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Overview

What you'll be able to do!

machine translation "hello!" → "bonjour!"

document search "Can I get a refund?" → "What's your return policy?" … "May I get my money back?"

Learning Objectives

- Transform vector
- "K nearest neighbors"
- Hash tables
- Divide vector space into regions
- Locality sensitive hashing
- Approximated nearest neighbors

Machine translation

Document search

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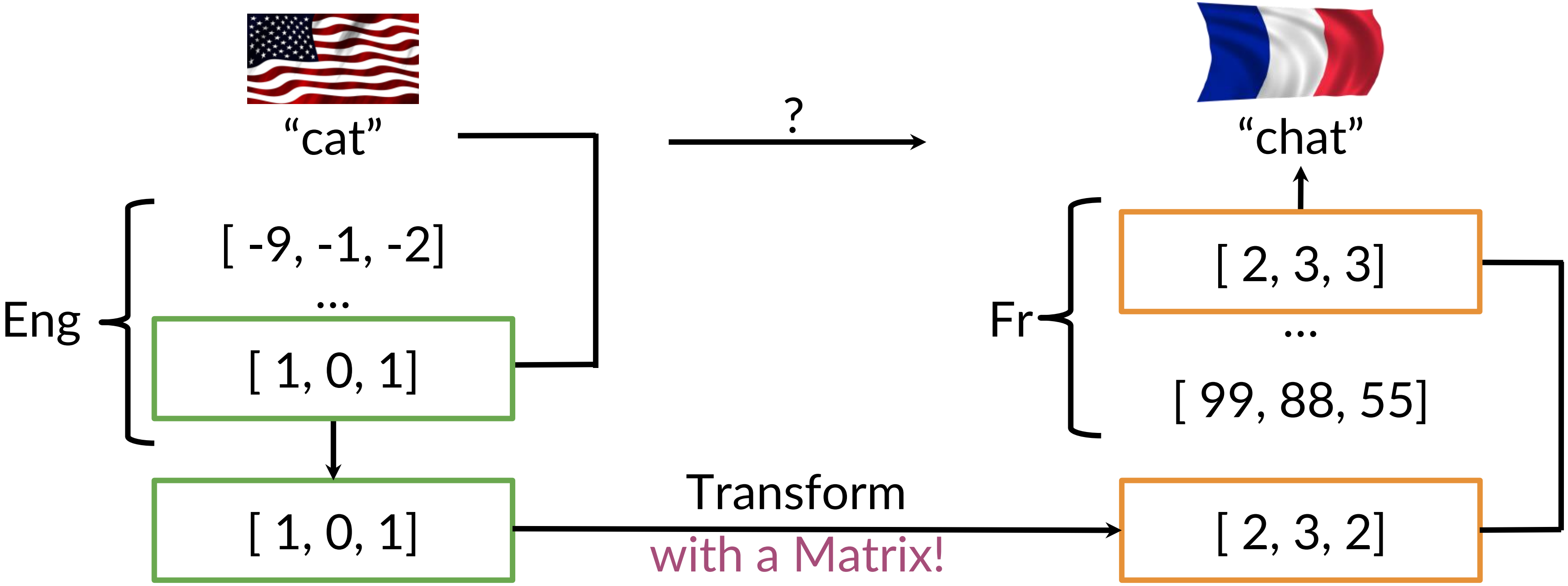
Transforming word vectors

Outline

- Translation = Transformation
- How to get a good transformation

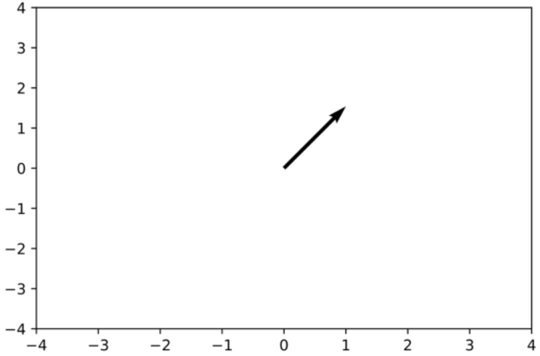
Overview of Translation

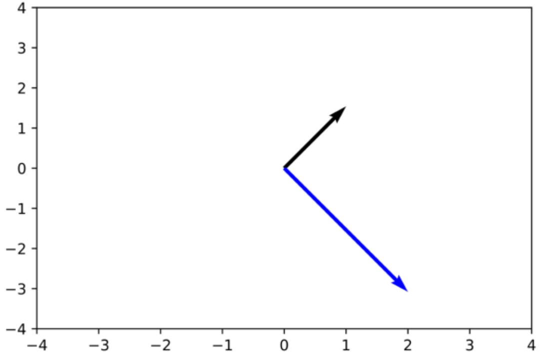


Transforming vectors

$$\begin{pmatrix} 1 & 1 \end{pmatrix} \begin{pmatrix} 2 & 0 \\ 0 & -2 \end{pmatrix} = \begin{pmatrix} 2 & -2 \end{pmatrix}$$

X R Y





Transforming vectors

```
R = np.array([[2,0],

x = np.array([[1,1]])

np.dot(x,R)
```

```
array([[2,-2]])
```

Try it yourself!

