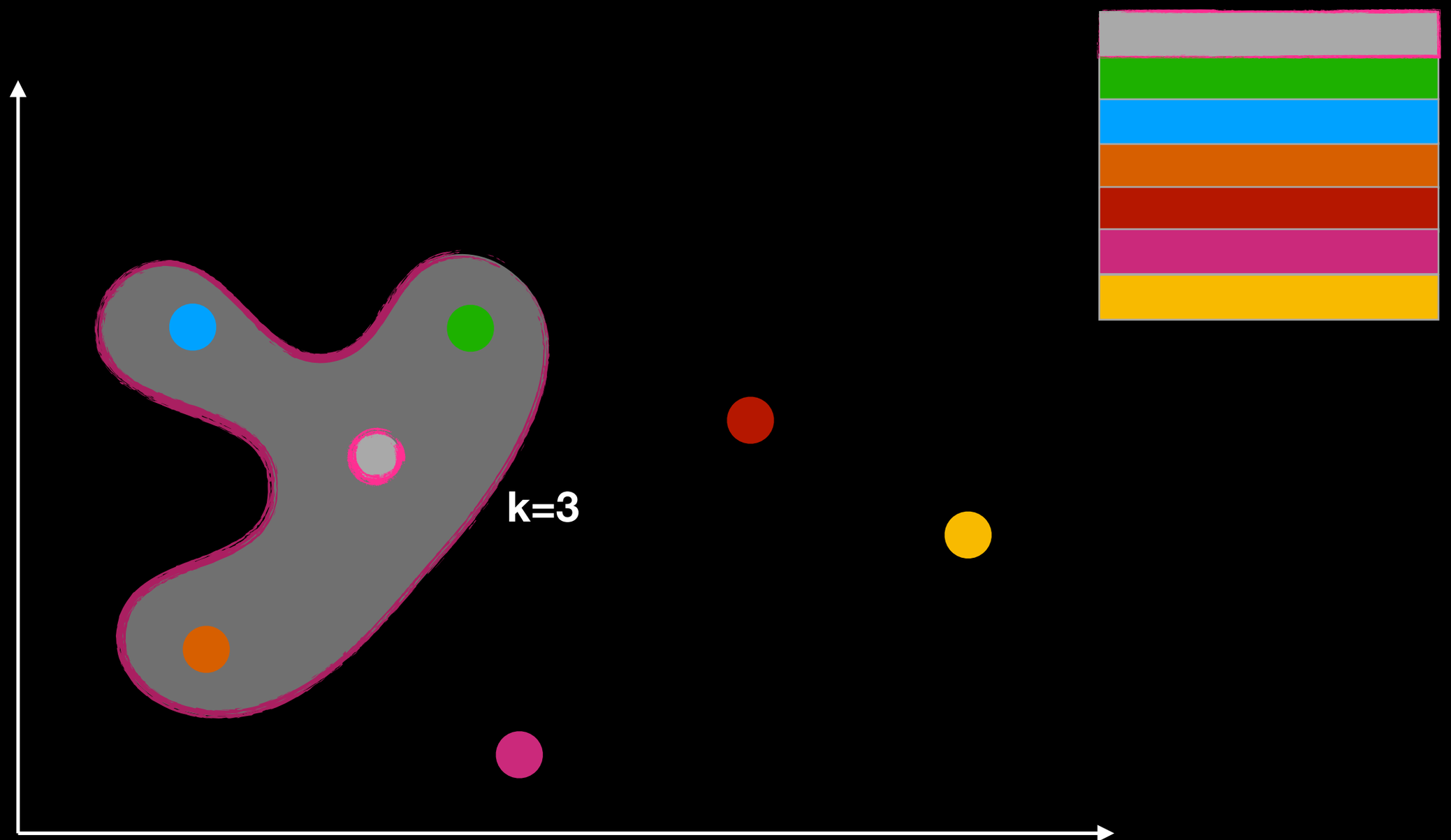
Nearest neighbors



Nearest neighbors



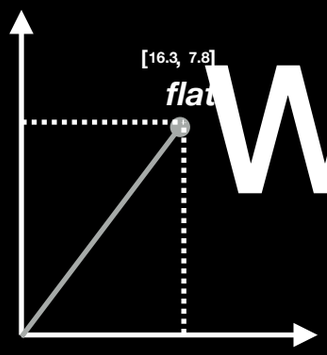
Nearest neighbors



Word2Vec – Intuitively

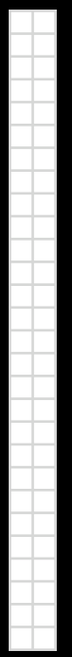
```
place all words randomly on fridge

for each pair of words:
    if in same sentence:
        move closer together
    else:
        move further apart
```

