

# Distributional Semantics

LING 571 — Deep Processing Methods in NLP

November 7, 2022

Shane Steinert-Threlkeld

# 571 in the News

# Scope Ambiguity

The image shows a Fox News broadcast. In the center, a man with white hair, wearing a dark suit and a grey face mask, is speaking into a microphone. To his right, a graphic titled "KEY STATES" displays vote differences for four states: Georgia (+3,635), Nevada (+11,438), N. Carolina (+76,701), and Pennsylvania (+64,261). The graphic also shows the number of electoral votes for each state. At the bottom, a news ticker reads "TRUMP ALLEGES FRAUD, ATTEMPTS TO 'RIG' ELECTION" and "FOX NEWS ALERT". Below the alert, it shows "MONTANA | PRESIDENT | D | BIDEN 40.6% | R | TRUMP 56.9% | IN: 99%". The top left corner of the screen displays "THE WHITE HOUSE" and "LIVE | 7:09 PM ET".

THE WHITE HOUSE  
LIVE | 7:09 PM ET

★ KEY STATES ★  
VOTE DIFFERENCE

State	Electoral Votes	Vote Difference
GEORGIA	16	+3,635
NEVADA	6	+11,438
N. CAROLINA	15	+76,701
PENNSYLVANIA	20	+64,261

FOX NEWS channel

TRUMP ALLEGES FRAUD, ATTEMPTS TO "RIG" ELECTION

FOX NEWS ALERT

MONTANA | PRESIDENT | D | BIDEN 40.6% | R | TRUMP 56.9% | IN: 99%

# Implicature

It's kind of like how I don't go around calling my current spouse my "first wife", even though it's technically accurate

 **roxane gay**  @rgay · Nov 6

You will see a lot of republicans using the phrase "legal vote" today. This is rhetoric designed to imply that there are also illegal votes. There aren't.

# Presuppositions

Actually don't ask questions with false presuppositions, this is like entry-level semantics & propaganda



**Kayleigh McEnany**  @kayleighmcenany · 21h

ASK: Why were Republican poll watchers systematically blocked from observing the vote count?

It's a simple question with no satisfactory answer !!

# The Big Dark



NWS Seattle ✓  
@NWSSeattle

Alright, so we're back on Pacific Standard Time now.

This was probably inevitable...

We now present....Big Dark...the playlist.

#wawx

## The Big Dark The Playlist

**Keep It Dark - Genesis**  
**Darkness - The Police**  
**Shot in the Dark - Ozzy Osbourne**  
**Dark Necessities - Red Hot Chili Peppers**  
**Decks Dark - Radiohead**  
**The Dark Side - Muse**  
**Little Dark Age - MGMT**  
**Under Cover of Darkness - The Strokes**  
**Dancing in the Dark - Bruce Springsteen**  
**On the Dark Side - John Cafferty and The Beaver Brown  
Band**  
**Waiting for the Night - Depeche Mode**  
**This Time of Night - New Order**  
**A Night Like This - The Cure**  
**Night Sky - CHVRCHES**  
**Nocturnal - Disclosure feat. the Weeknd**  
**So Dark - Prince**  
**Midnight City - M83**

ALT

10:06 AM · Nov 6, 2022 · Twitter Web App

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- Daylight Savings Time



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- Daylight Savings Time
- “Je bent niet van suiker gemaakt ...”



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# W What's your favorite thing about cold/dark days?

Total Results: 0

Powered by  **Poll Everywhere**

Start the presentation to see live content. For screen share software, share the entire screen. Get help at [pollev.com/app](https://pollev.com/app)

# Distributional Similarity

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  - We make *tezgüino* from corn.
- Tezguino; corn-based alcoholic beverage. (From [Lin, 1998a](#))

# Distributional Similarity

- How can we represent the “company” of a word?

# Distributional Similarity

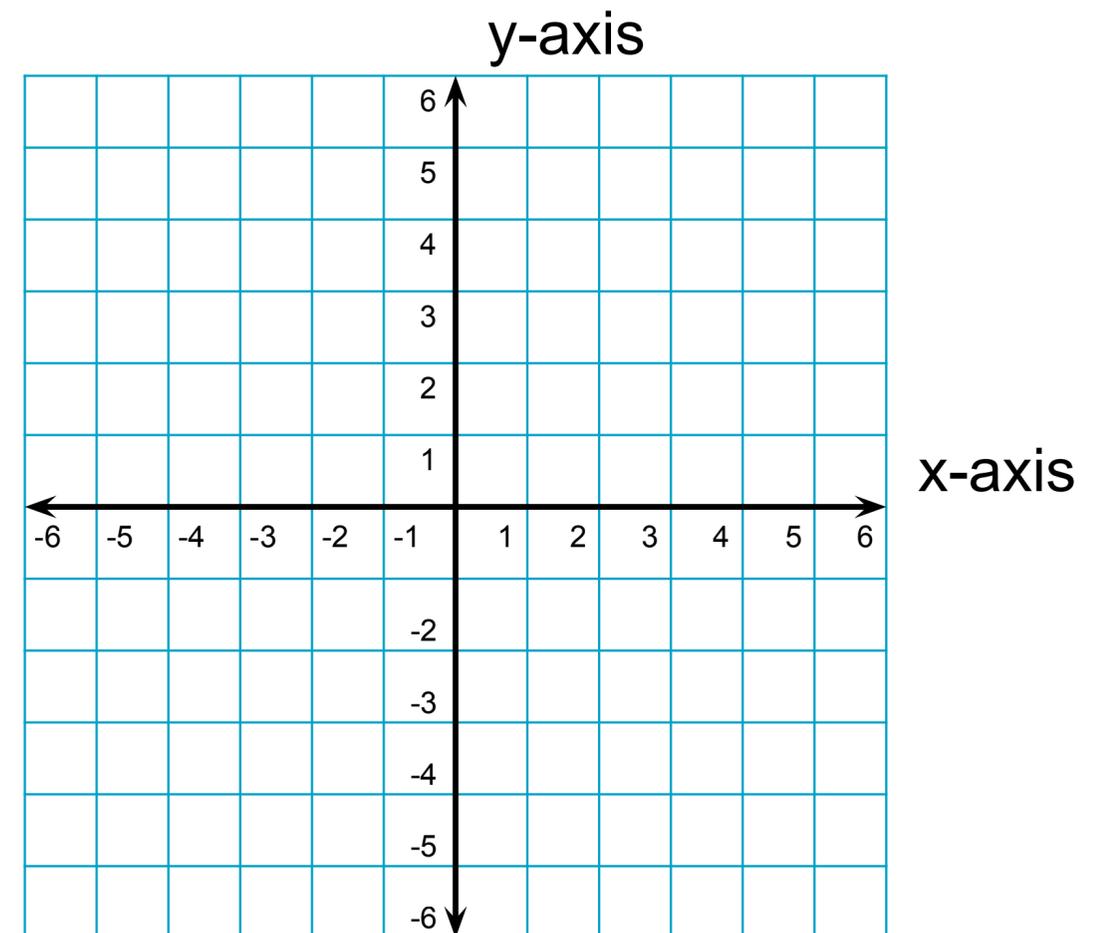
- How can we represent the “company” of a word?
- How can we make similar words have similar representations?

# Vectors: A Refresher

- A vector is a list of numbers
- Each number can be thought of as representing a “dimension”