Align word vectors

$$\mathbf{XR} \approx \mathbf{Y}$$

$$\underbrace{\begin{pmatrix} \text{[“cat” vector]} \\ \text{[… vector]} \\ \text{[“zebra” vector]} \end{pmatrix}}_{\mathbf{X}} \qquad \underbrace{\begin{pmatrix} \text{[“chat” vecteur]} \\ \text{[… vecteur]} \\ \text{[“zébresse” vecteur]} \end{pmatrix}}_{\mathbf{Y}}$$

subsets of the full vocabulary

Solving for R

initialize R

in a loop:

$$Loss = \| \mathbf{XR} - \mathbf{Y} \|_F$$

$$g = \frac{d}{dR} Loss$$ gradient

$$R = R - \alpha g$$ update

Frobenius norm

$$\parallel \mathbf{XR} - \mathbf{Y} \parallel_F$$

$$\mathbf{A} = \begin{pmatrix} 2 & 2 \\ 2 & 2 \end{pmatrix}$$

$$\|\mathbf{A}_F\| = \sqrt{2^2 + 2^2 + 2^2 + 2^2}$$

$$\|\mathbf{A}_F\| = 4$$

$$\|\mathbf{A}\|_F \equiv \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} |a_{ij}|^2}$$

Frobenius norm

```
A = np.array([[2,2],
```

```
A_squared = np.square(A)
A_squared
```

```
array([[4,4],
```

```
A_Frobenious = np.sqrt(np.sum(A_squared))
A_Frobenious
```

```
4.0
```

Try it yourself!

Frobenius norm squared

$$\|\mathbf{XR} - \mathbf{Y}\|_F^2$$

$$\mathbf{A} = \begin{pmatrix} 2 & 2 \\ 2 & 2 \end{pmatrix}$$

$$\|\mathbf{A}\|_F^2 = \left(\sqrt{2^2 + 2^2 + 2^2 + 2^2}\right)^2$$

$$\|\mathbf{A}\|_F^2 = 16$$

Gradient

$$Loss = \|\mathbf{XR} - \mathbf{Y}\|_F^2$$

$$g = \frac{d}{dR}Loss = \frac{2}{m}\left(\mathbf{X}^T(\mathbf{XR} - \mathbf{Y})\right)$$

$\boxed{\text{Implement in the assignment!}}$

Summary

- $\mathbf{XR} \approx \mathbf{Y}$
- minimize $\|\mathbf{XR} - \mathbf{Y}\|_F^2$

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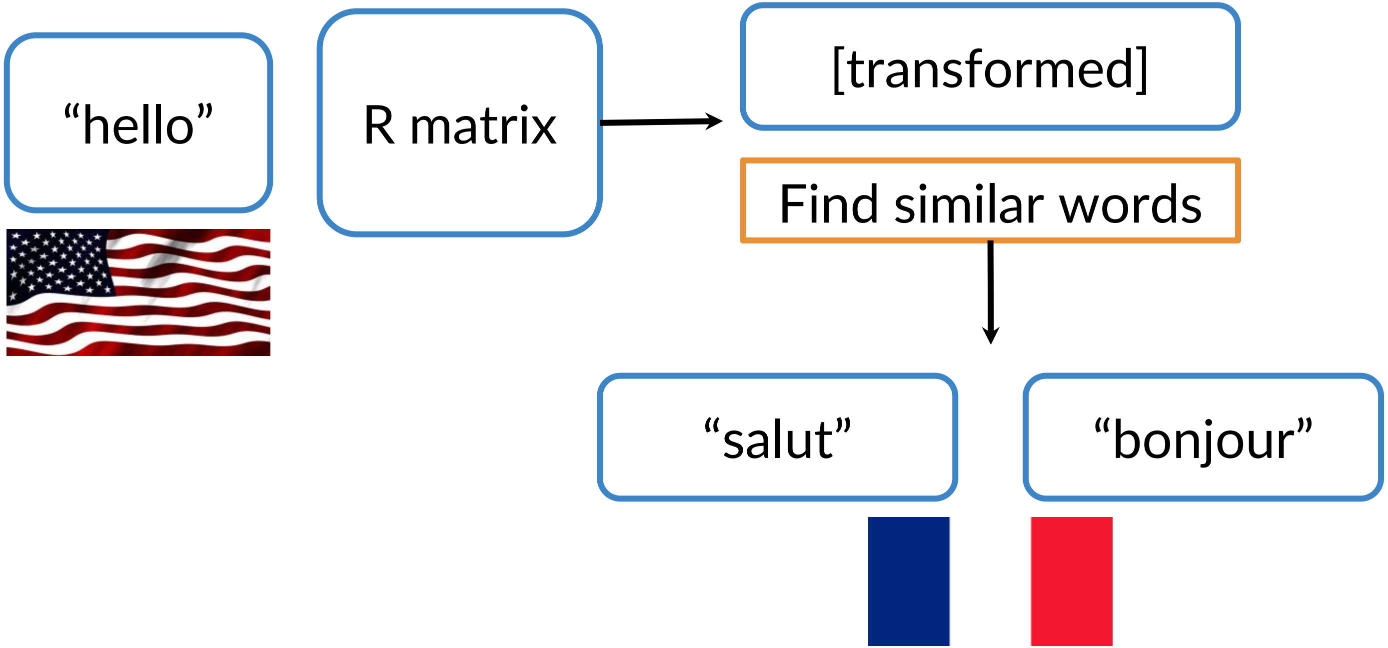
K-nearest neighbors