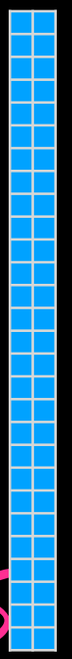


Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

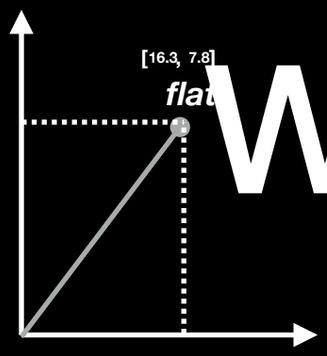


MATRIX OF CONTEXT WORDS



Renting out large *apartment* in great location

Bocconi



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

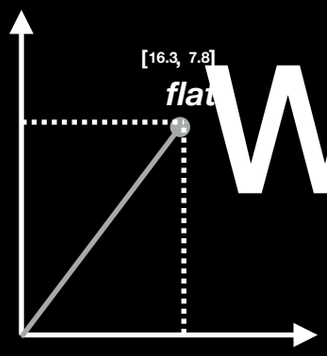
OUTPUT **apartment**

INPUT **rent** **large** **great** **location**

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

Bocconi



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

OUTPUT

apartment

INPUT

rent

large

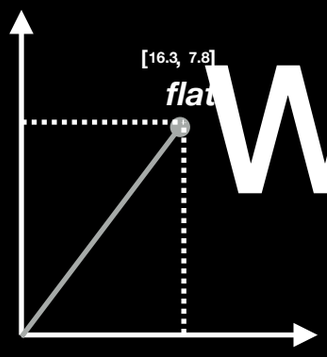
great

location

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

Bocconi



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

OUTPUT

apartment

SUM

INPUT

rent

large

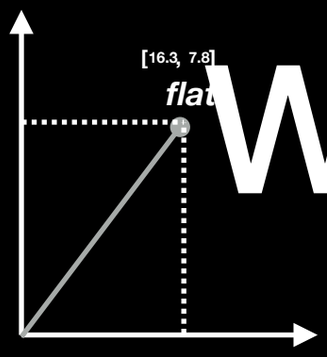
great

location

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

Bocconi



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

OUTPUT

garden

SUM

INPUT

rent

large

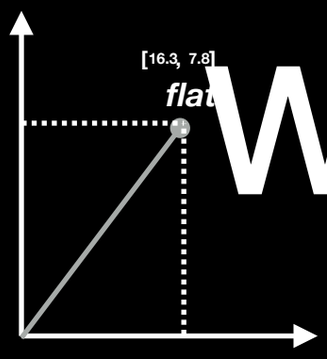
great

location

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

Bocconi



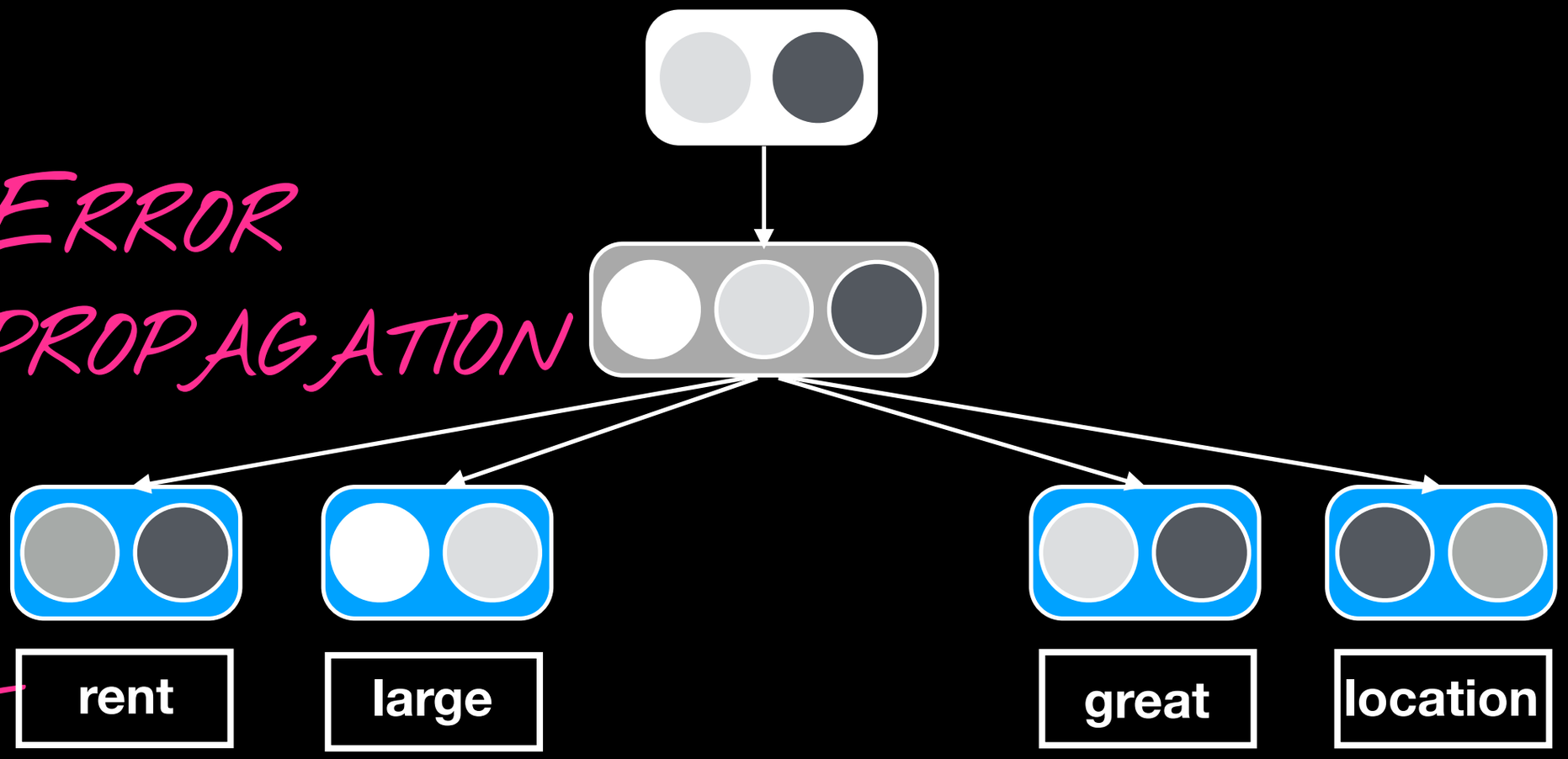
Word2Vec – CBOW Model

OUTPUT

apartment

MATRIX OF TARGET WORDS

ERROR BACKPROPAGATION



INPUT

rent

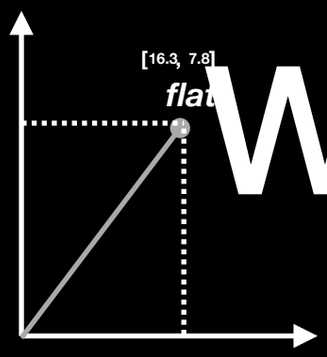
large

great

location

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location



Word2Vec – CBOW Model

OUTPUT

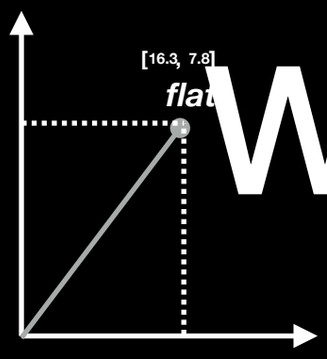
MATRIX OF TARGET WORDS

ERROR BACKPROPAGATION

INPUT

MATRIX OF CONTEXT WORDS

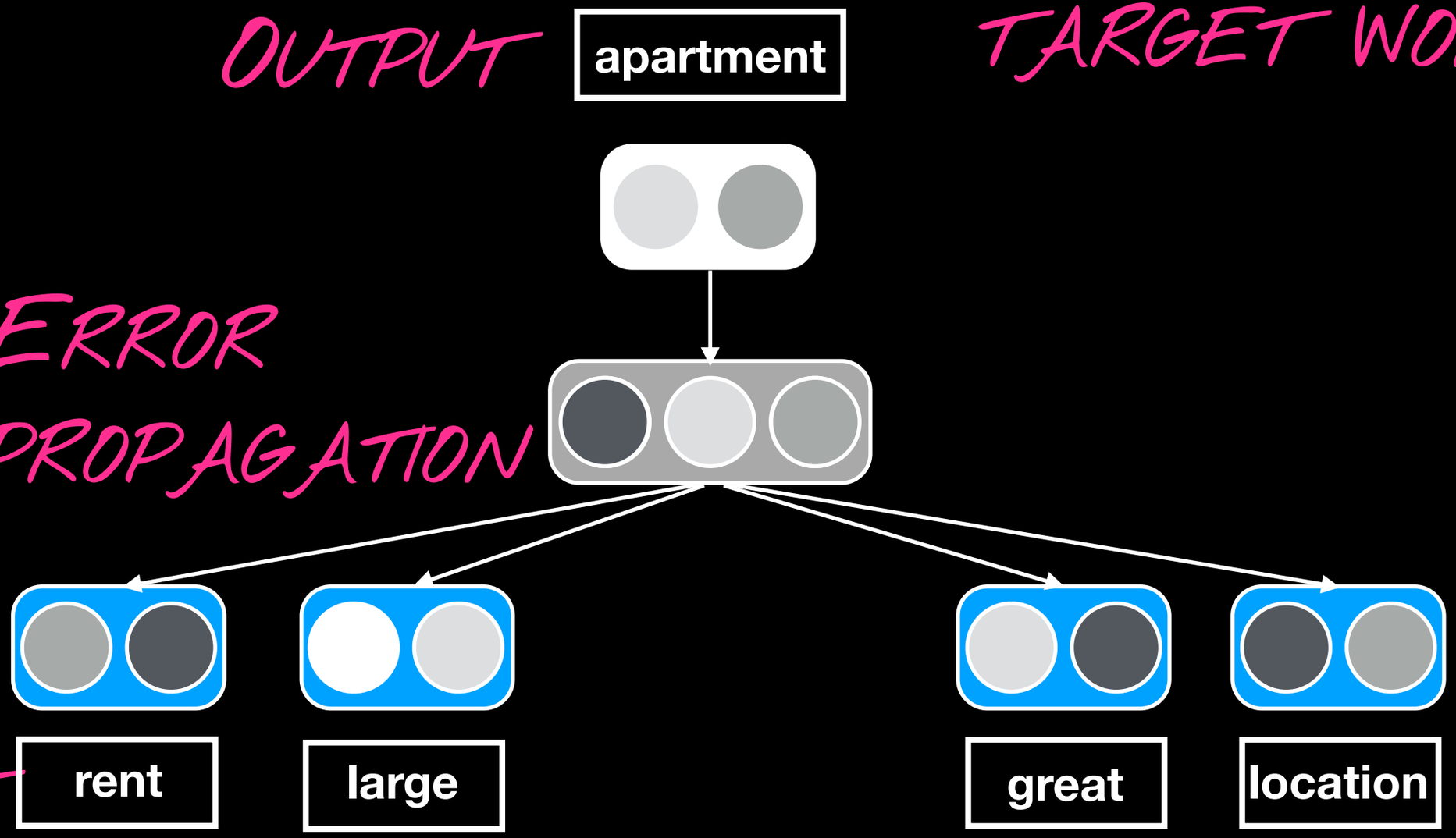
Renting out large *apartment* in great location