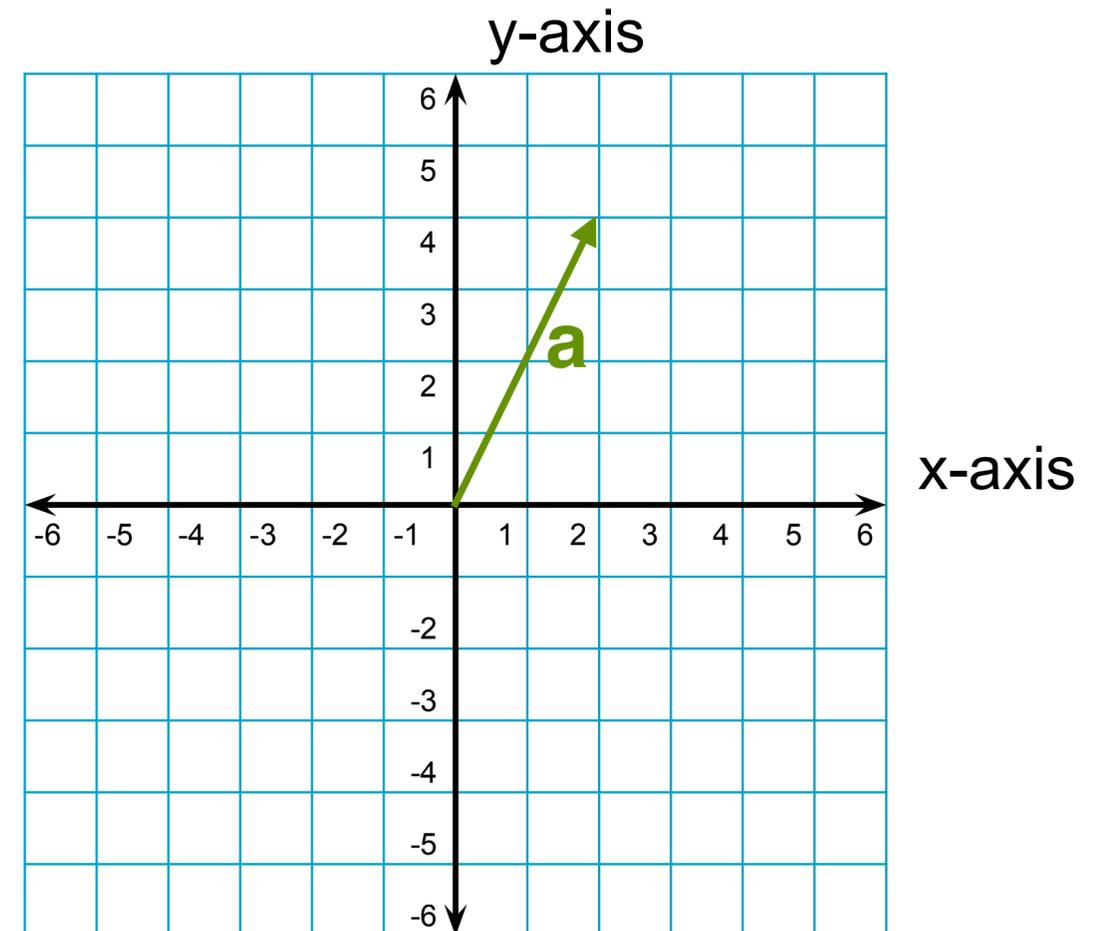
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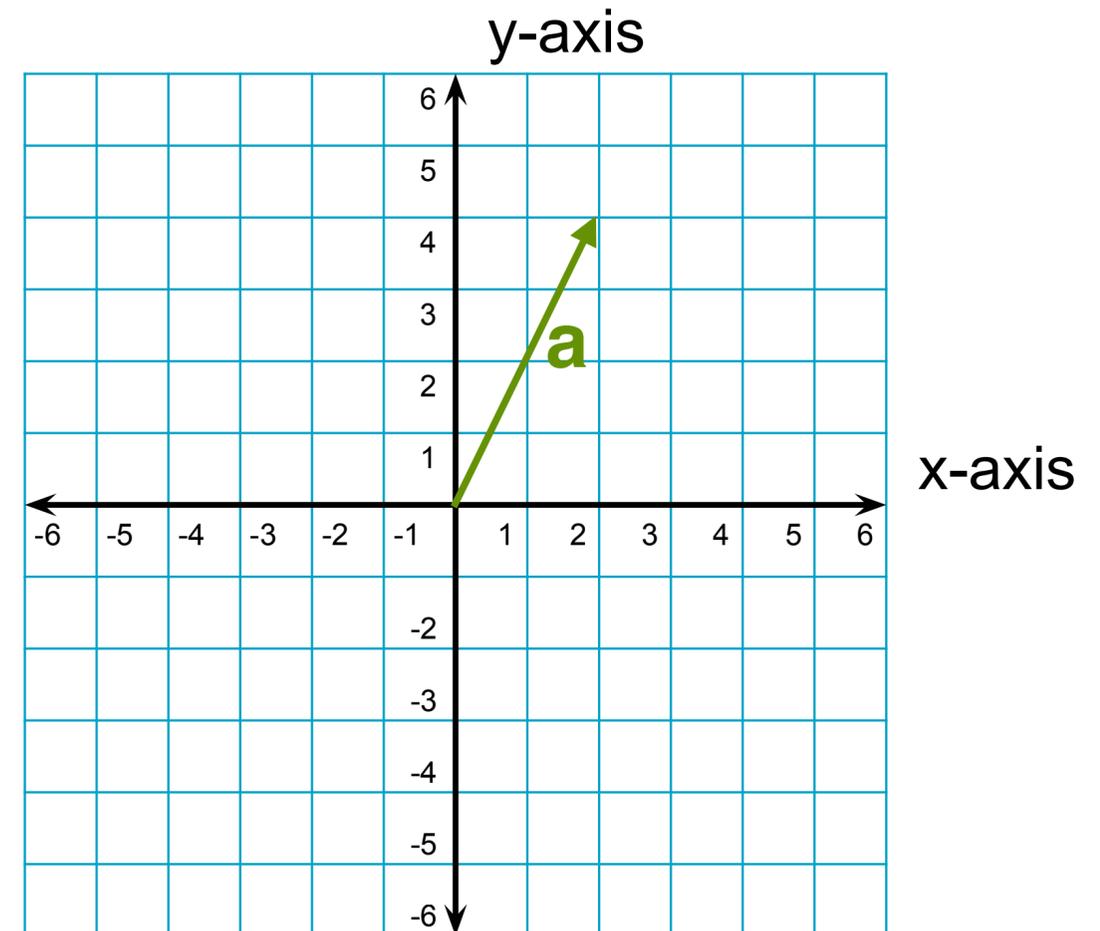
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  - $\vec{a} = \langle 2, 4 \rangle$



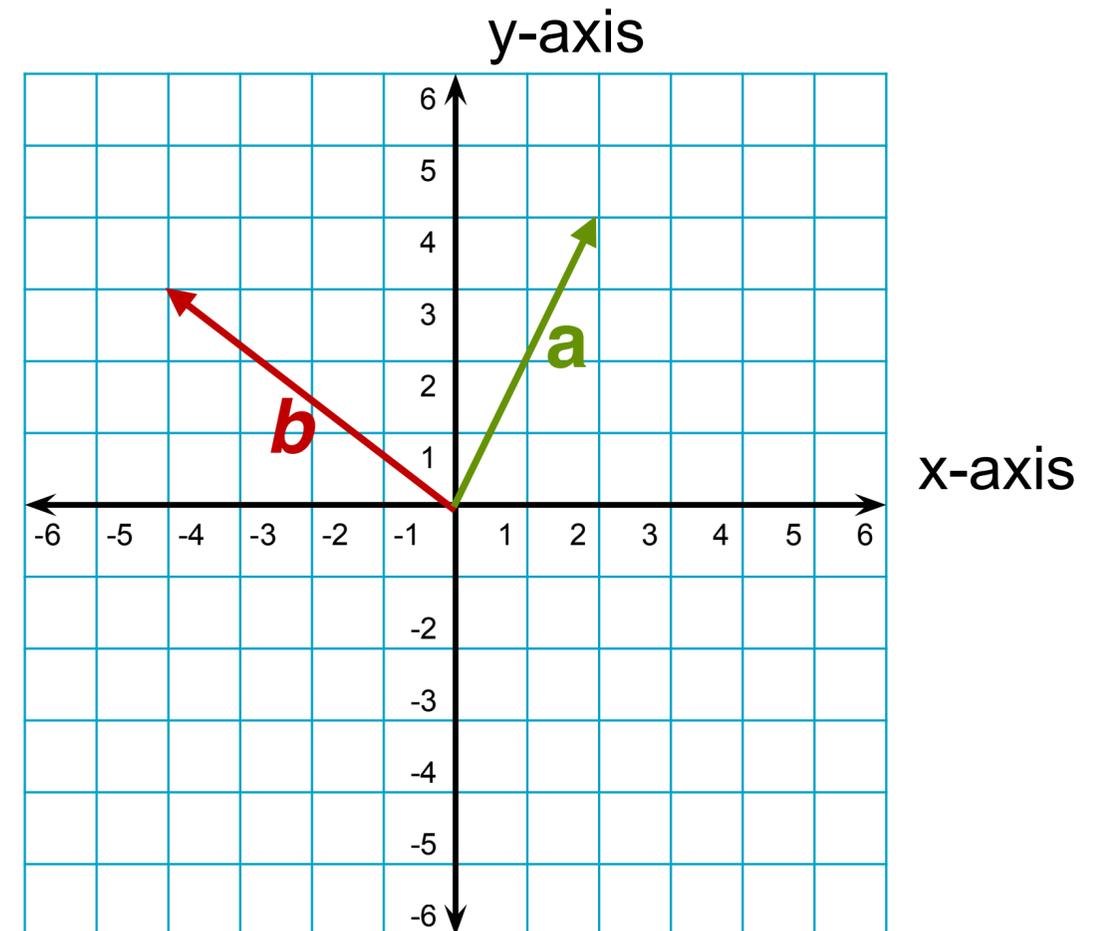
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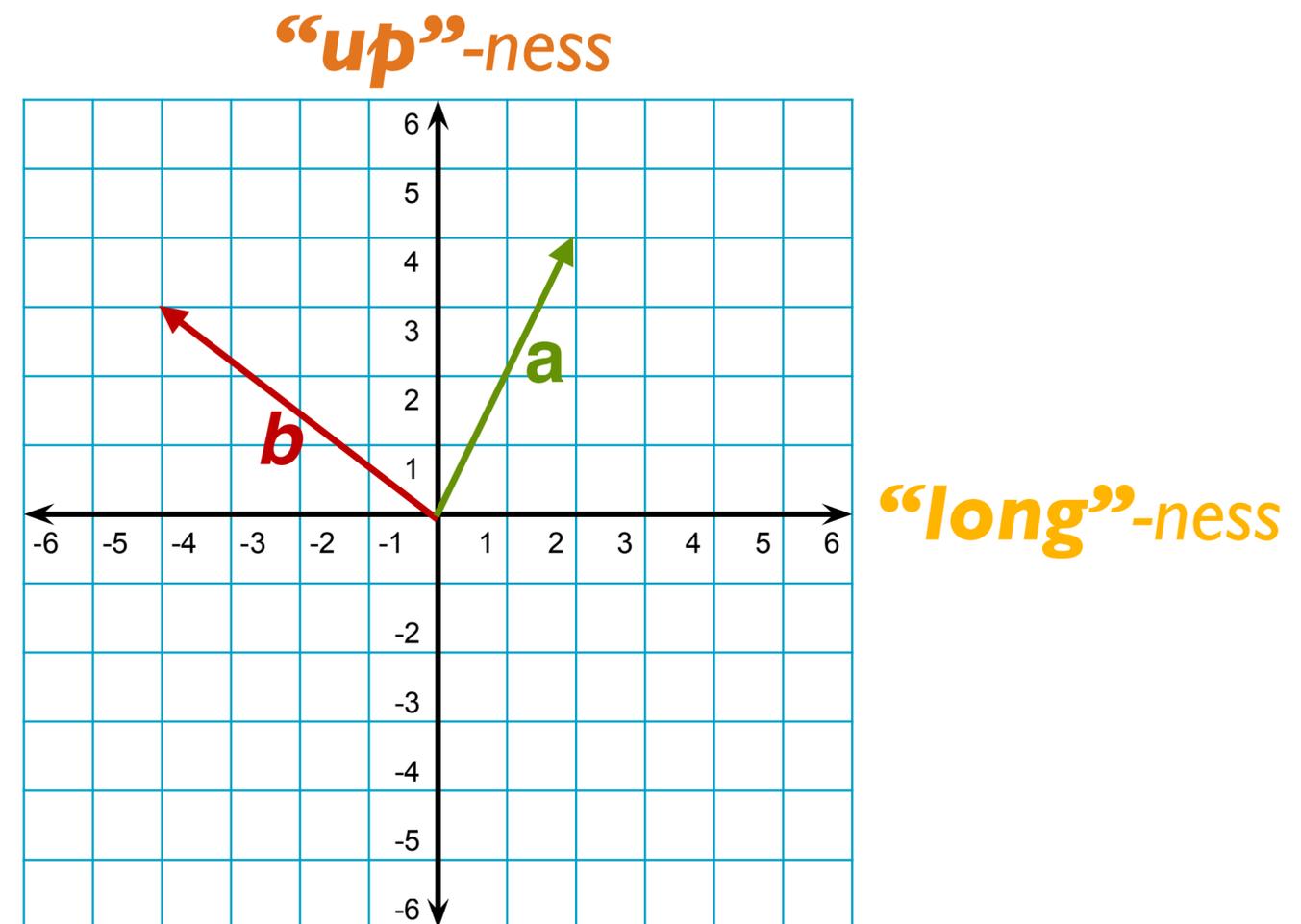
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- What if we thought of each dimension as “quantity” of a word, rather than an arbitrary dimension?