Outline

- K closest matches $\longrightarrow$ K-nearest neighbors

Finding the translation



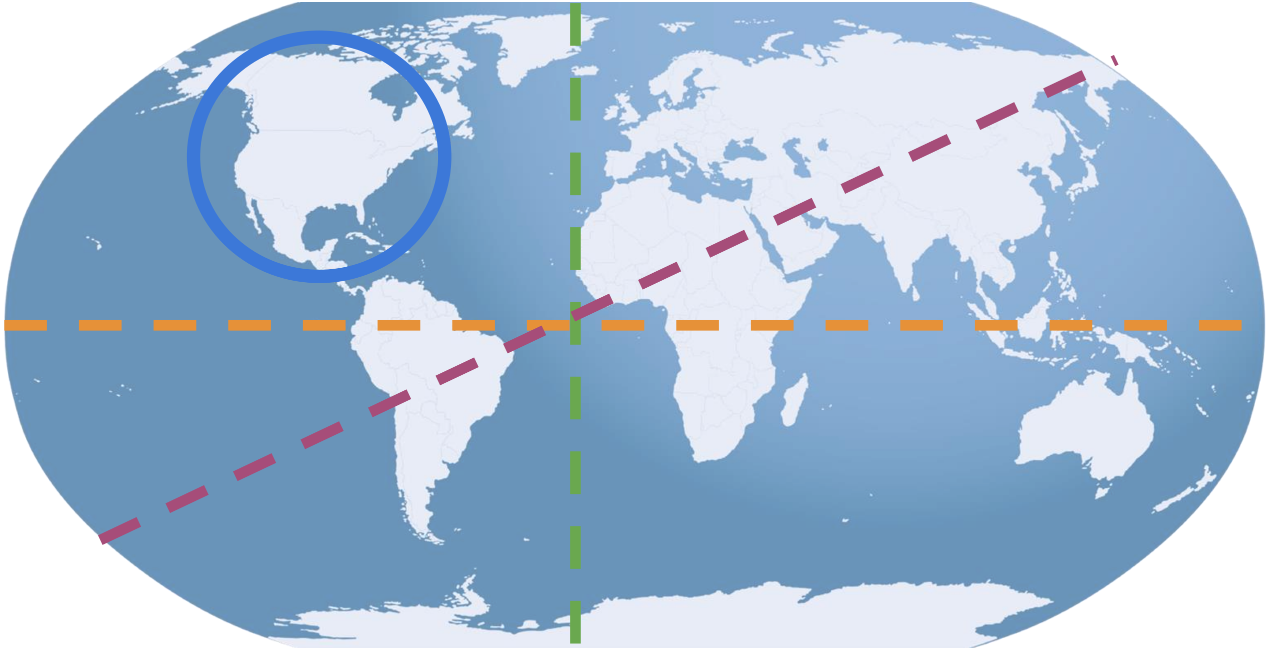
Nearest neighbours

You

San Francisco

Friend	Location	Nearest
	Shanghai	2
	Bangalore	3
	Los Angeles	1

Nearest neighbors



Hash
tables!

Summary

- K-nearest neighbors, for closest matches
- Hash tables

Hash tables and hash functions

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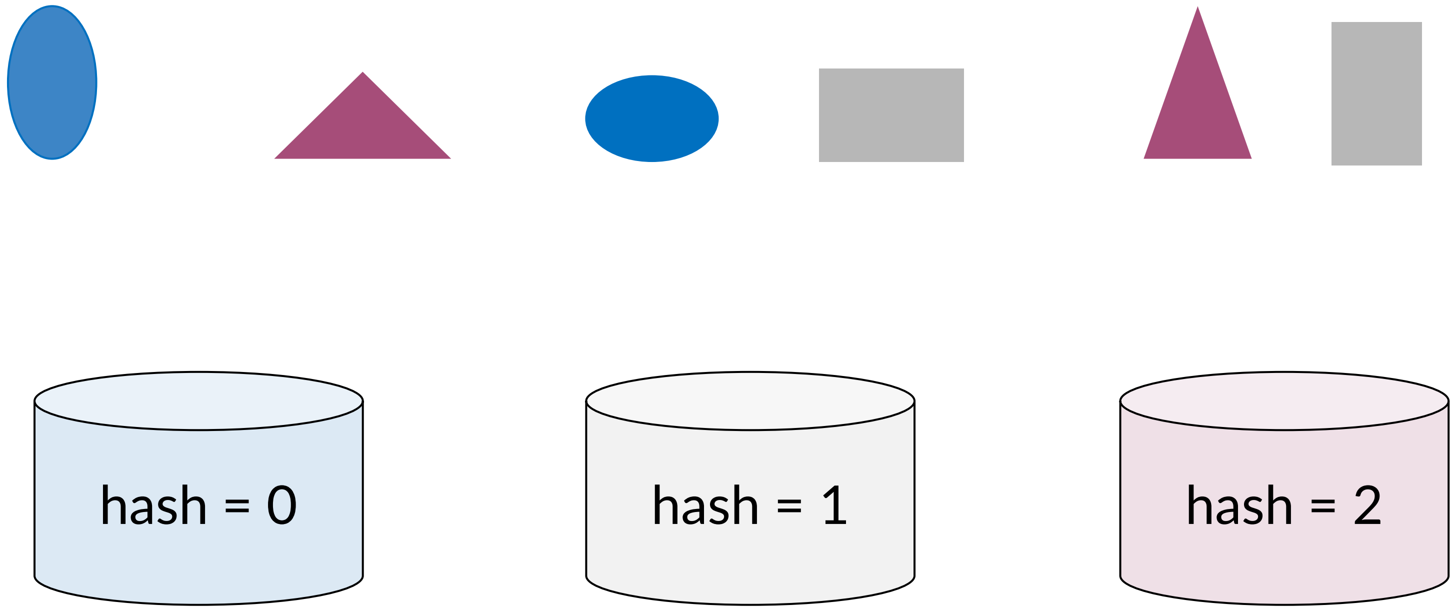
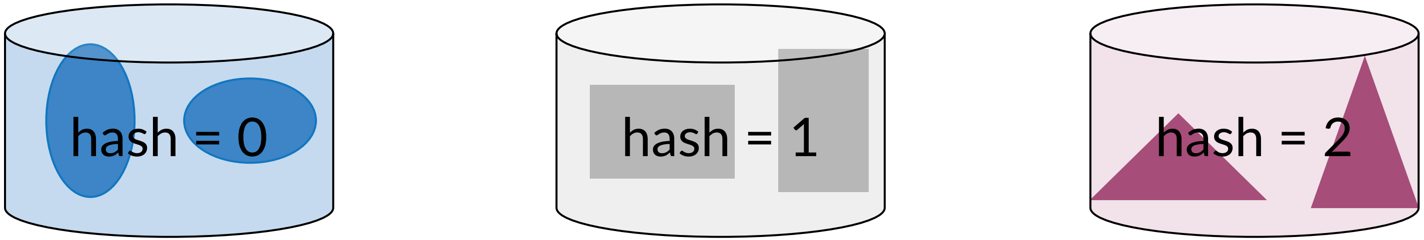
Outline