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

OUTPUT



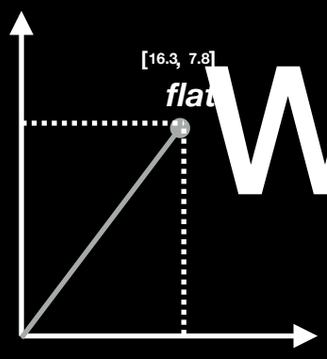
ERROR BACKPROPAGATION

INPUT

MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

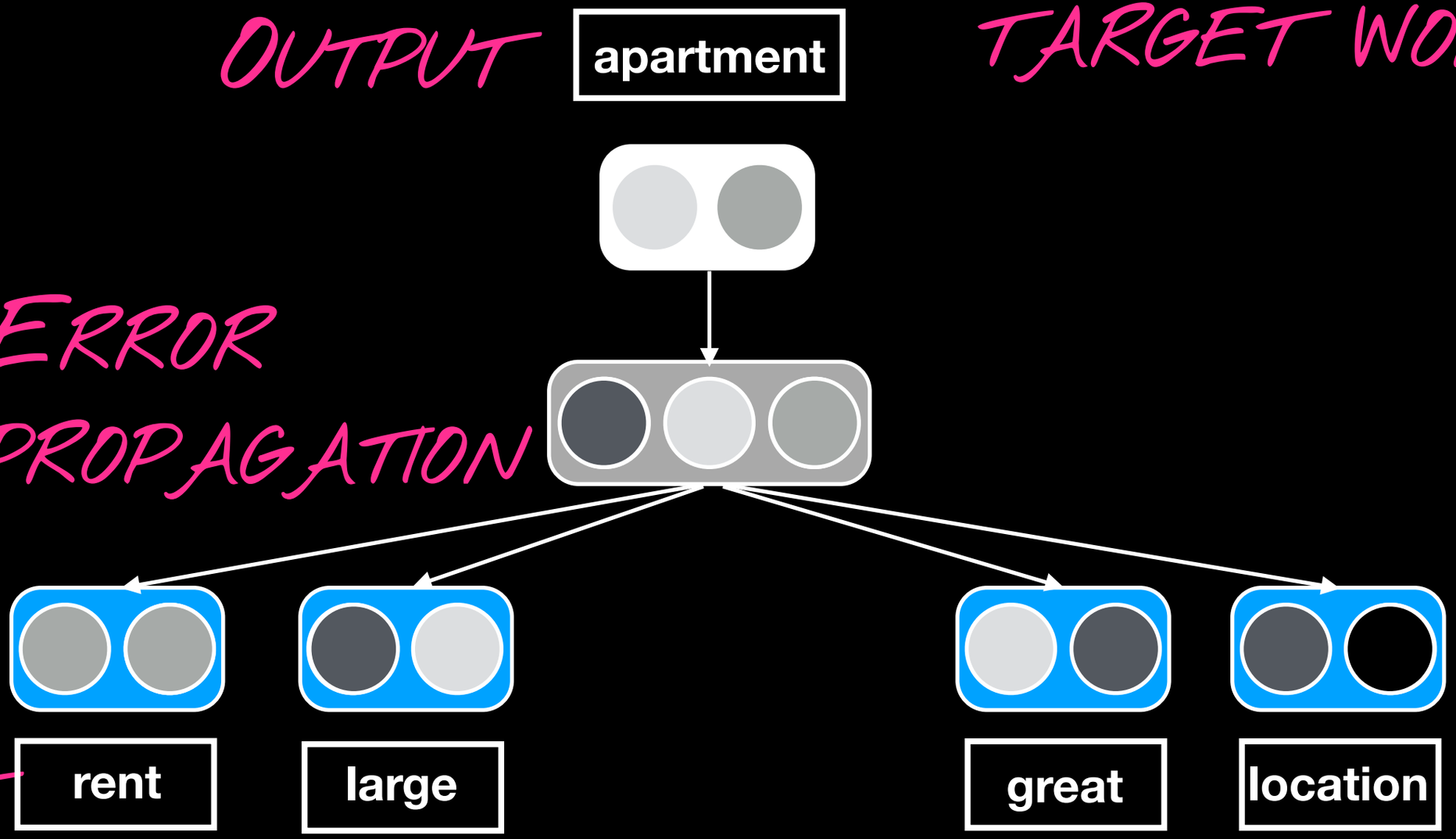
Bocconi



Word2Vec – CBOW Model

MATRIX OF TARGET WORDS

OUTPUT



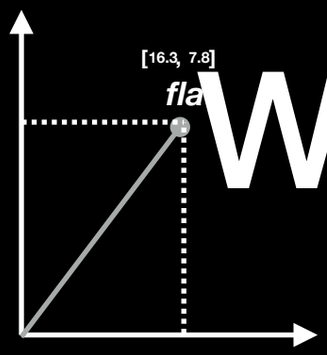
ERROR BACKPROPAGATION

INPUT

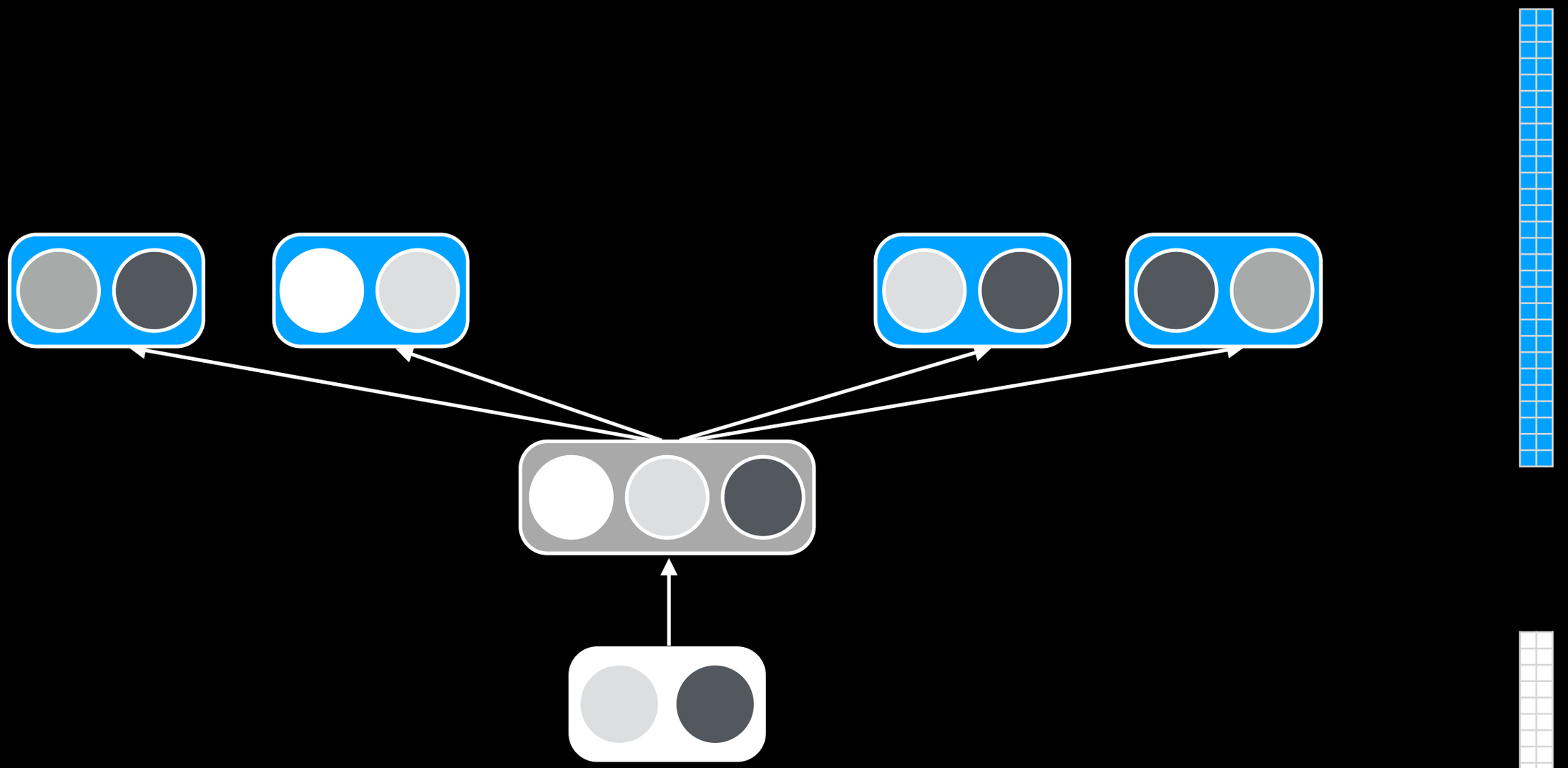
MATRIX OF CONTEXT WORDS

Renting out large *apartment* in great location

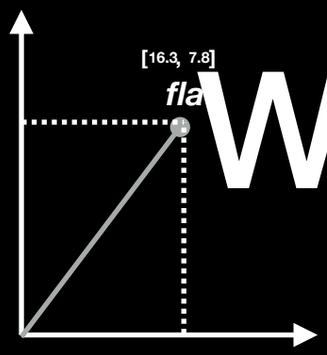