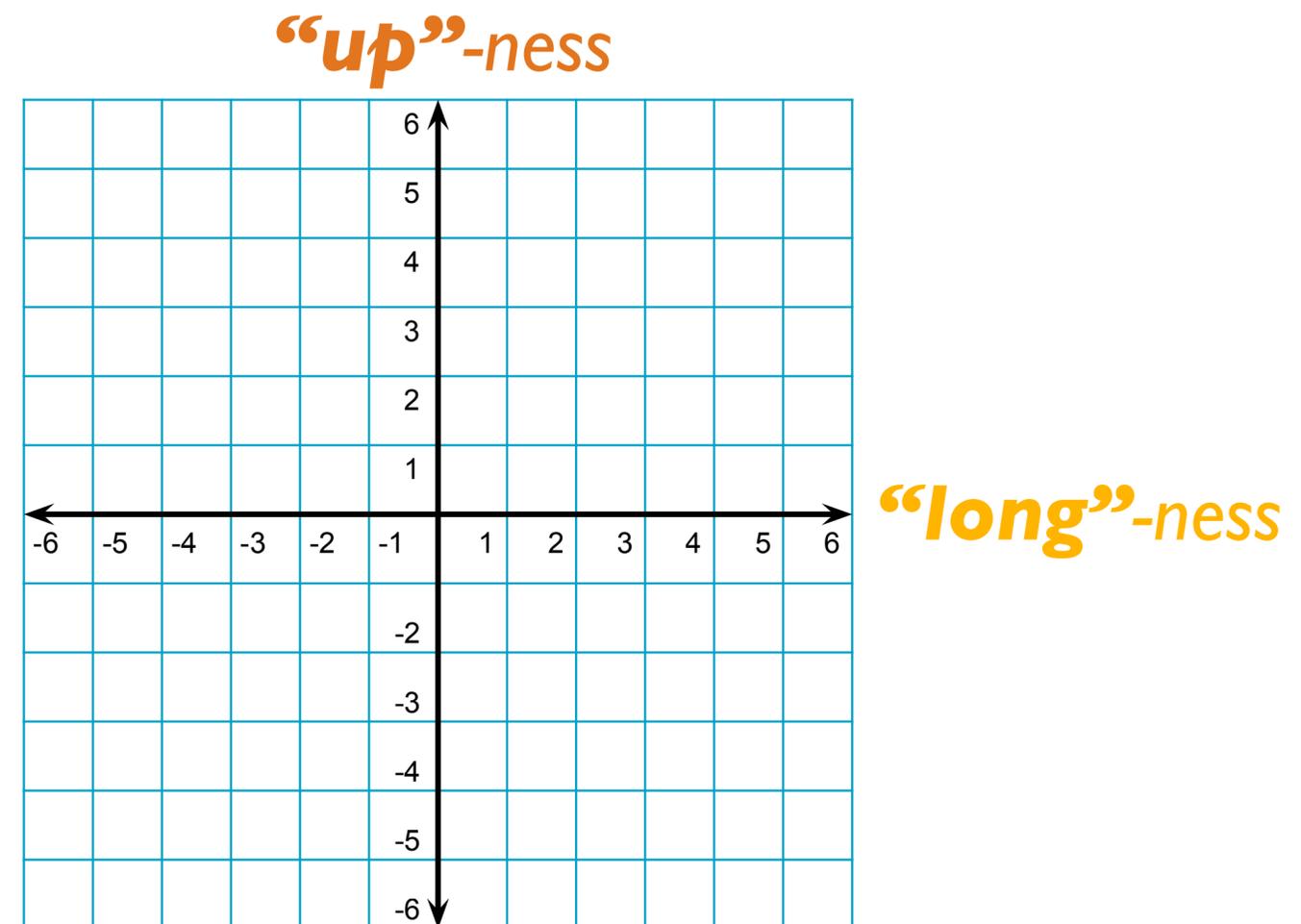
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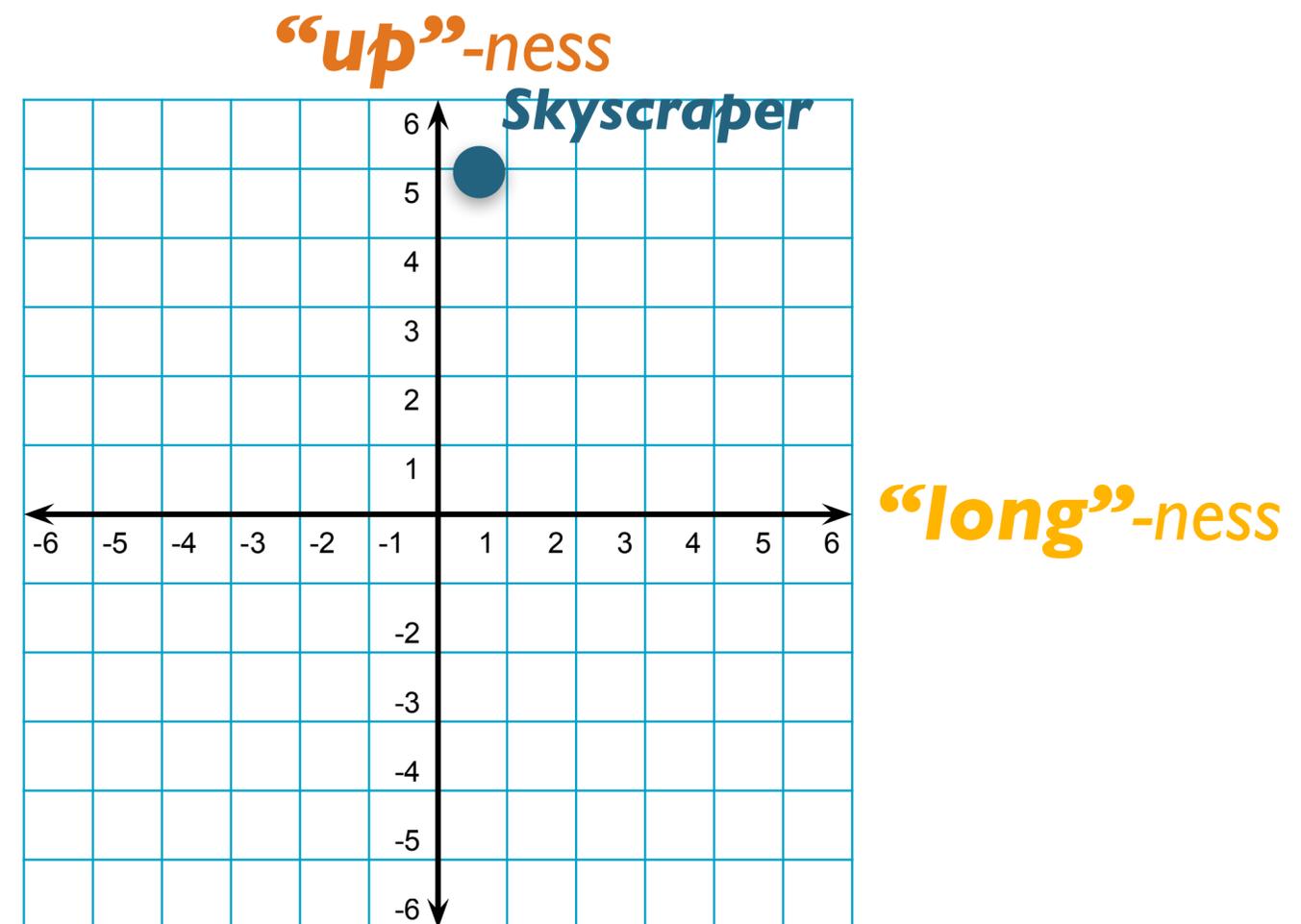
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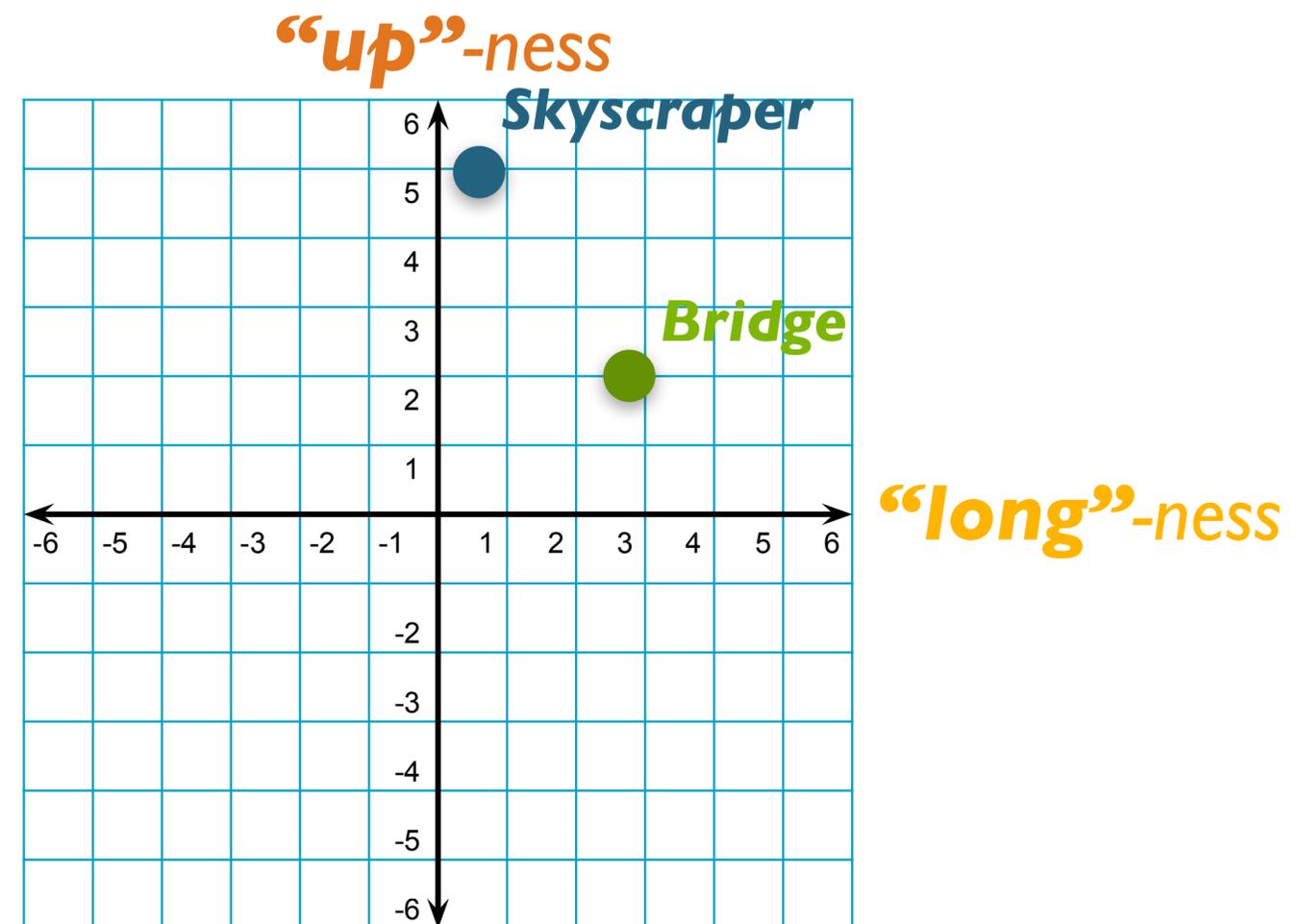
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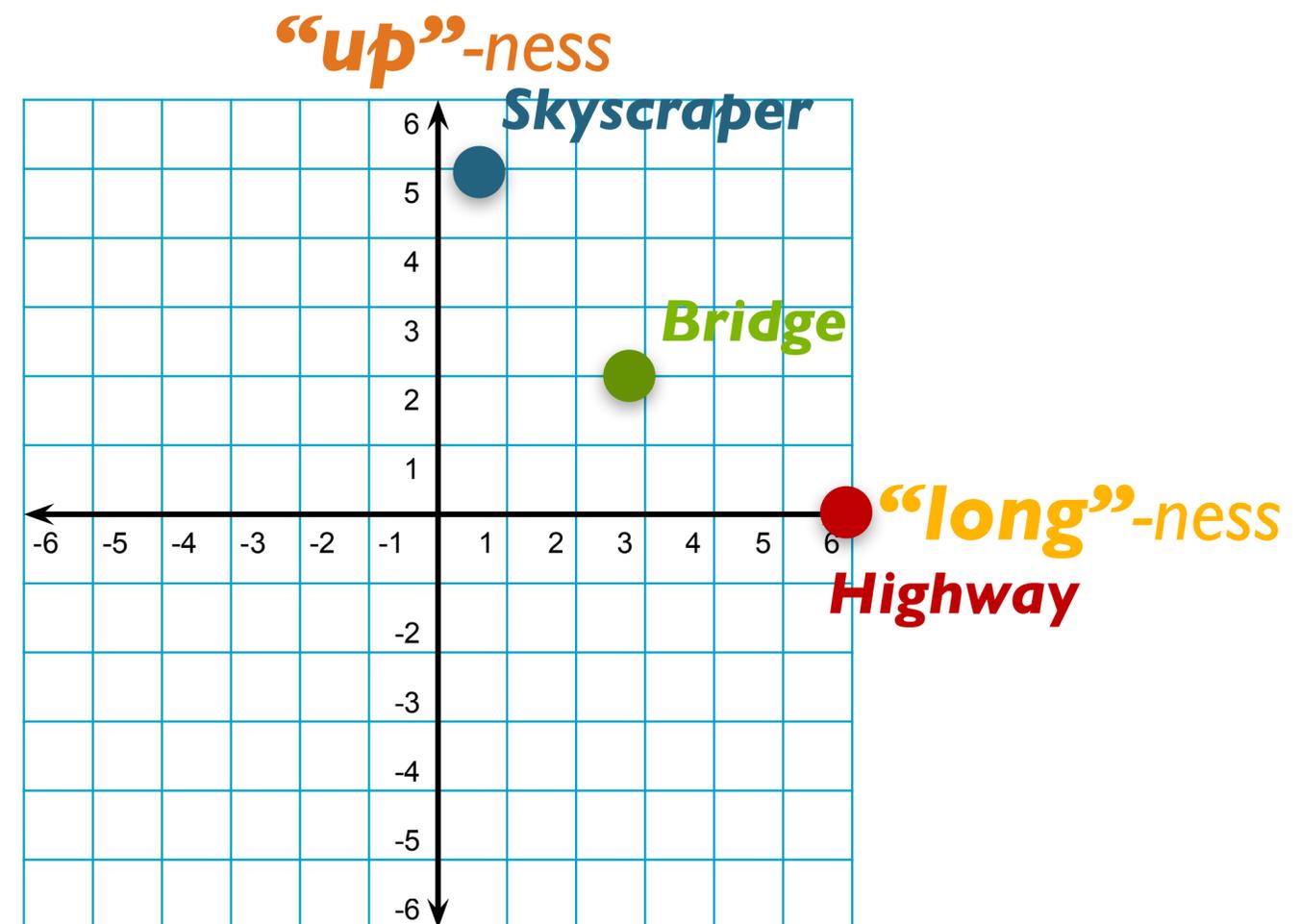