- Hash values
- Hash functions

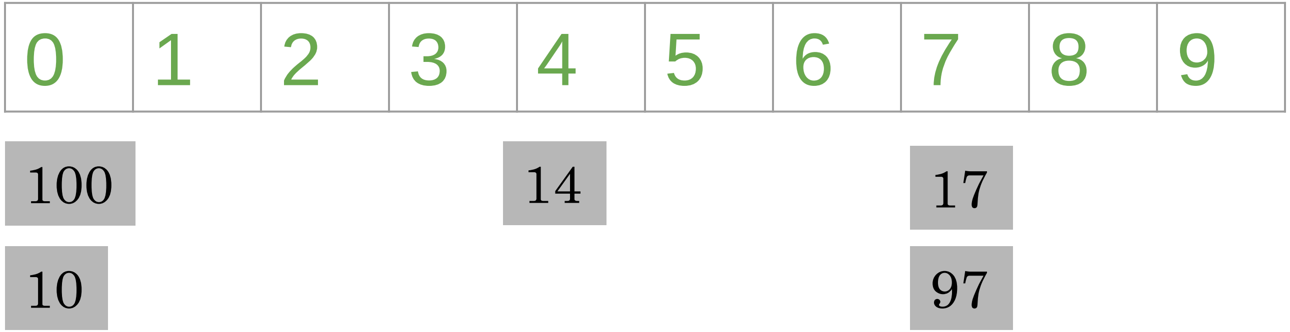
Hash tables



Hash tables



Hash function



Hash function (vector) ⟶ Hash value

Hash value = vector % number of buckets

Create a basic hash table

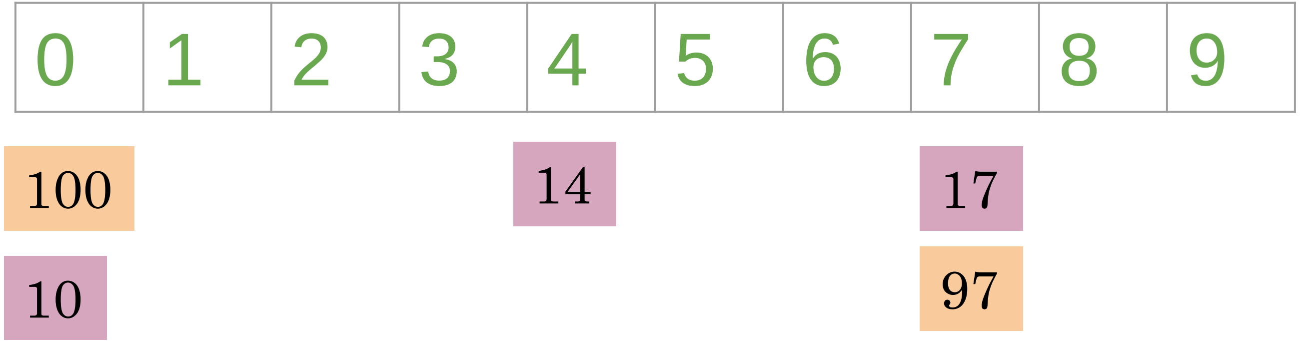
```
def basic_hash_table(value_l,n_buckets):

    def hash_function(value_l,n_buckets):
            return int(value_l) % n_buckets

    hash_table = {i:[] for i in range(n_buckets)}
    for value in value_l:
            hash_value =
hash_function(value,n_buckets)

    return hash_table
```

Hash function



Hash function by location?

0	1	2	3	4	5	6	7	8	9

14 100

10 97

17

Locality sensitive hashing, next!

Summary

Hash function (vector) ⟶ Hash value

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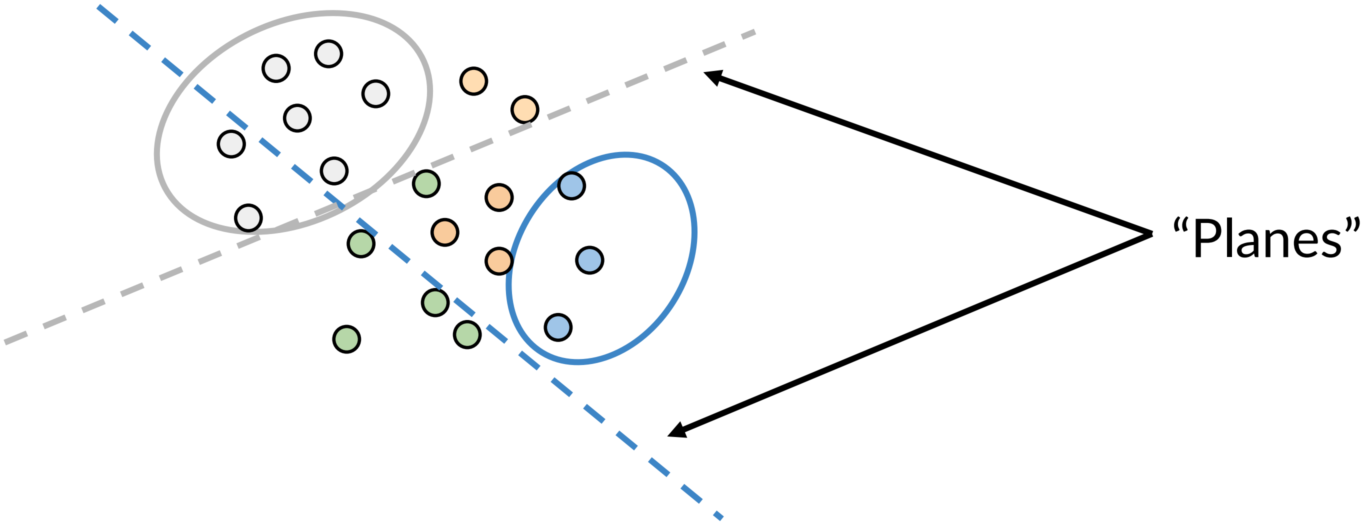
Locality sensitive hashing