Bocconi



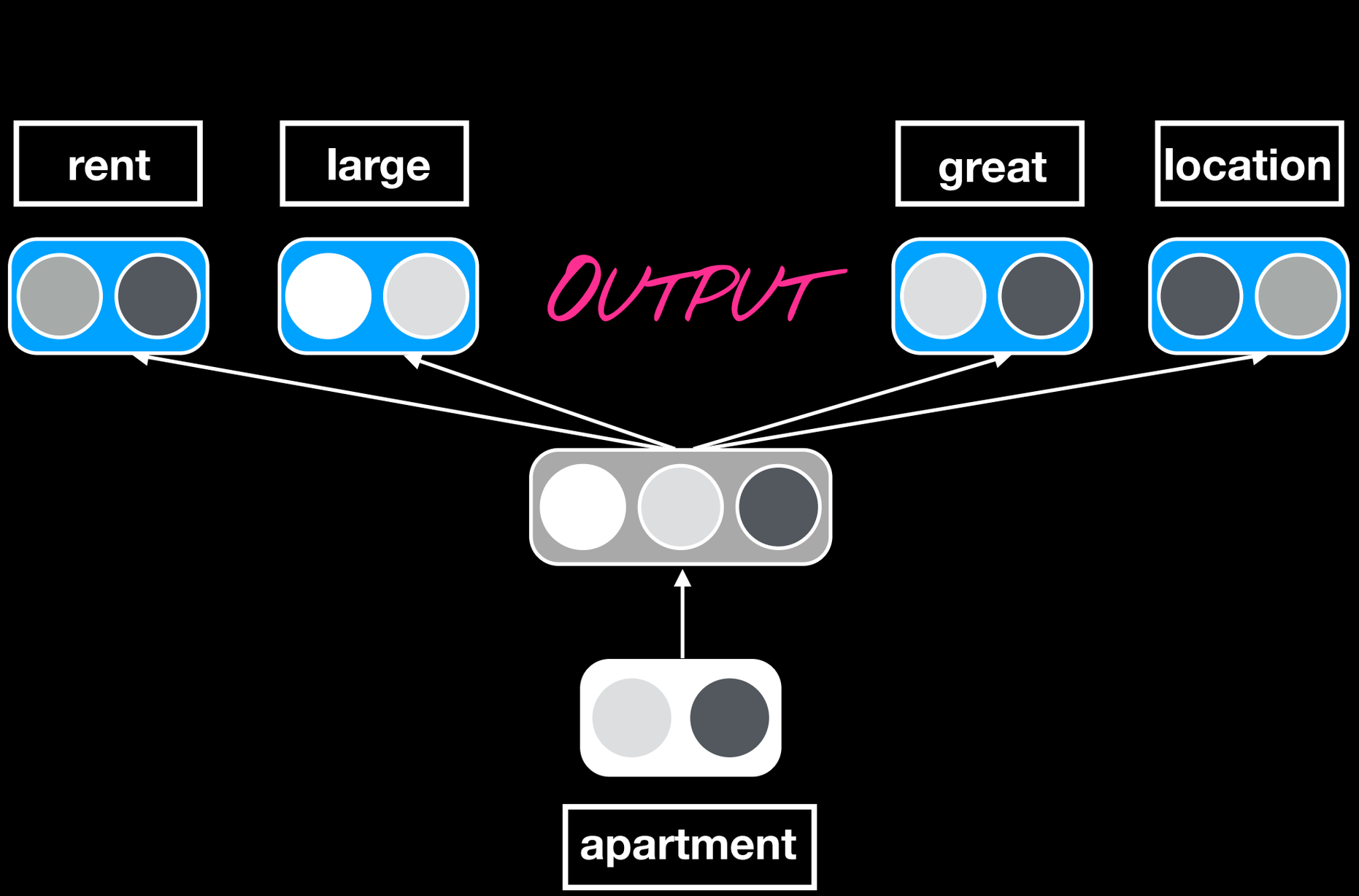
Word2Vec – Skipgram Model



Renting out large *apartment* in great location

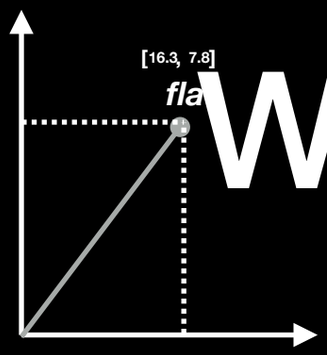


Word2Vec – Skipgram Model

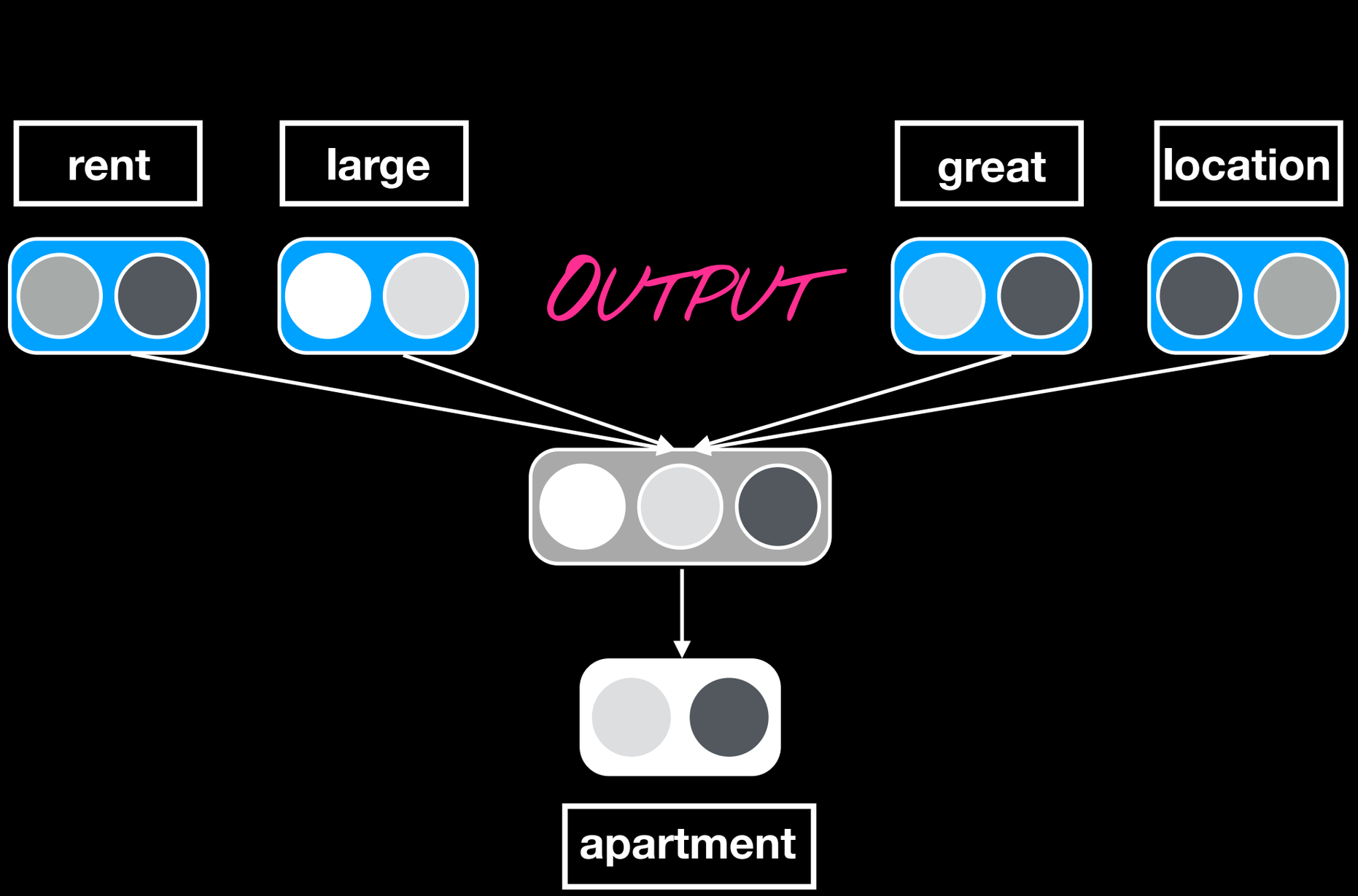


Renting out large *apartment* in great location

Bocconi

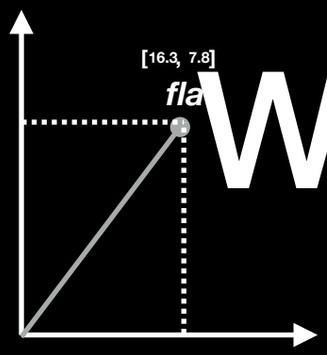


Word2Vec – Skipgram Model

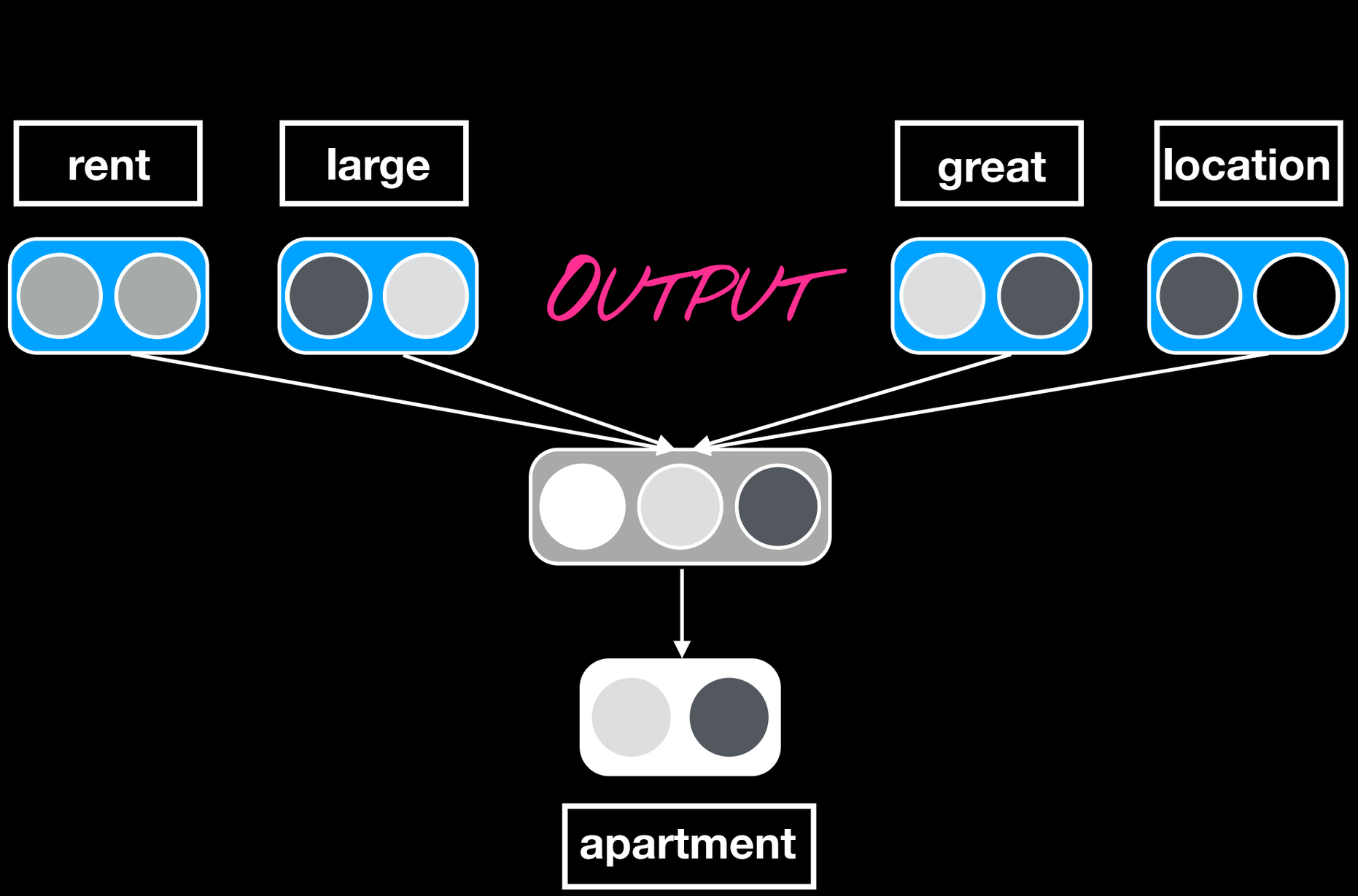


Renting out large *apartment* in great location

Bocconi

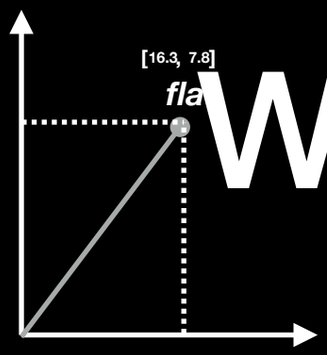