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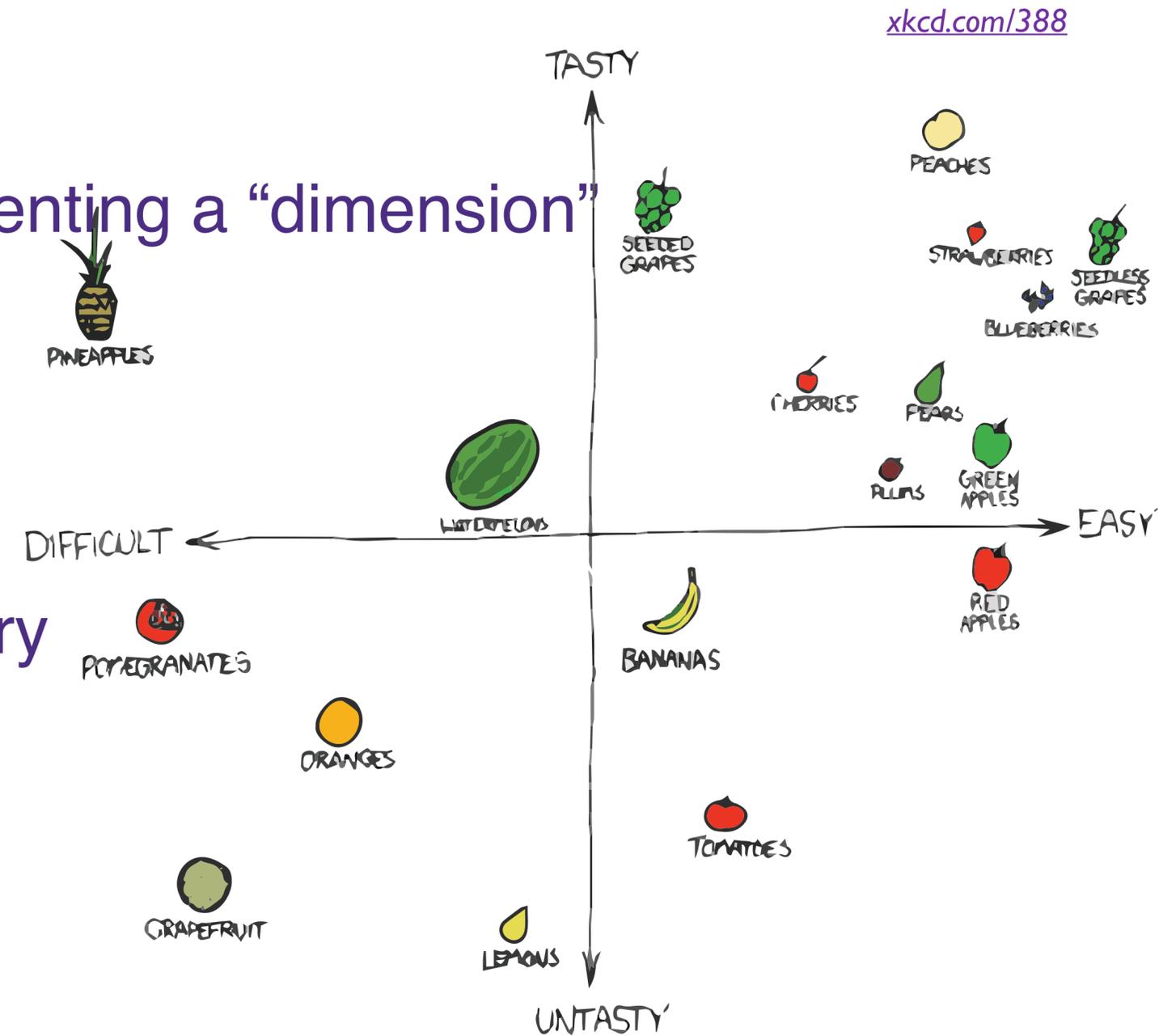
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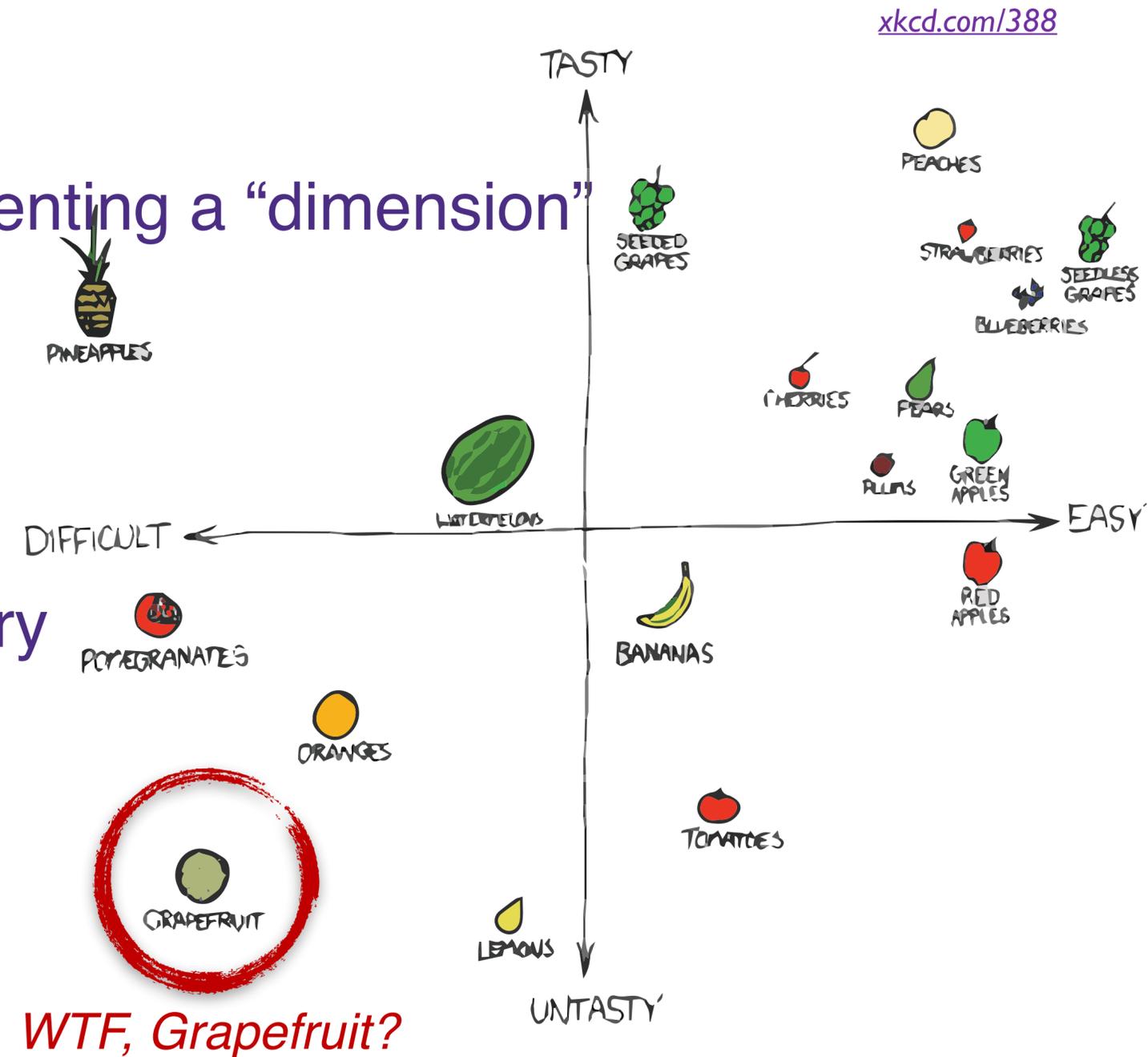
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# Vector Space: Documents