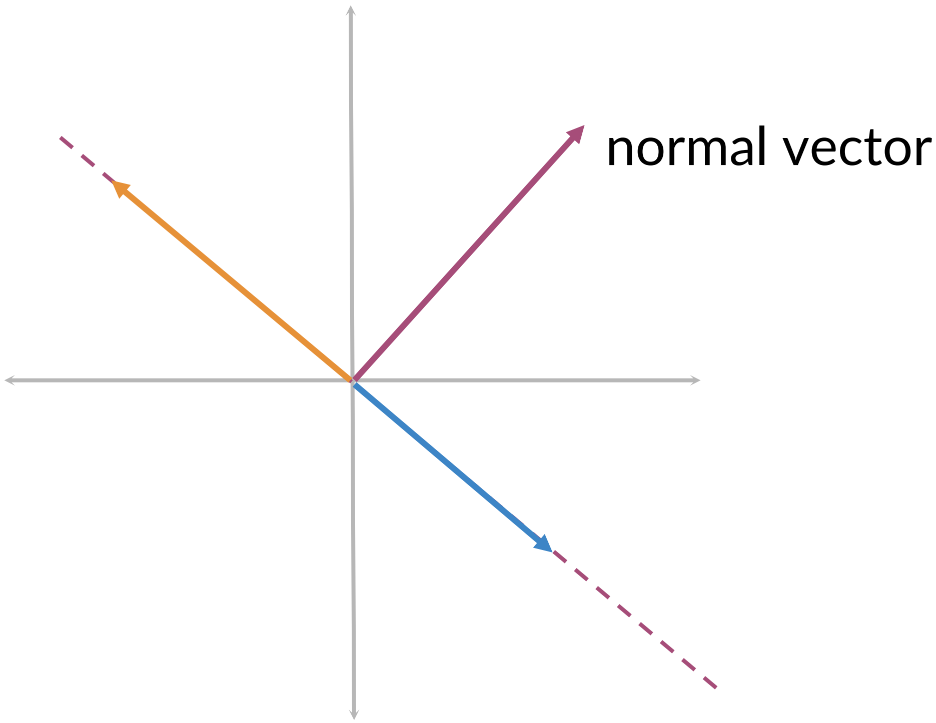
Outline

- Locality sensitive hashing with planes in vector spaces

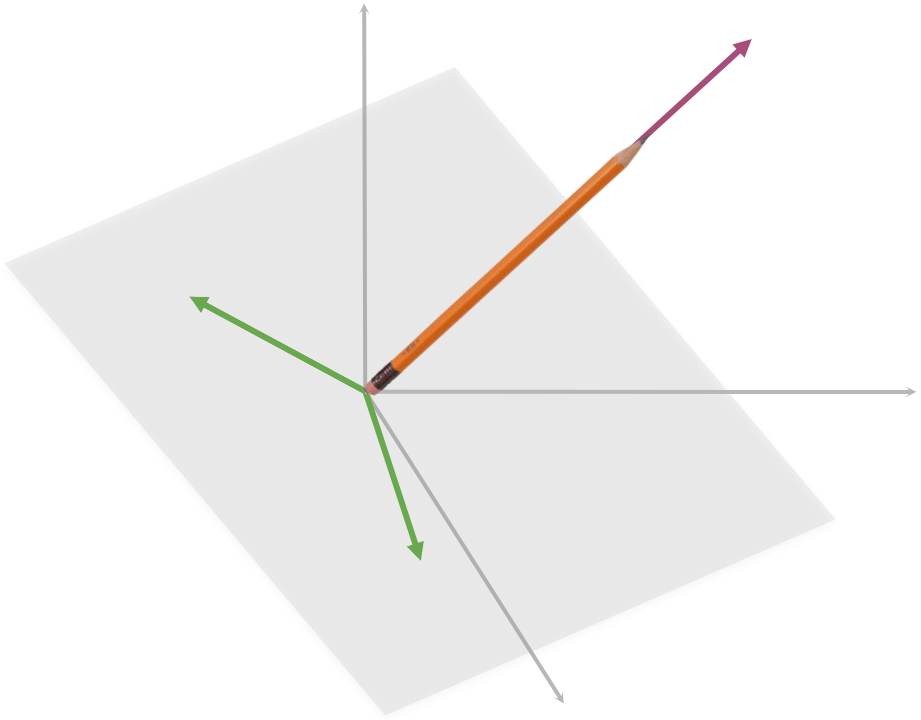
Locality Sensitive Hashing



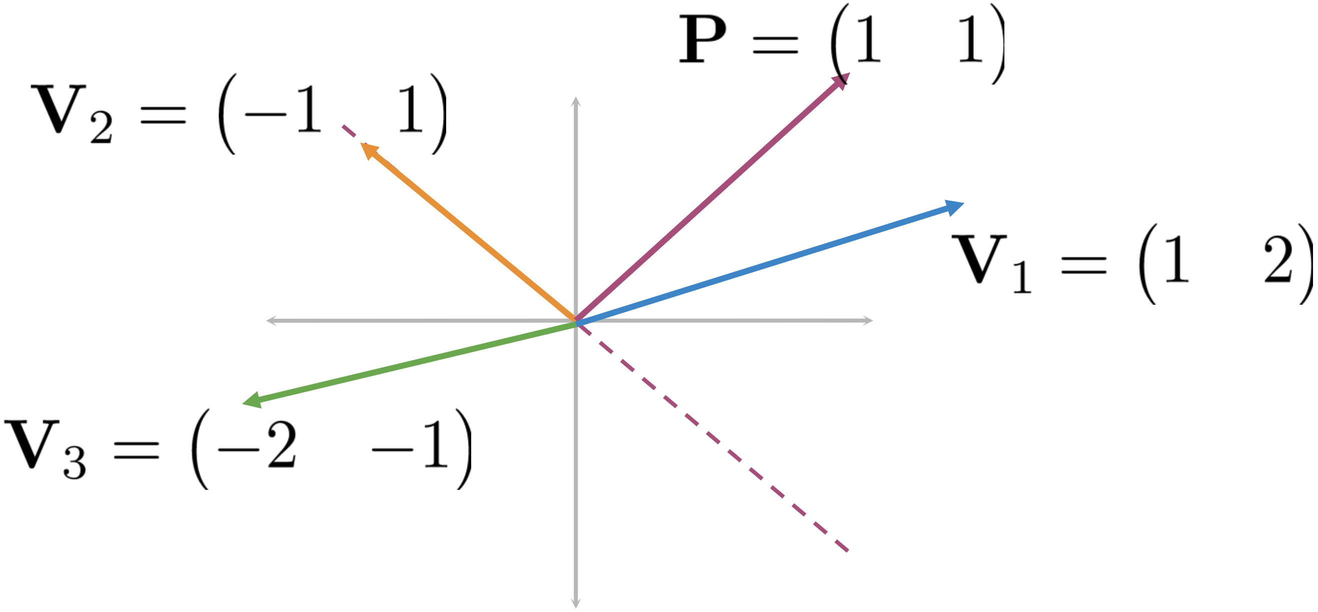
Planes



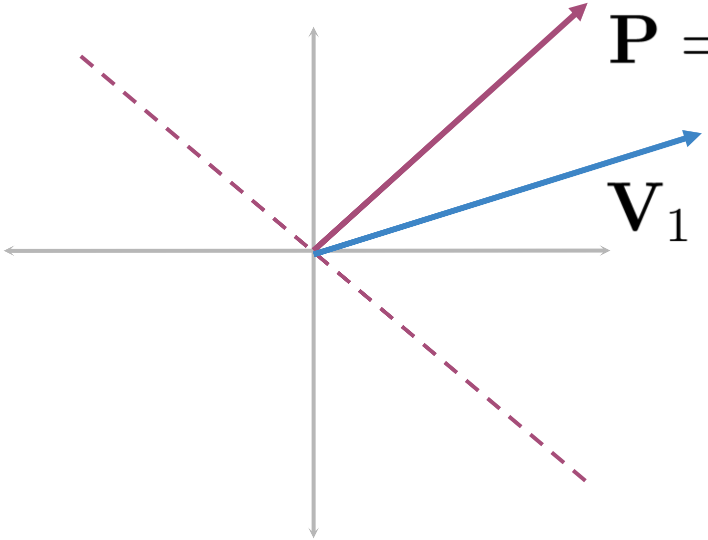
Planes



Which side of the plane?



Which side of the plane?



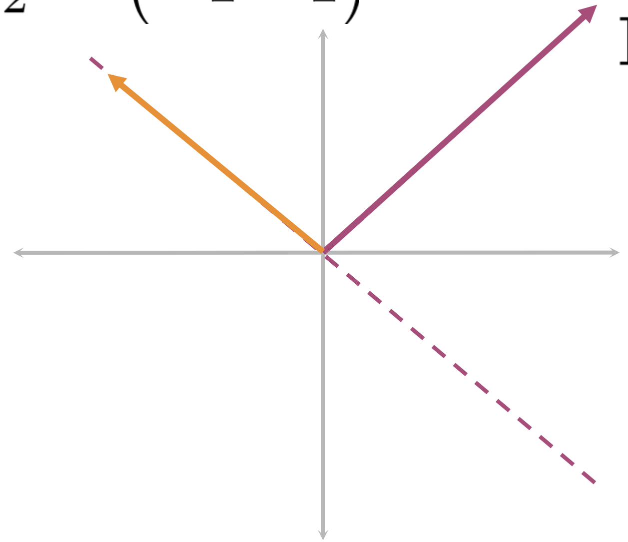