Word2Vec – Skipgram Model

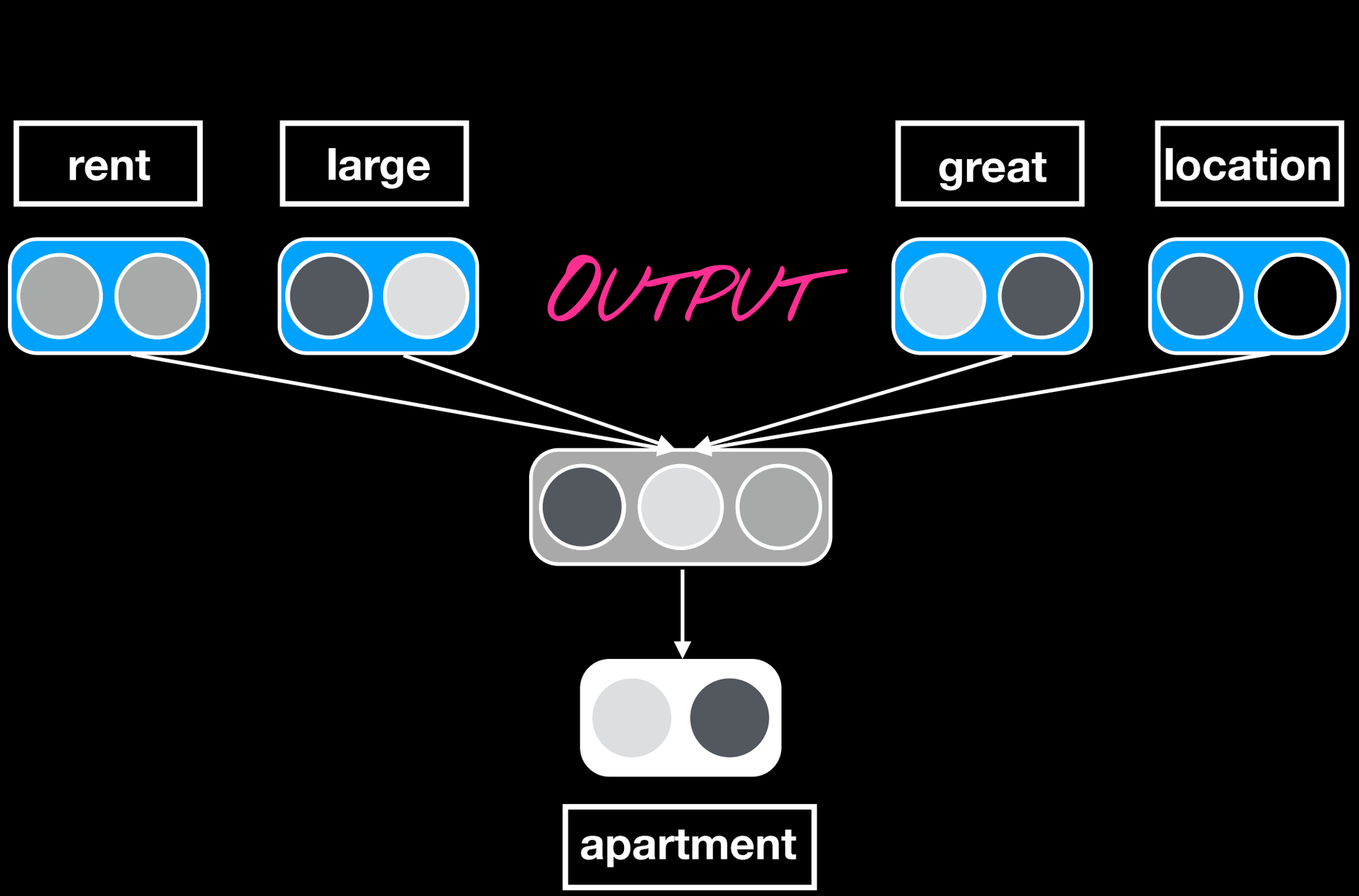


Renting out large *apartment* in great location

Bocconi

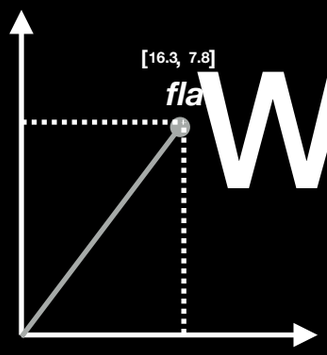


Word2Vec – Skipgram Model

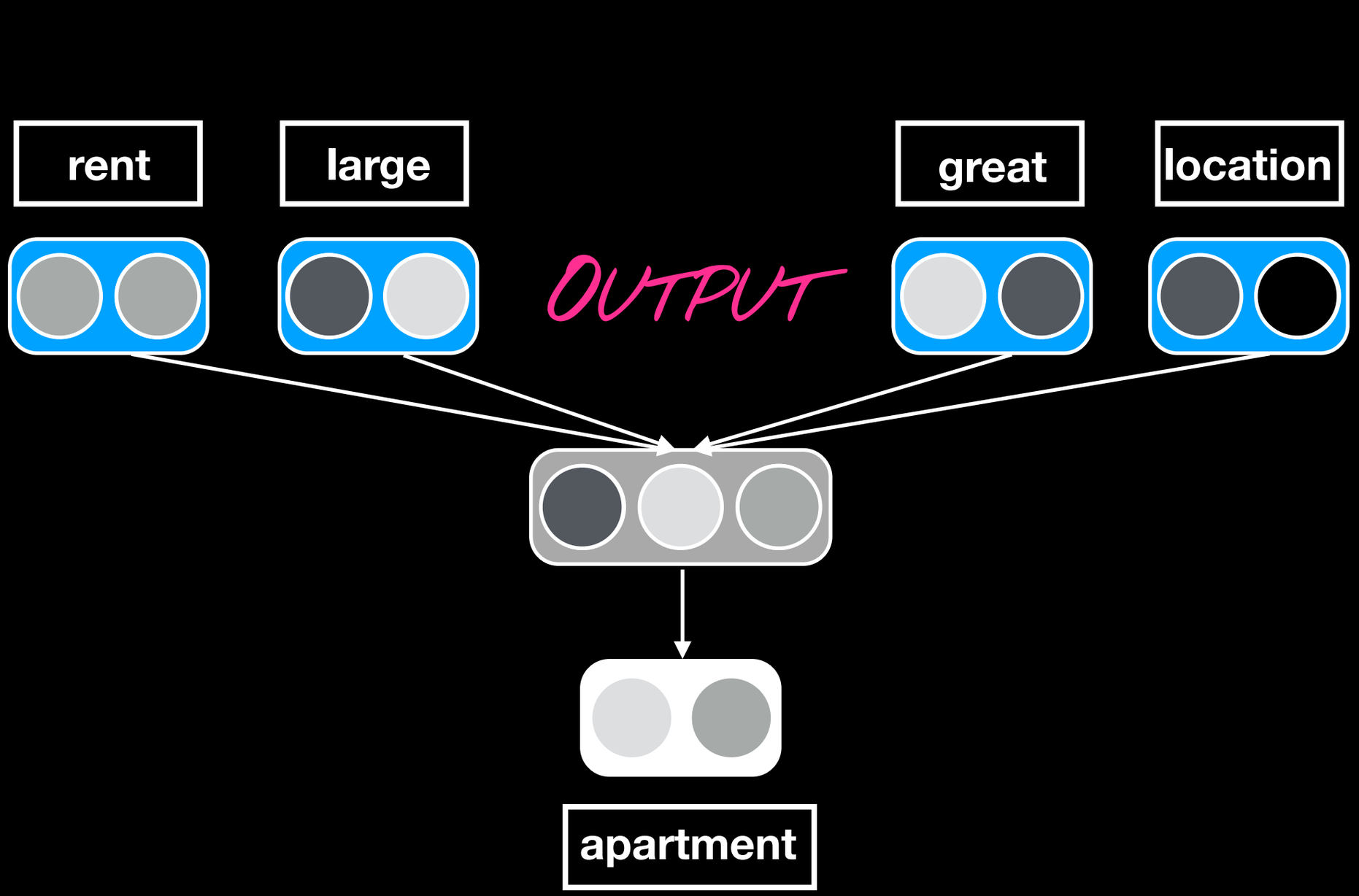


Renting out large *apartment* in great location

Bocconi



Word2Vec – Skipgram Model

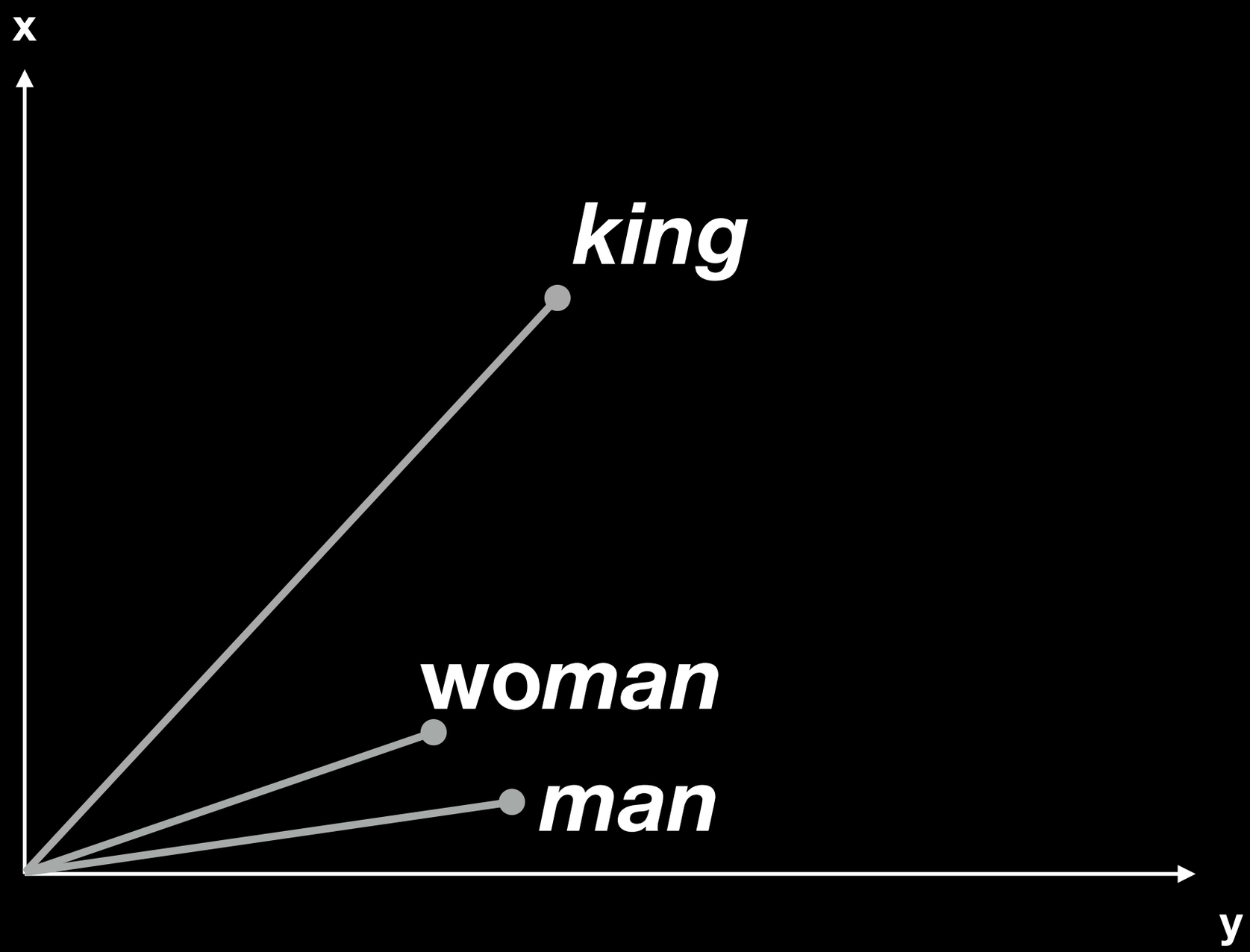


Renting out large *apartment* in great location

Bocconi

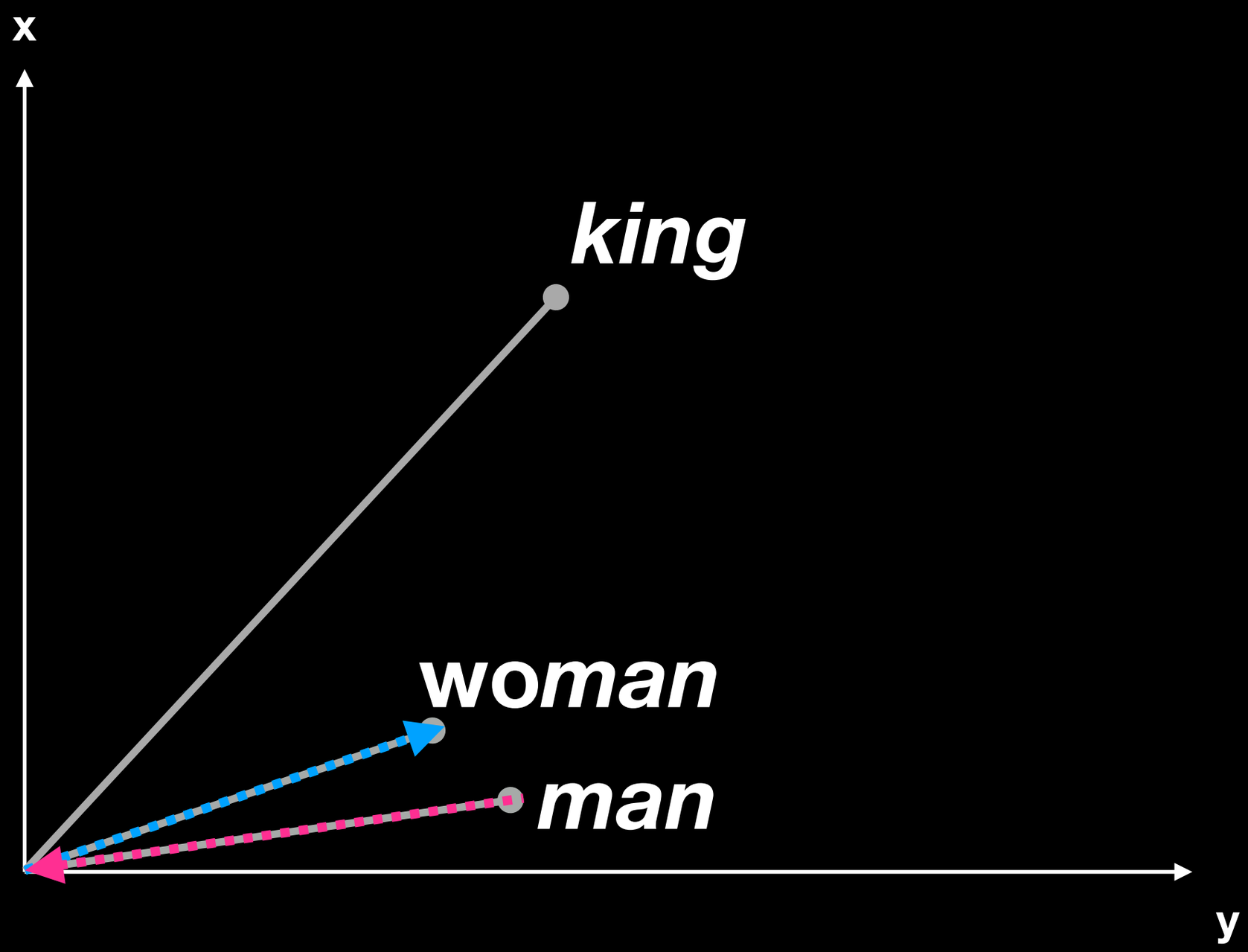
Vector Space Semantics

king – man + woman ≈ ???