- We can represent documents as vectors, with each dimension being a count of a particular word

Shakespeare Plays × Counts of Words

	<i>As You Like It</i>	<i>Twelfth Night</i>	<i>Julius Caesar</i>	<i>Henry V</i>
<b>battle</b>	1	1	8	15
<b>soldier</b>	2	2	12	36
<b>fool</b>	37	58	1	5
<b>clown</b>	5	117	0	0

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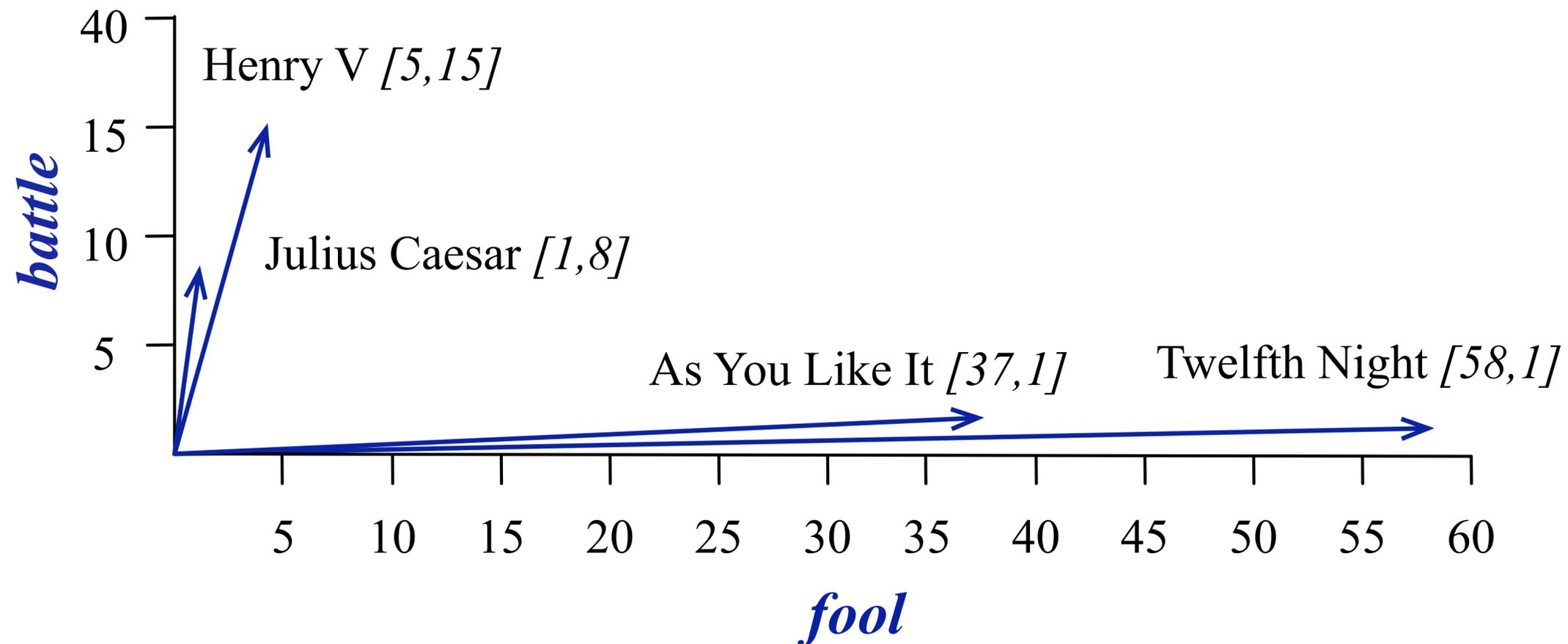
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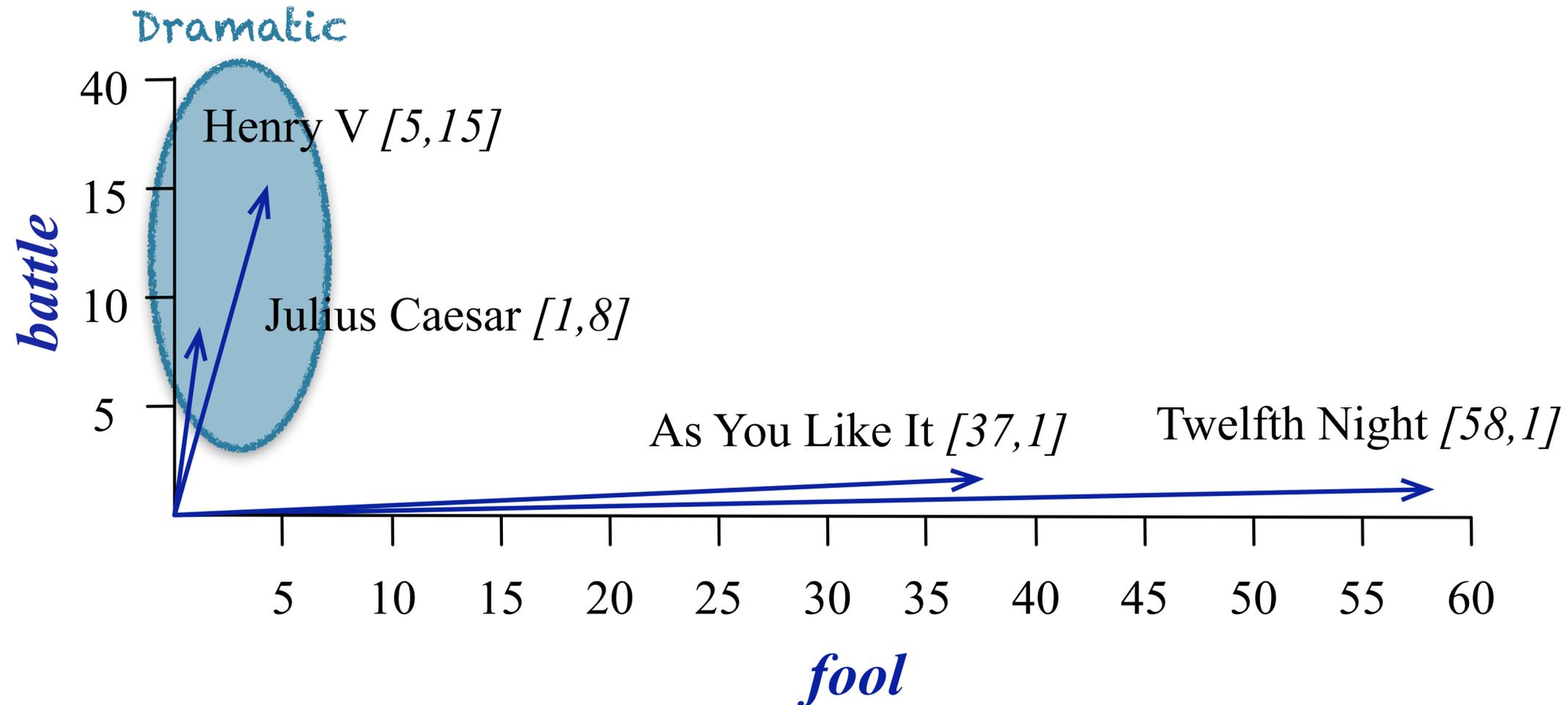
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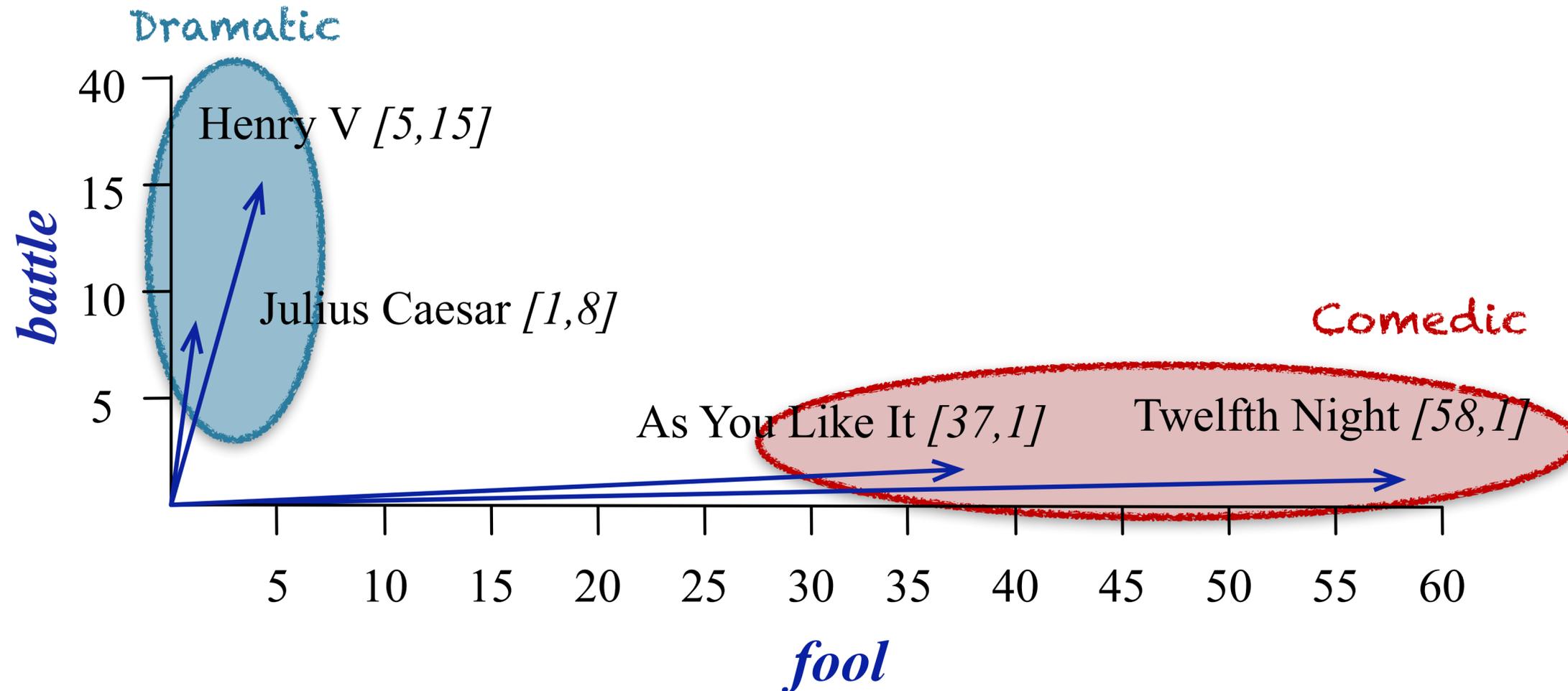
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# Vector Space: **Words**

- Find thematic clusters for **words** based on words that occur *around* them.

# Distributional Similarity

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# Distributional Similarity

- Represent ‘company’ of word such that similar words will have similar representations
  - ‘Company’ = context
- Word represented by context feature vector
  - Many alternatives for vector
- Initial representation:
  - ‘Bag of words’ feature vector
  - Feature vector length  $N$ , where  $N$  is size of vocabulary
    - $f_i = 1$  if  $word_i$  within window size  $w$  of  $word$

There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

### ***Biological Example***

The Paulus company was founded in 1938. Since those days the product range has been the subject of constant expansions and is brought up continuously to correspond with the state of the art. We're engineering, manufacturing and commissioning world-wide ready-to-run **plants** packed with our comprehensive know-how. Our Product Range includes pneumatic conveying systems for carbon, carbide, sand, lime and many others. We use reagent injection in molten metal for the...

### ***Industrial Example***

Label the First Use of "Plant"



There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: 1, of: 1)



There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: 1, animal: 1, kind: 1, of: 1)

-3

+3



There are **more** kinds of **plants** and animals **in** the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: 1, animal: 1, **in:** 1, kind: 1, **more:** 1, of: 1)

-4

+4



There **are** more kinds of **plants** and animals in **the** rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: 1, animal: 1, **are:** 1, in: 1, kind: 1, more: 1, of: 1, **the:** 1)

-5

+5

←—————→