$$\mathbf{P} = \begin{pmatrix} 1 & 1 \end{pmatrix}$$

$$\mathbf{V}_1 = \begin{pmatrix} 1 & 2 \end{pmatrix}$$

$$\mathbf{P}\mathbf{V}_1^T = 3$$

Which side of the plane?

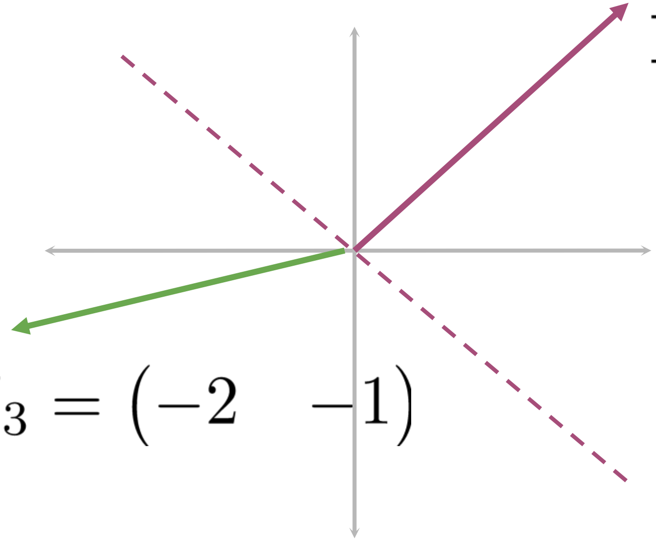
$$\mathbf{V}_2 = \begin{pmatrix} -1 & 1 \end{pmatrix}$$



$$\mathbf{P} = \begin{pmatrix} 1 & 1 \end{pmatrix}$$

$$\mathbf{P}\mathbf{V}_2^T = 0$$

Which side of the plane?