Vector Space Semantics

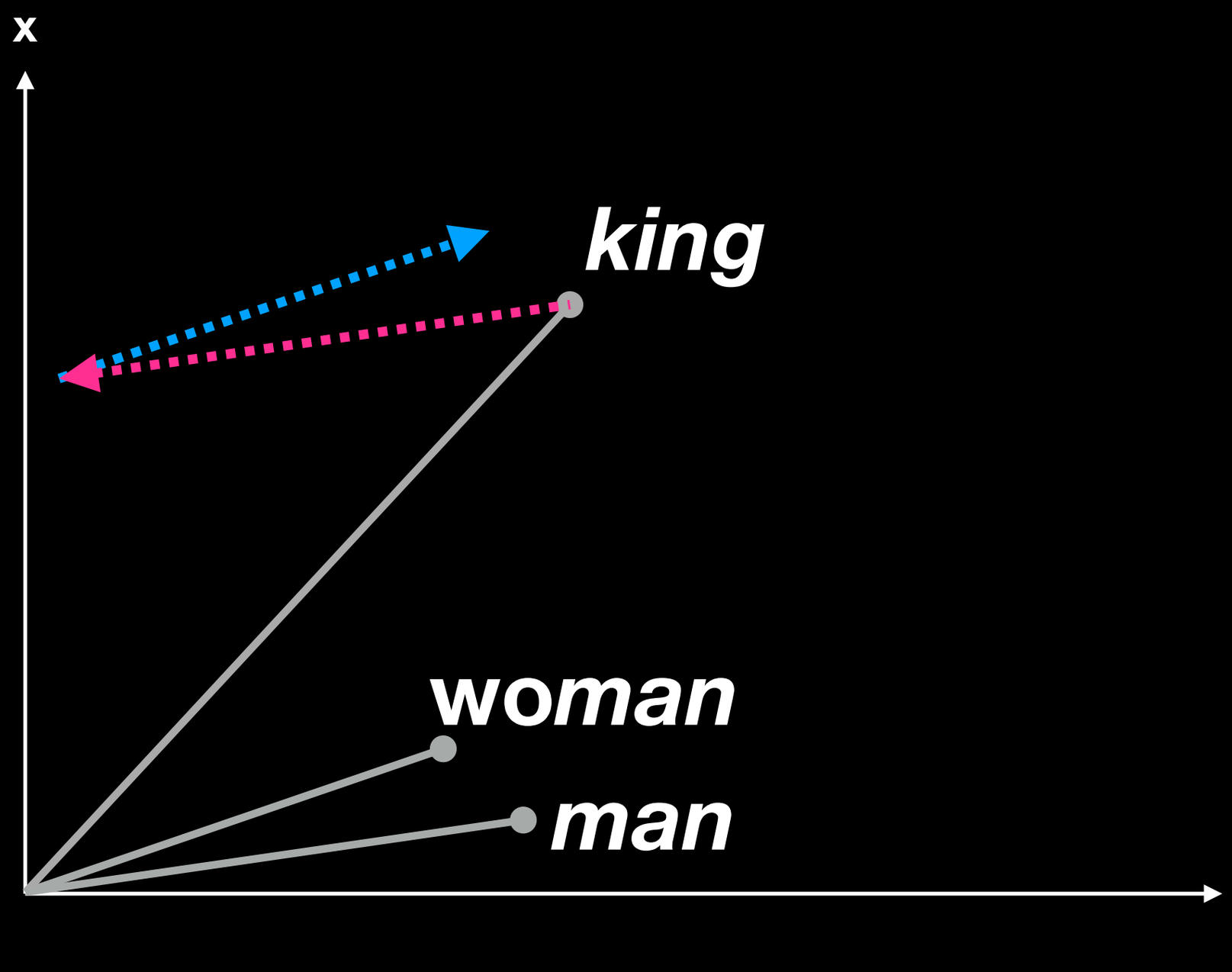
king – man + woman ≈ ???



Bocconi

Vector Space Semantics

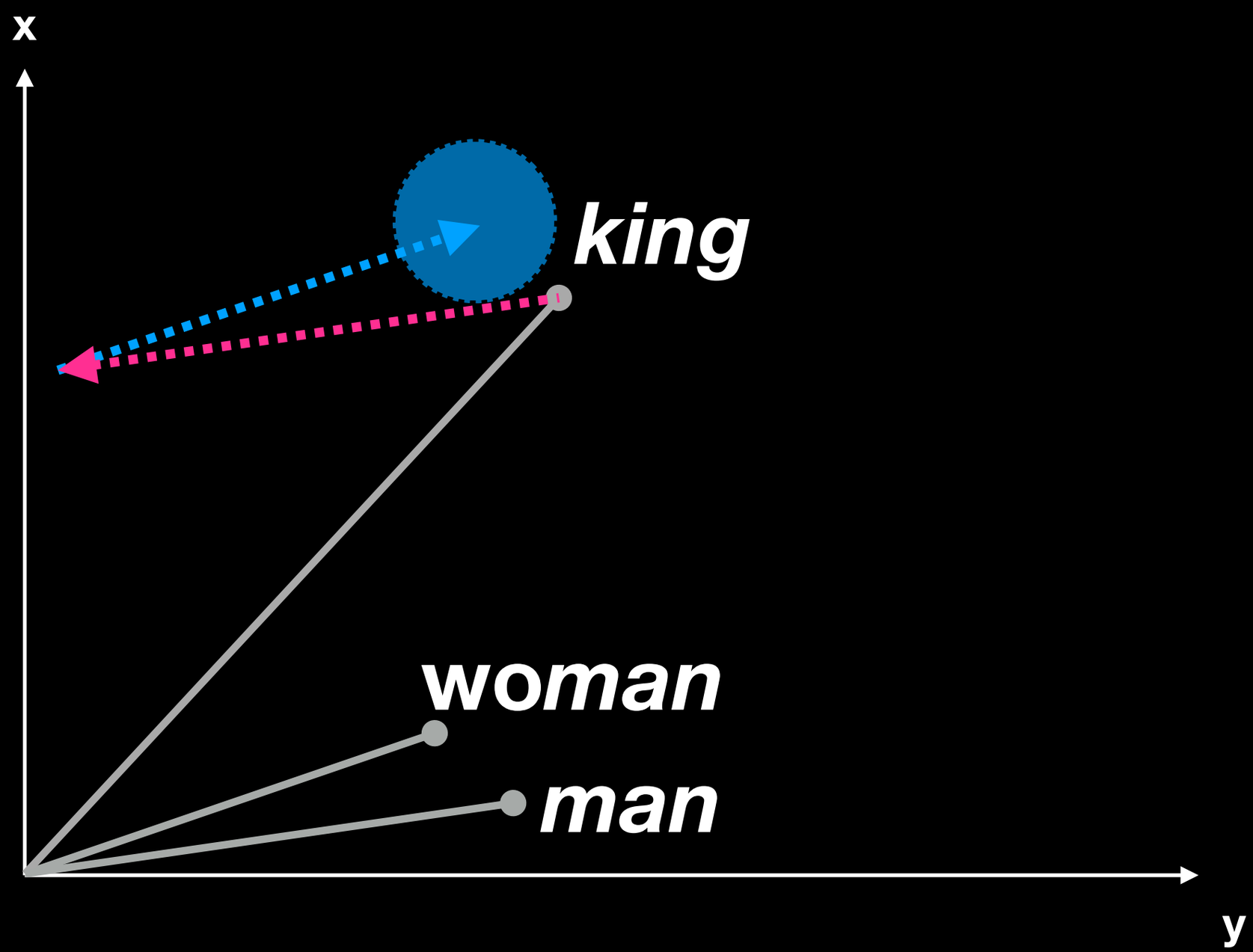
king – man + woman ≈ ???



Bocconi

Vector Space Semantics

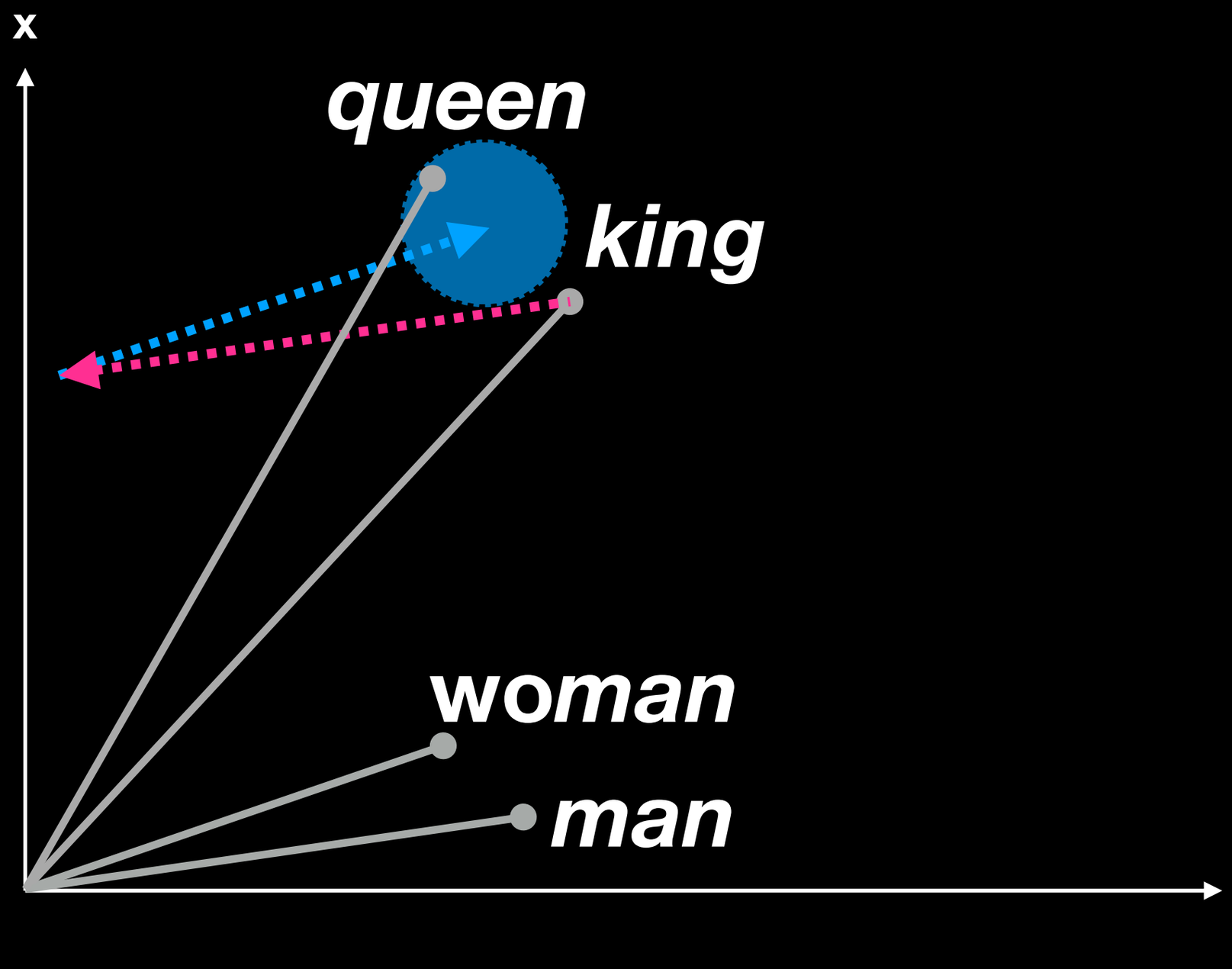
king – man + woman ≈ ???