There are more kinds of **plants** and animals in the **rainforests** than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: |, animal: |, are: |, in: |, kind: |, more: |, of: |, **rainforest:** |, the: |, **there:** |)

There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known **species** of **plants** and **animals** live in the rainforest. Many are found nowhere else. There are even **plants** and animals in the rainforest that we have not yet discovered.

**plant:** (and: 1, **animal:** 2, are: 1, in: 1, kind: 1, more: 1, of: 1, rainforest: 1, the: 1, there: 1, **species:** 1)

There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found nowhere else. There **are** even **plants** and **animals** in the rainforest that we have not yet discovered.

**plant:** (and: 1, **animal:** 3, **are:** 2, in: 1, kind: 1, more: 1, of: 1, rainforest: 1, the: 1, there: 1, species: 1)

There are more kinds of **plants** and animals in the rainforests than anywhere else on Earth. Over half of the millions of known species of **plants** and animals live in the rainforest. Many are found **nowhere** else. There are even **plants** and animals in the **rainforest** that we have not yet discovered.

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# Context Feature Vector

	<b>aardvark</b>	<b>...</b>	<b>computer</b>	<b>data</b>	<b>pinch</b>	<b>result</b>	<b>sugar</b>
<b>apricot</b>	0	...	0	0	1	0	1
<b>pineapple</b>	0	...	0	0	1	0	1
<b>digital</b>	0	...	2	1	0	1	0
<b>information</b>	0	...	1	6	0	4	0

# Distributional Similarity Questions

What is the right neighborhood?

How should we weight the features?

How can we compute the similarity between vectors?

# Similarity “Neighborhood”

## 1. Fixed window

- How many words in the neighborhood?
  - +/- 500 words: ‘topical context’
  - +/- 1 or 2 words: collocations, predicate-argument

## 2. Only words in some grammatical relation [\(Hindle, 1990\)](#)

- Parse text (dependency)
  - Include *subj-verb*; *verb-obj*; *adj-mod*
  - $N \times R$  vector: word  $\times$  relation

# Similarity “Neighborhood”: Fixed Window

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  - British National Corpus (BNC)
  - Nearest neighbors of “dog”

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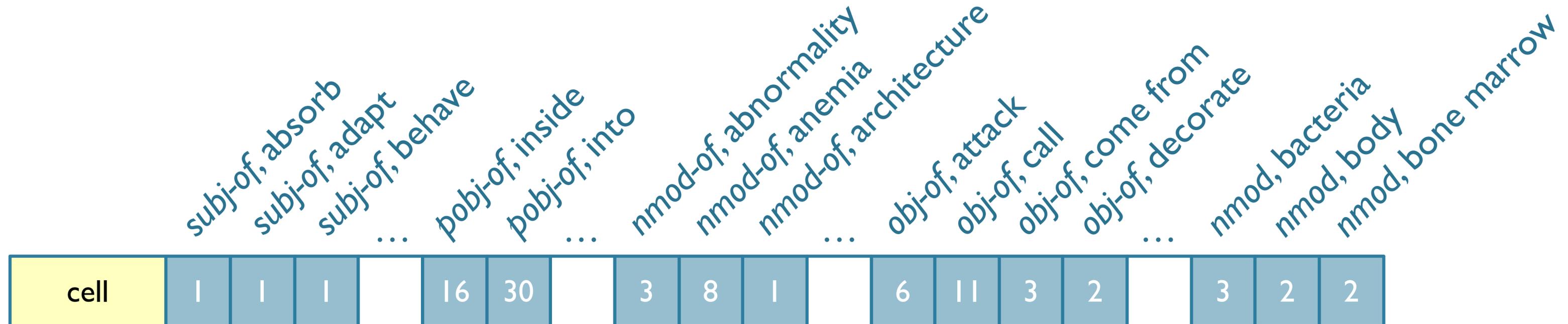
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- 2-word window:
  - *Cat, horse, fox, pet, rabbit, pig, animal, mongrel, sheep, pigeon*