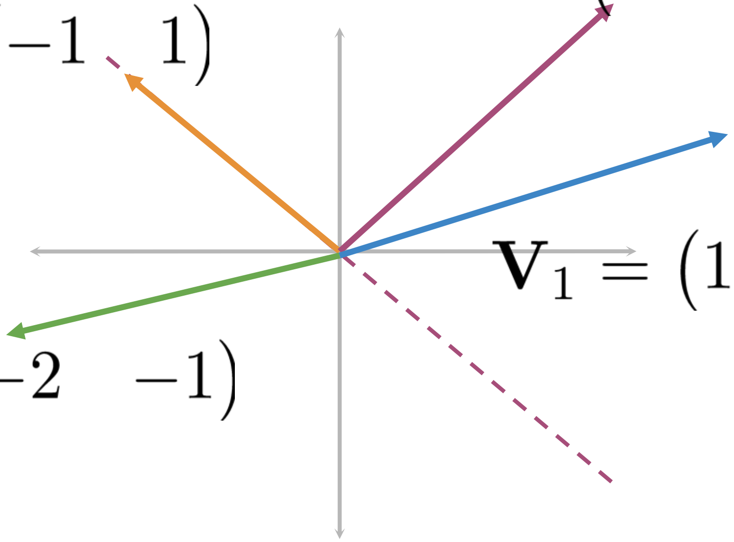


$$\mathbf{P} = \begin{pmatrix} 1 & 1 \end{pmatrix}$$

$$\mathbf{V}_3 = \begin{pmatrix} -2 & -1 \end{pmatrix}$$

$$\mathbf{P}\mathbf{V}_3^T = -3$$

Which side of the plane?



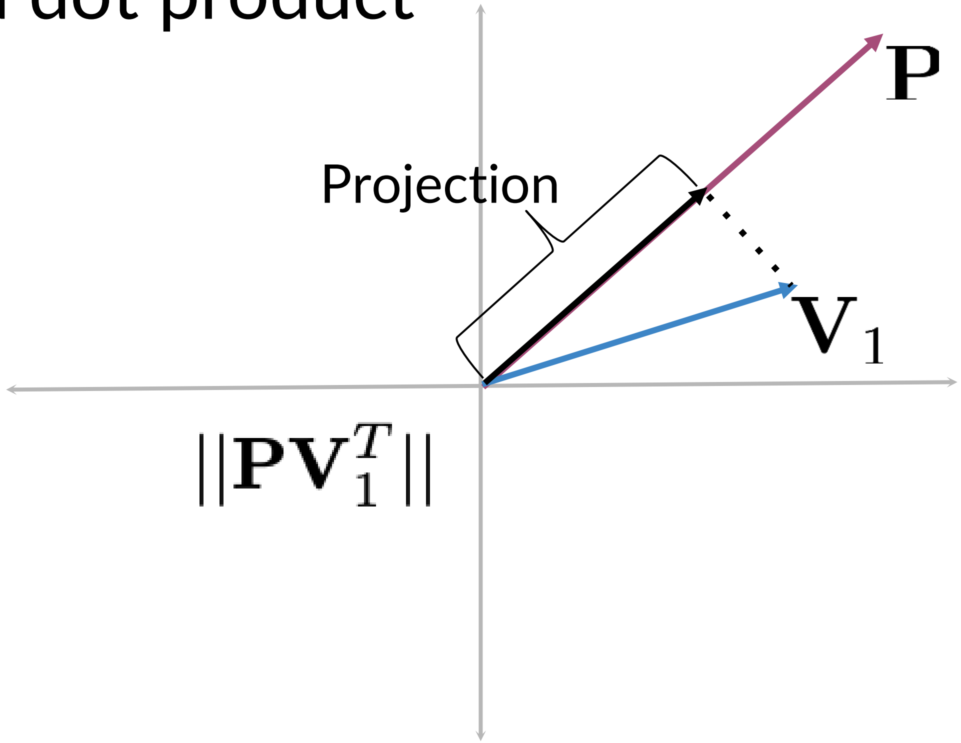
$$\mathbf{P}\mathbf{V}_1^T = 3$$

$$\mathbf{P}\mathbf{V}_2^T = 0$$

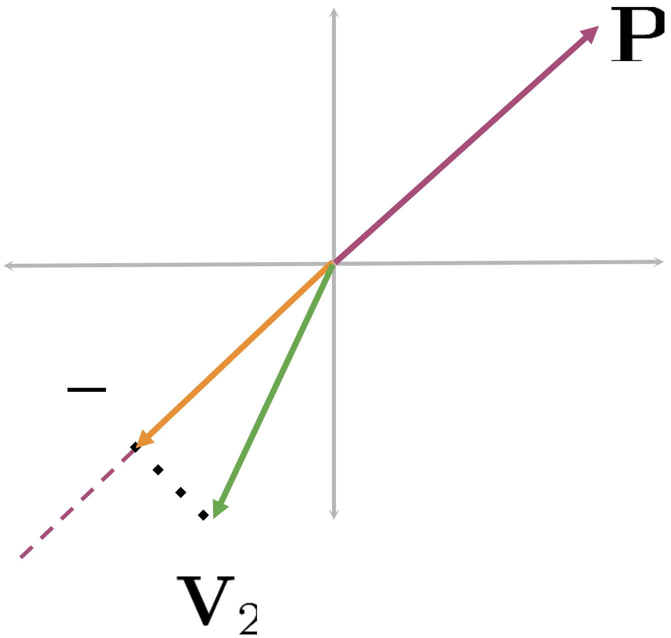
$$\mathbf{P}\mathbf{V}_3^T = -3$$

Notice the signs?