Bocconi

Vector Space Semantics

king – man + woman ≈ queen



Bocconi

Part 2

Representing Documents as Vectors

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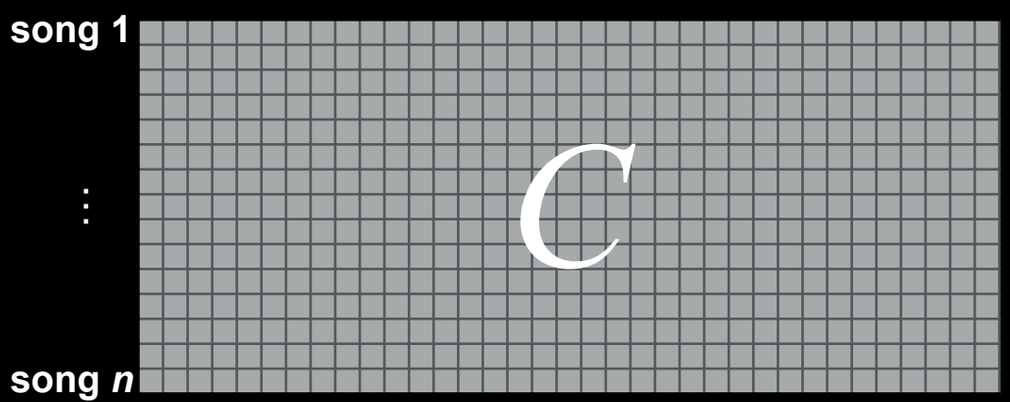
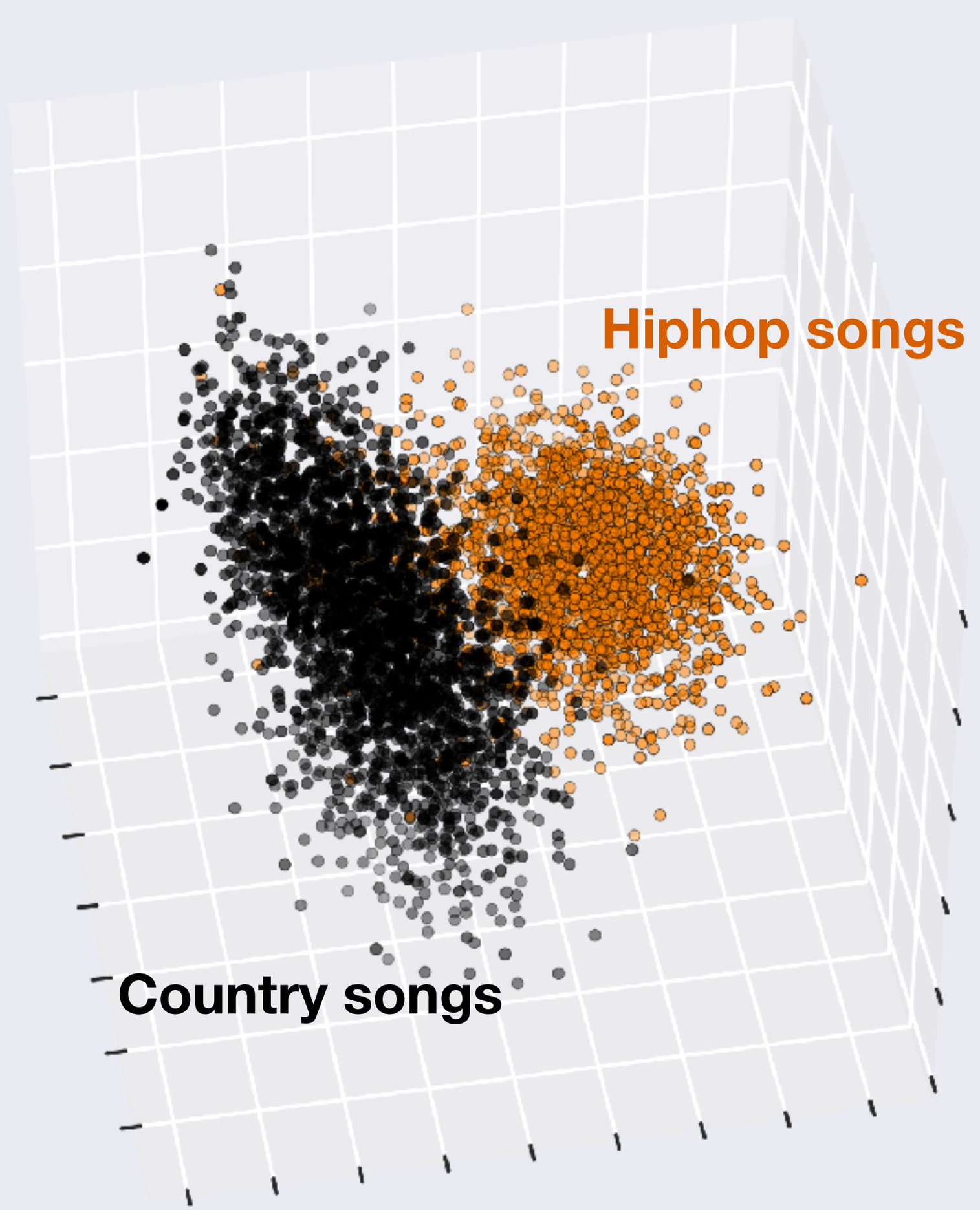
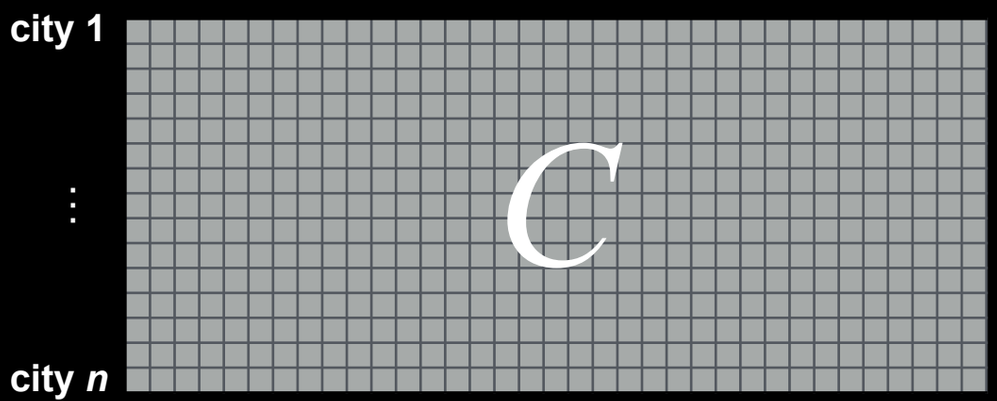
Example 1: Songs

Billboard HOT 100





Example 2: Cities



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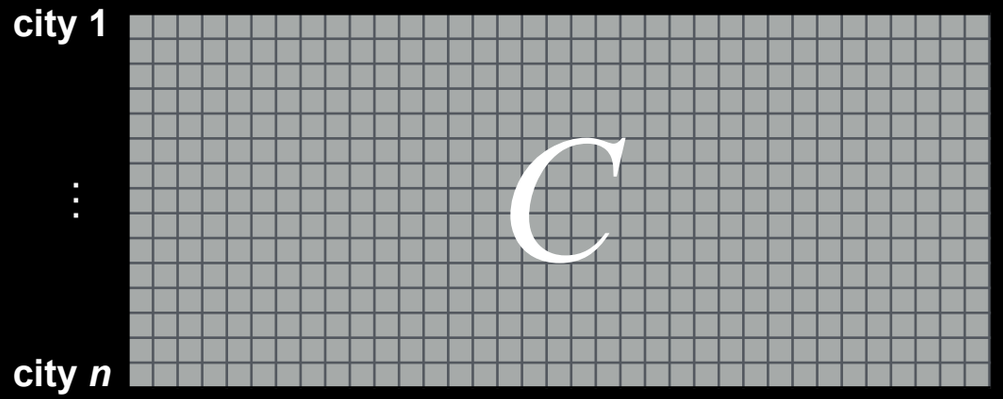
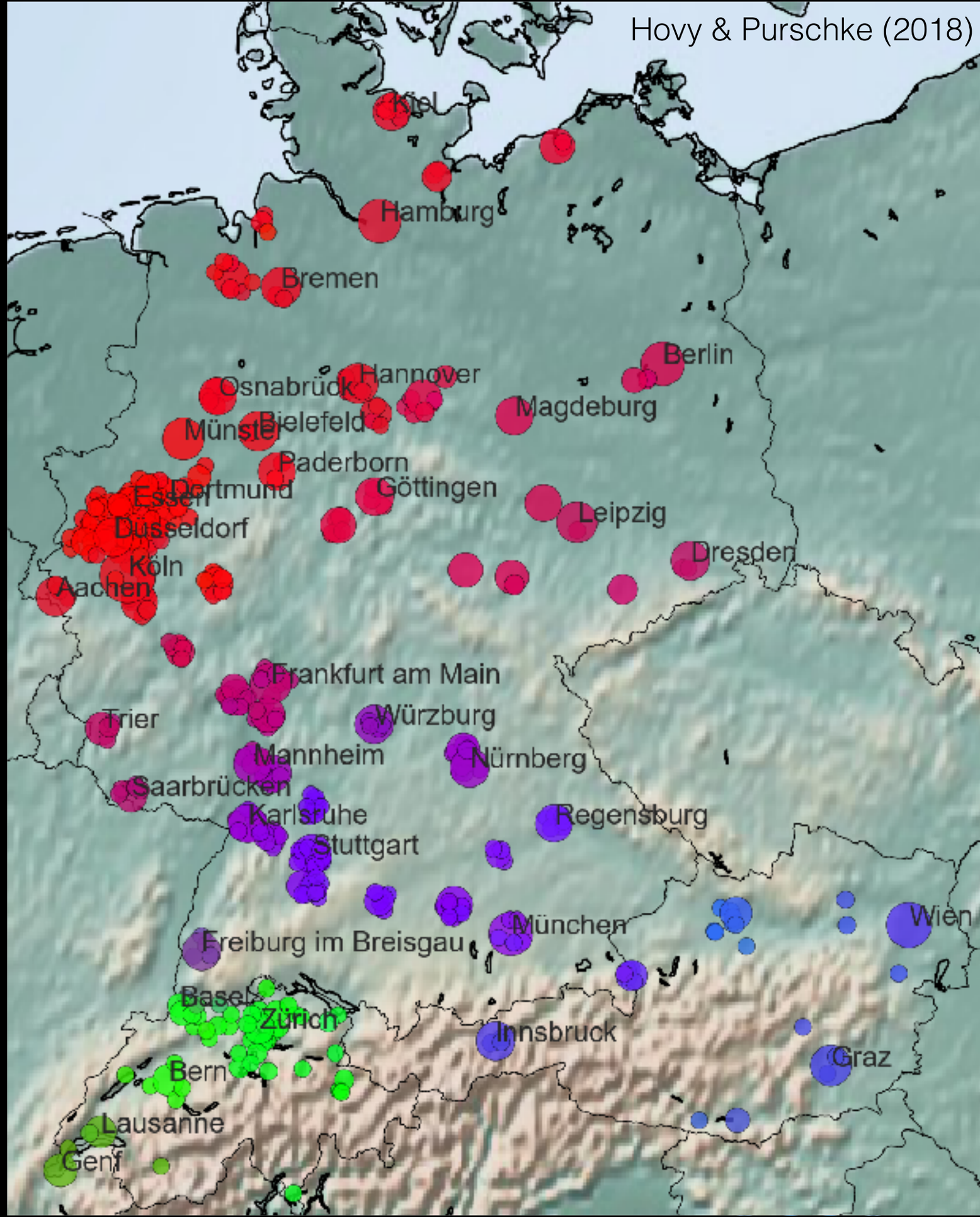
Example 2: Cities





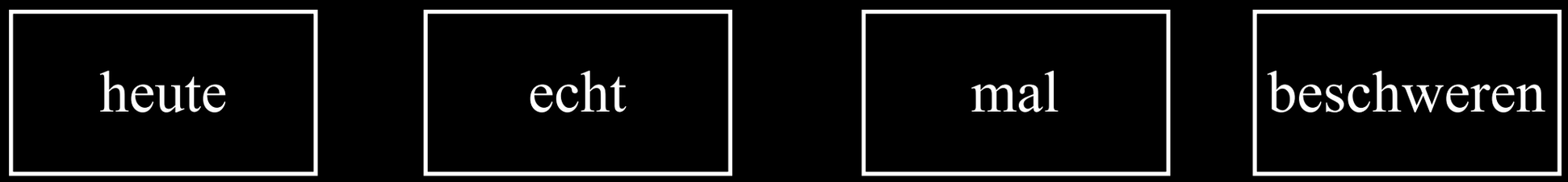
Doc2Vec – Intuitively

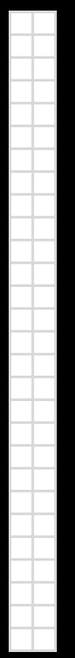
Le & Mikolov (2014)