# Similarity “Neighborhood”: Fixed Window

- Same corpus, different windows
  - British National Corpus (BNC)
  - Nearest neighbors of “dog”
- 2-word window:
  - *Cat, horse, fox, pet, rabbit, pig, animal, mongrel, sheep, pigeon*
- 30-word window:
  - *Kennel, puppy, pet, terrier, Rottweiler, canine, cat, to bark, Alsatian*

# Similarity “Neighborhood”: Grammatical Relations

- Build a vector from dependency triples: [\(Lin, 1998\)](#)
  - $(w_1 \text{ dep\_rel } w_2)$



*Dependency vector for “cell,” counts from 64M word corpus.*

# “Neighborhood”: Window vs. Grammatical Relations

- Grammatical relations:
  - Richer representation
  - Much more POS information
- Window:
  - Only need text!
  - Scales very, very well. (Maybe too well.)
  - Adding explicit supervision from parsers often doesn't help dramatically

# Distributional Similarity Questions

What is the right neighborhood?

**How should we weight the features?**

How can we compute the similarity between vectors?

# Weighting Features: Binary vs. Nonbinary?

- Binary?
  - Minimally informative
  - Can't capture intuition that frequent features more indicative of relationship.
- Frequency
  - Or rather, probability:  $assoc_{prob}(w, f) = P(f|w)$
  - ...but how do we know which words are informative?
  - *the, it, they* — not likely to help differentiate target word

# Weighting Features: Pointwise Mutual Information

- PMI is measure of how often two events  $x$  and  $y$  occur, vs. expected frequency if they were independent ([Fano, 1961](#))

$$PMI(x, y) = \log_2 \frac{P(x, y)}{P(x) \cdot P(y)}$$

# Weighting Features: Pointwise Mutual Information

- We can formulate for word/feature occurrence:  $assoc_{PMI}(w, f) = \log_2 \frac{P(w, f)}{P(w) \cdot P(f)}$
- Generally only use positive values
  - Negatives inaccurate unless corpus huge
- Can also rescale/smooth context values

# Weighting Features: (Positive) Pointwise Mutual Information

$$\mathit{assoc}_{PMI}(w, f) = \log_2 \frac{P(w, f)}{P(w) \cdot P(f)}$$

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$$\text{assoc}_{PMI}(w, f) = \log_2 \frac{P(w, f)}{P(w) \cdot P(f)}$$

$$p_{ij} = \frac{f_{ij}}{\sum_{i=1}^W \sum_{j=1}^C f_{ij}}$$

probability of feature  
 $f$  relating  $i$  to  $j$

$$p_{i*} = \frac{\sum_{j=1}^C f_{ij}}{\sum_{i=1}^W \sum_{j=1}^C f_{ij}}$$

probability of feature  
 $f$  relating  $i$  to *anything*

$$p_{*j} = \frac{\sum_{i=1}^W f_{ij}}{\sum_{i=1}^W \sum_{j=1}^C f_{ij}}$$

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# Weighting Features: (Positive) Pointwise Mutual Information

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$$p_{*j} = \frac{\sum_{i=1}^W f_{ij}}{\sum_{i=1}^W \sum_{j=1}^C f_{ij}}$$

probability of feature  
 $f$  relating *anything* to  $j$

$$PPMI_{ij} = \max\left(\log_2 \frac{p_{ij}}{p_{i*} \cdot p_{*j}}, 0\right)$$

Get (non-negative) ratio

# Weighting Features: (Positive) Pointwise Mutual Information

- For pure word co-occurrence, feature  $f$  is the colocated word.

# Weighting Features: Pointwise Mutual Information

- Total words (sum of whole table) = **19**

	aardvark	computer	data	pinch	result	sugar
apricot	0	0	0	1	0	1
pineapple	0	0	0	1	0	1
digital	0	2	1	0	1	0
information	0	1	6	0	4	0

# Weighting Features: Pointwise Mutual Information

- Total words (sum of whole table) = 19
  - $P(w)$ , where  $w$  is *information* =  $11/19 = .579$

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# Weighting Features: Pointwise Mutual Information

- Total words (sum of whole table) = 19
  - $P(w)$ , where  $w$  is *information* =  $11/19 = .579$
  - $P(f)$ , where  $f$  is *data* =  $7/19 = .368$

	aardvark	computer	data	pinch	result	sugar
apricot	0	0	0	1	0	1
pineapple	0	0	0	1	0	1
digital	0	2	1	0	1	0
information	0	1	6	0	4	0

# Weighting Features: Pointwise Mutual Information

- Total words (sum of whole table) = 19
  - $P(w)$ , where  $w$  is *information* =  $11/19 = .579$
  - $P(f)$ , where  $f$  is *data* =  $7/19 = .368$
  - $P(w,f)$ , where  $(w,f)$  is *(information,data)* =  **$6/19 = .316$**

	aardvark	computer	data	pinch	result	sugar
apricot	0	0	0	1	0	1
pineapple	0	0	0	1	0	1
digital	0	2	1	0	1	0
information	0	1	6	0	4	0

# Weighting Features: Pointwise Mutual Information

$$PPMI_{assoc} = \log_2 \frac{P(w, f)}{P(w) \cdot P(f)}$$

$$= \log_2 \frac{0.316}{0.579 \cdot 0.368}$$

$$= 0.568$$

- Total words (sum of whole table) = 19
  - $P(w)$ , where  $w$  is *information* =  $11/19 = .579$
  - $P(f)$ , where  $f$  is *data* =  $7/19 = .368$
  - $P(w, f)$ , where  $(w, f)$  is *(information, data)* =  $6/19 = .316$

	aardvark	computer	data	pinch	result	sugar
apricot	0	0	0	1	0	1
pineapple	0	0	0	1	0	1
digital	0	2	1	0	1	0
information	0	1	6	0	4	0

# PPMI re-scaling

	<b>computer</b>	<b>data</b>	<b>result</b>	<b>pie</b>	<b>sugar</b>	<b>count(w)</b>
<b>cherry</b>	2	8	9	442	25	486
<b>strawberry</b>	0	0	1	60	19	80
<b>digital</b>	1670	1683	85	5	4	3447
<b>information</b>	3325	3982	378	5	13	7703
<b>count(context)</b>	4997	5673	473	512	61	11716

**Figure 6.9** Co-occurrence counts for four words in 5 contexts in the Wikipedia corpus, together with the marginals, pretending for the purpose of this calculation that no other words/contexts matter.

# PPMI re-scaling

	computer	data	result	pie	sugar
cherry	0	0	0	4.38	3.30
strawberry	0	0	0	4.10	5.51
digital	0.18	0.01	0	0	0
information	0.02	0.09	0.28	0	0

**Figure 6.11** The PPMI matrix showing the association between words and context words, computed from the counts in Fig. 6.10. Note that most of the 0 PPMI values are ones that had a negative PMI; for example  $\text{PMI}(\text{cherry}, \text{computer}) = -6.7$ , meaning that *cherry* and *computer* co-occur on Wikipedia less often than we would expect by chance, and with PPMI we replace negative values by zero.

# Weighting Features: Pointwise Mutual Information

- Downside:
  - PPMI favors rare events
- Solutions:
  - Change the  $P(f)$  to be raised to the power of  $\alpha$ 
    - Increases the probability assigned to rare contexts
  - Laplace smoothing (add- $n$ )

# Distributional Similarity Questions

What is the right neighborhood?

How should we weight the features?

**How can we compute the similarity between vectors?**

# Vector Distances: Manhattan & Euclidean

- **Manhattan Distance**

$$dist_{manhattan} = (\vec{x}, \vec{y}) = \sum_{i=1}^N |x_i - y_i|$$

- (Distance as cumulative horizontal + vertical moves)

# Vector Distances: Manhattan & Euclidean

- **Manhattan Distance**

$$dist_{manhattan} = (\vec{x}, \vec{y}) = \sum_{i=1}^N |x_i - y_i|$$

- (Distance as cumulative horizontal + vertical moves)

- **Euclidean Distance**

$$dist_{euclidean} = \sqrt{\sum_{i=1}^N (x_i - y_i)^2}$$

# Vector Distances: Manhattan & Euclidean

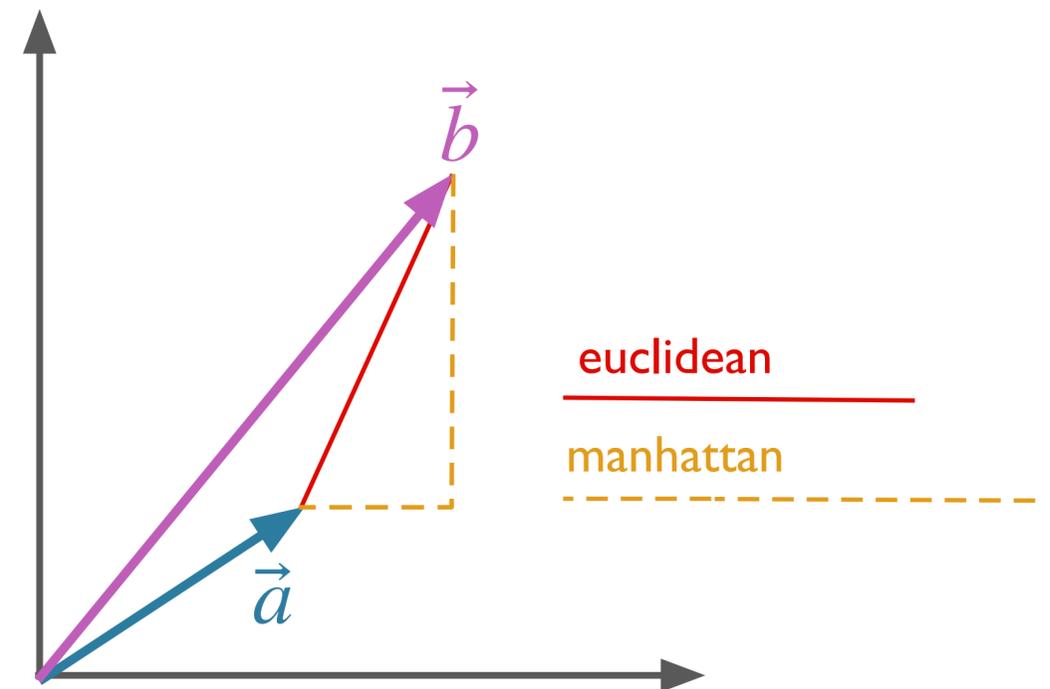
- **Manhattan Distance**

$$dist_{manhattan} = (\vec{x}, \vec{y}) = \sum_{i=1}^N |x_i - y_i|$$

- (Distance as cumulative horizontal + vertical moves)

- **Euclidean Distance**

$$dist_{euclidean} = \sqrt{\sum_{i=1}^N (x_i - y_i)^2}$$



# Vector Distances: Manhattan & Euclidean

- **Manhattan Distance**

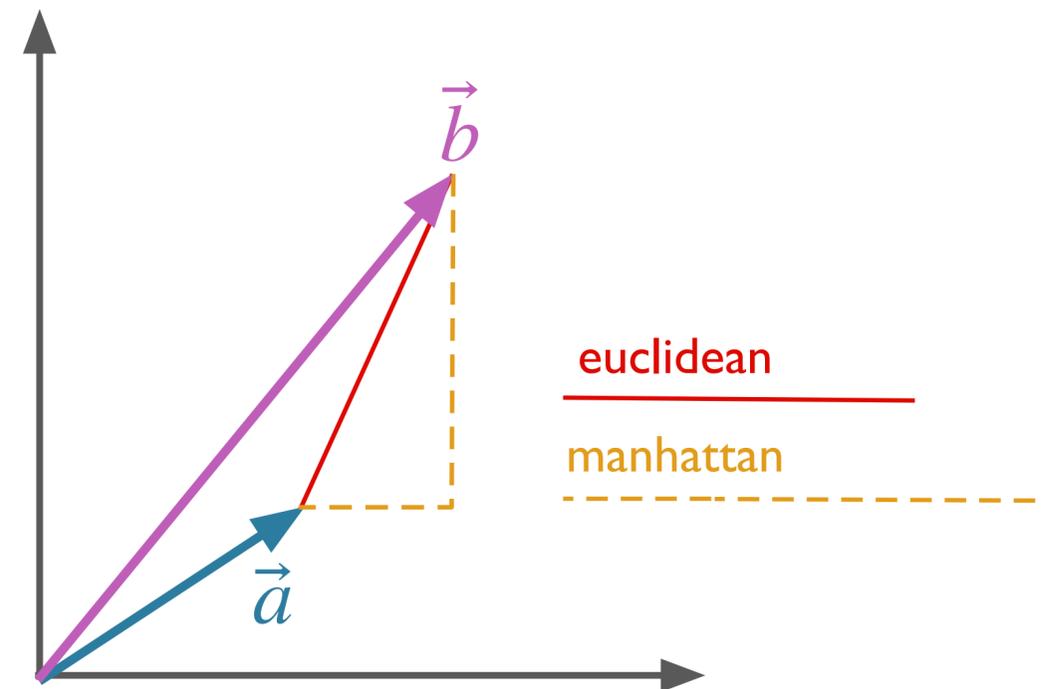
$$dist_{manhattan} = (\vec{x}, \vec{y}) = \sum_{i=1}^N |x_i - y_i|$$

- (Distance as cumulative horizontal + vertical moves)

- **Euclidean Distance**

$$dist_{euclidean} = \sqrt{\sum_{i=1}^N (x_i - y_i)^2}$$

- Too sensitive to extreme values



# Vector Similarity: Dot Product

- Produces real number scalar from product of vectors' components

$$sim_{dot-product}(\vec{v}, \vec{w}) = \vec{v} \cdot \vec{w} = \sum_{i=1}^N v_i \times w_i$$

- Biased toward **longer** (larger magnitude) vectors
  - In our case, vectors with fewer zero counts

# Vector Similarity: Cosine

- If you normalize the dot product for vector magnitude...
- ...result is same as cosine of angle between the vectors.

$$\text{sim}_{\text{cosine}}(\vec{v}, \vec{w}) = \frac{\vec{v} \cdot \vec{w}}{|\vec{v}| |\vec{w}|} = \frac{\sum_{i=1}^N v_i \times w_i}{\sqrt{\sum_{i=1}^N v_i^2} \sqrt{\sum_{i=1}^N w_i^2}}$$

# Sample Results

- Based on Lin dependency model
  - **Hope (N)**: optimism, chance, expectation, prospect, dream, desire, fear
  - **Hope (V)**: would like, wish, plan, say, believe, think
- **Brief (N)**: legal brief, affidavit, filing, petition, document, argument, letter
- **Brief (A)**: lengthy, hour-long, short, extended, frequent, recent, short-lived, prolonged, week-long

# Recap

- We can build feature vectors to represent context of a word
- These features could be:

- A. A bottle of *tezgüino* is on the table.
- B. Everybody likes *tezgüino*.
- C. *Tezgüino* makes you drunk.
- D. We make *tezgüino* from corn.

*tezgüino*

*tequila*

*apricots*

*pizza*

# Recap

- We can build feature vectors to represent context of a word
- These features could be:
  1. Occurs before *drunk*

A. A bottle of *tezgüino* is on the table.  
B. Everybody likes *tezgüino*.  
C. *Tezgüino* makes you drunk.  
D. We make *tezgüino* from corn.

	1	
<i>tezgüino</i>	1	
<i>tequila</i>	1	
<i>apricots</i>	0	
<i>pizza</i>	0	

# Recap

- We can build feature vectors to represent context of a word
- These features could be:
  1. Occurs before *drunk*
  2. Occurs after *bottle*

A. A bottle of *tezgüino* is on the table.  
B. Everybody likes *tezgüino*.  
C. *Tezgüino* makes you drunk.  
D. We make *tezgüino* from corn.

	1	2
<i>tezgüino</i>	1	1
<i>tequila</i>	1	1
<i>apricots</i>	0	0
<i>pizza</i>	0	0

# Recap

- We can build feature vectors to represent context of a word
- These features could be:
  1. Occurs before *drunk*
  2. Occurs after *bottle*
  3. Is direct object of *likes*

A. A bottle of *tezgüino* is on the table.  
B. Everybody likes *tezgüino*.  
C. *Tezgüino* makes you drunk.  
D. We make *tezgüino* from corn.

	1	2	3
<i>tezgüino</i>	1	1	1
<i>tequila</i>	1	1	1
<i>apricots</i>	0	0	1
<i>pizza</i>	0	0	1

# Recap

- We can build feature vectors to represent context of a word
- These features could be:
  1. Occurs before *drunk*
  2. Occurs after *bottle*
  3. Is direct object of *likes*
  4. Is direct object of *make*

A. A bottle of *tezgüino* is on the table.  
B. Everybody likes *tezgüino*.  
C. *Tezgüino* makes you drunk.  
D. We make *tezgüino* from corn.

	1	2	3	4
<i>tezgüino</i>	1	1	1	1
<i>tequila</i>	1	1	1	1
<i>apricots</i>	0	0	1	0
<i>pizza</i>	0	0	1	1

# Recap

- These feature vectors can be as simple as co-occurrence
- ...for vocabulary  $V$ 
  - ...for each element  $i$
  - is word  $v_i$  within window  $w$  of target?

A. A bottle of *tezgüino* is on the table.  
B. Everybody likes *tezgüino*.  
C. *Tezgüino* makes you drunk.  
D. We make *tezgüino* from corn.

bottle	drunk	matrix	table
1	1	0	0

Context matrix for *tezgüino* with  $w=3$

# Recap

- Intuition:
  - These co-occurrence vectors should be able to tell us something about words' similarities

	arts	boil	data	function	large	sugar	summarized	water
Apricot	0	1	0	0	1	1	0	1
Pineapple	0	1	0	0	1	1	0	1
Digital	0	0	1	1	1	0	1	0
Information	0	0	1	1	1	0	1	0

# Problem: Sparse Vectors!

- Big problem:
  - The vast majority of word pairs will be zero!
  - This leads to very sparse vectors.
- In the exercise:
  - (*election, primary*) is 2
  - (*election, midterm*) is 0
- ...how can we generalize better?

# Problem: Sparse Vectors!

- Term x document:

	c1	c2	c3	c4	c5	m1	m2	m3	m4
human	1	0	0	1	0	0	0	0	0
interface	1	0	1	0	0	0	0	0	0
computer	1	1	0	0	0	0	0	0	0
user	0	1	1	0	1	0	0	0	0
system	0	1	1	2	0	0	0	0	0
response	0	1	0	0	1	0	0	0	0
time	0	1	0	0	1	0	0	0	0
EPS	0	0	1	1	0	0	0	0	0
survey	0	1	0	0	0	0	0	0	1
trees	0	0	0	0	0	1	1	1	0
graph	0	0	0	0	0	0	1	1	1
minors	0	0	0	0	0	0	0	1	1