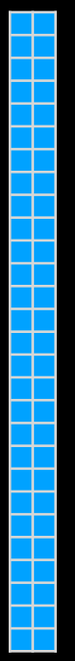
```
place words & cities randomly on fridge
for each pair of (word, city):
    if word seen in city:
        move closer together
    else:
        move further apart
```

Doc2Vec – Model

Le & Mikolov (2014)







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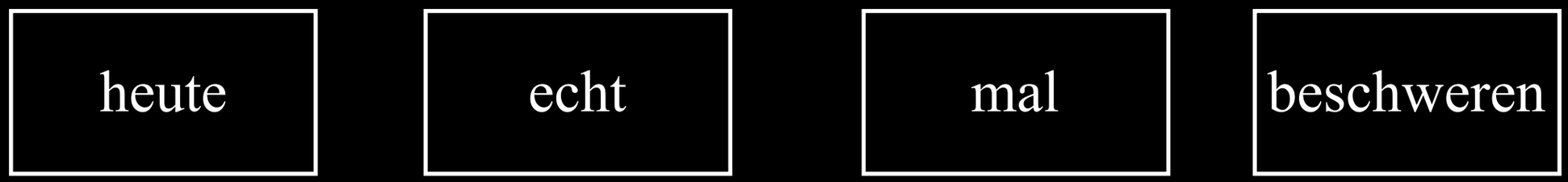
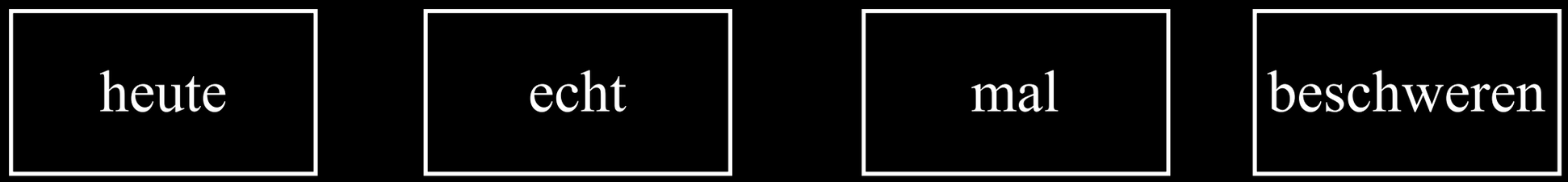
Doc2Vec – Model

Le & Mikolov (2014)



Doc2Vec – Model

Le & Mikolov (2014)



City matrix

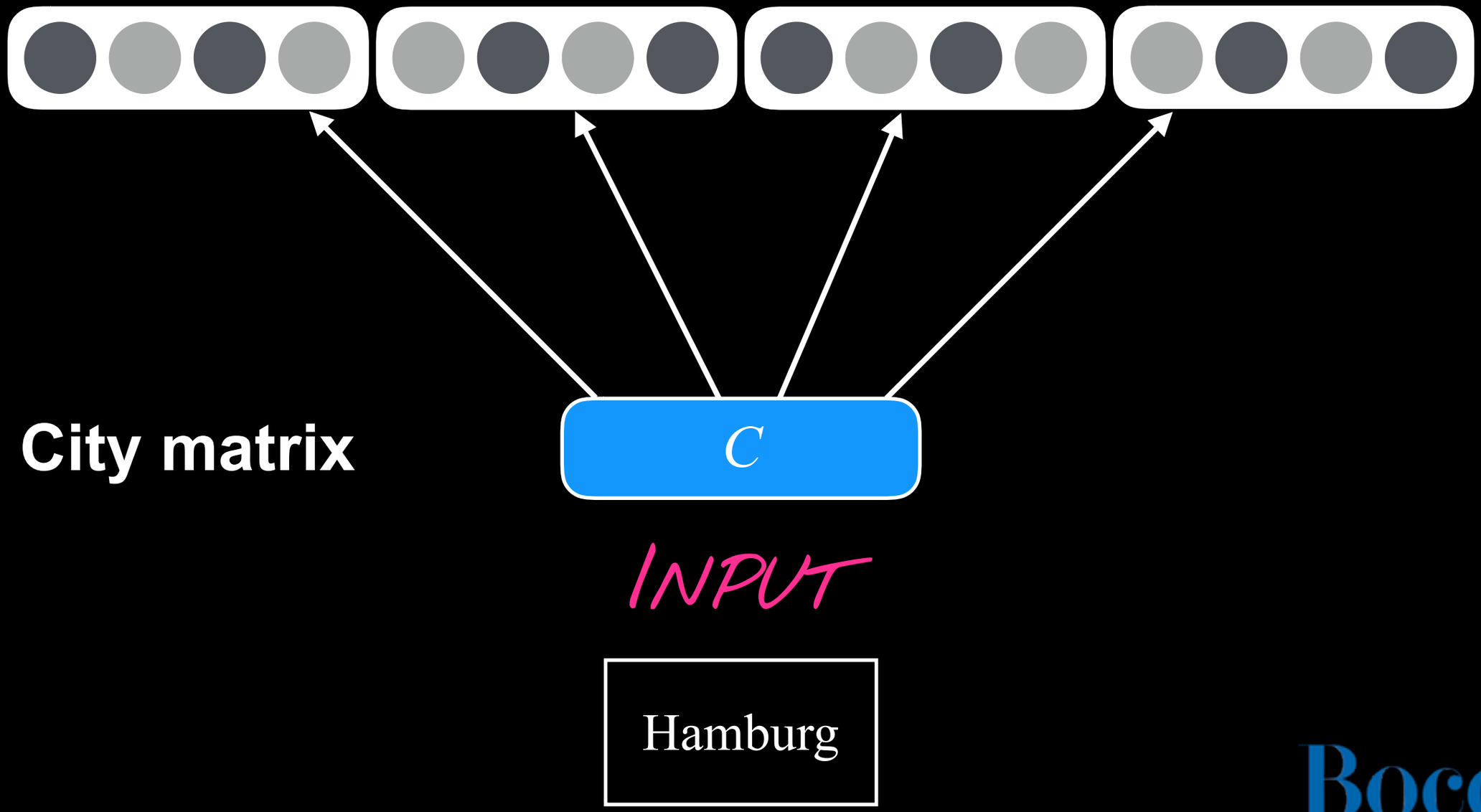
Bocconi

Doc2Vec – Model

Le & Mikolov (2014)

heute | echt | mal | beschweren

OUTPUT



City matrix

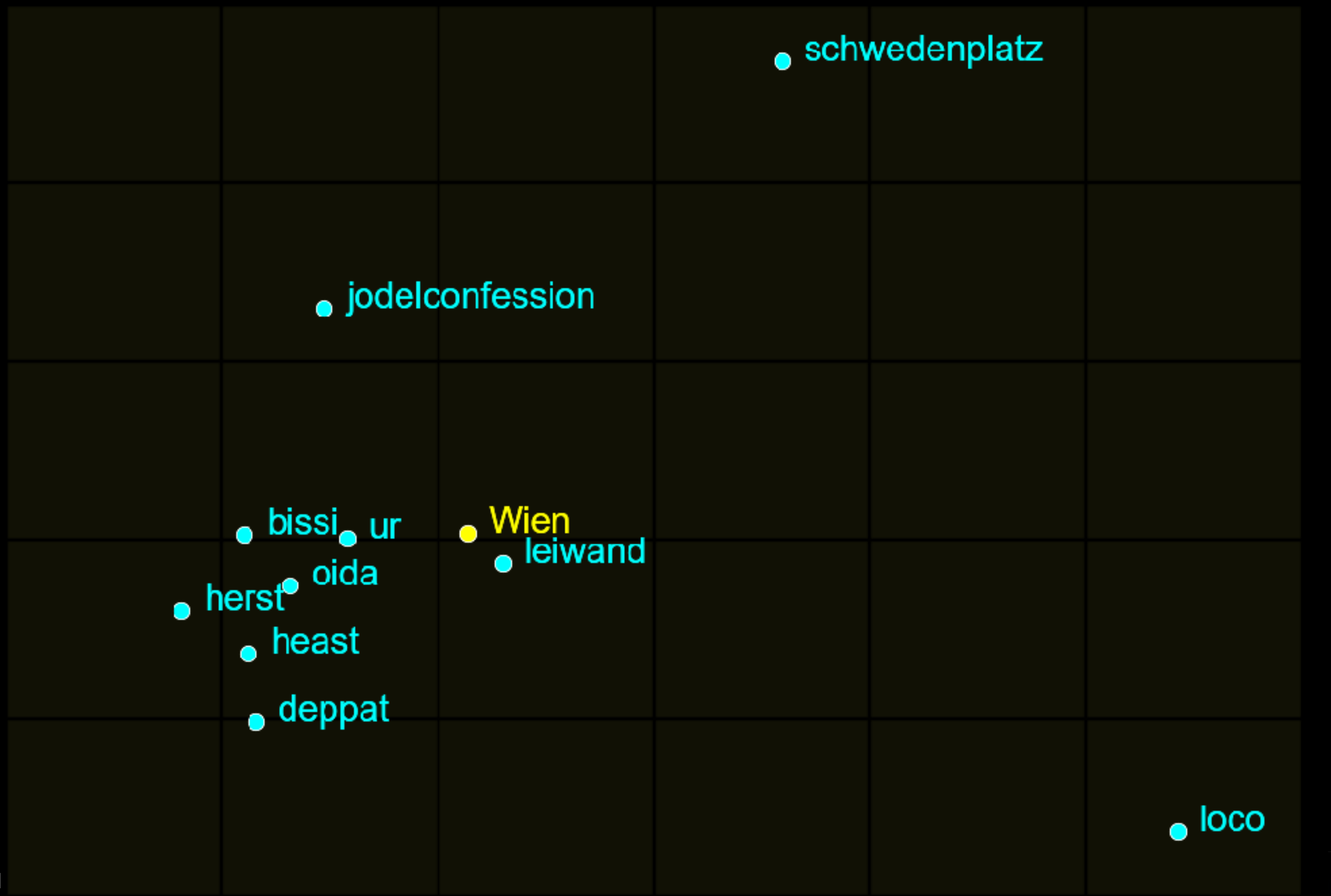
C

INPUT

Hamburg

Hovy & Purschke (2018)

Words and Documents



Hovy & Purschke (2018)

Words and Documents

Wrapping up…

Comparison

	Discrete	Distributed
Dimensions	Interpretable	Arbitrary
Content	Count-based	Coefficients
Density	Sparse	Dense
Strength	Interpretability	Similarity

Take home points

- Words and texts can be represented in two ways:
  - As **sparse, discrete** feature vectors over counts
  - As **dense, continuous** embedding vectors
- Discrete features allow us to **interpret** the input
- Word and document embeddings reflect **semantic similarity** in high-dimensional space