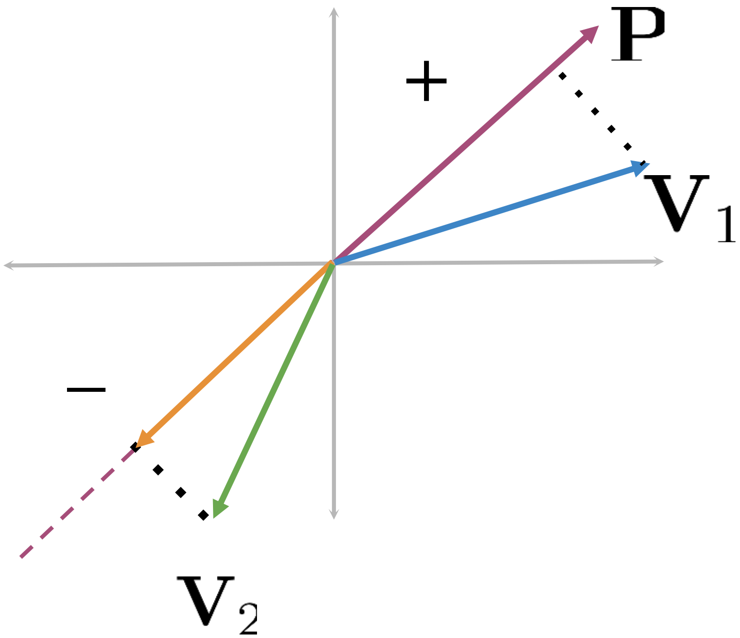
Visualizing a dot product



Visualizing a dot product



Visualizing a dot product



Sign indicates direction

Which side of the plane?

```
def side_of_plane(P,v):
    dotproduct = np.dot(P,v.T)
    sign_of_dot_product = np.sign(dotproduct)
    sign_of_dot_product_scalar= np.asscalar(sign_of_dot_product)
    return sign_of_dot_product_scalar
```

Try it!

Summary

- Sign of dot product $\longrightarrow$ Hash values

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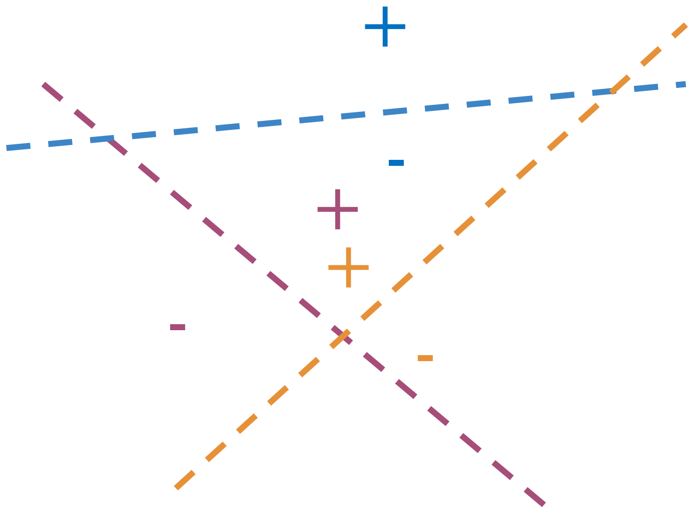
Multiple Planes

Outline

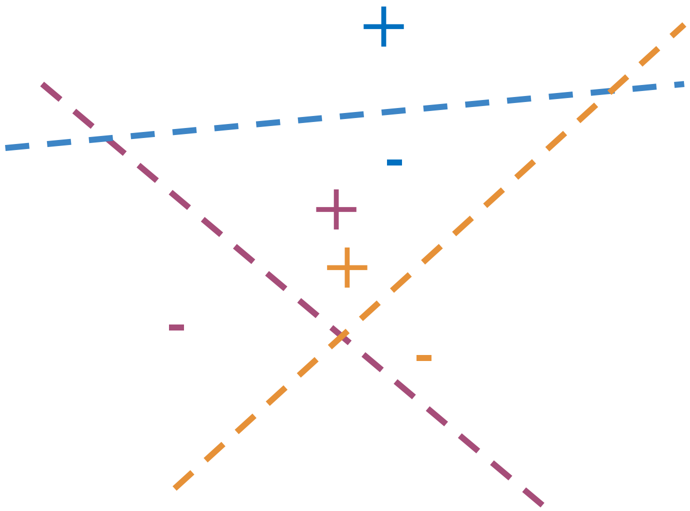
- Multiple planes $\longrightarrow$ Dot products $\longrightarrow$ Hash values

Multiple planes



single hash value?

Multiple planes, single hash value?



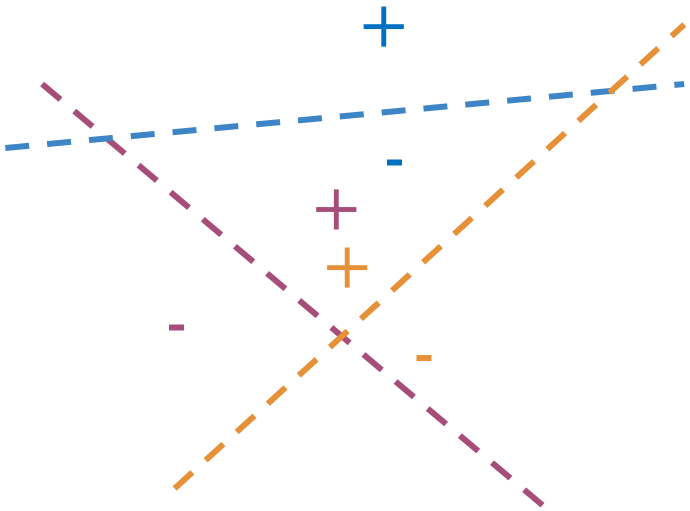
$$\mathbf{P}_1\mathbf{v}^T = 3, sign_1 = +1, h_1 = 1$$

$$\mathbf{P}_2\mathbf{v}^T = 5, sign_2 = +1, h_2 = 1$$

$$\mathbf{P}_3\mathbf{v}^T = -2, sign_3 = -1, h_3 = 0$$

$$hash = 2^0 \times h_1 + 2^1 \times h_2 + 2^2 \times h_3$$
$$= 1 \times 1 + 2 \times 1 + 4 \times 0$$
$$= 3$$

Multiple planes, single hash value!



$$sign_i \geq 0, \rightarrow h_i = 1$$

$$sign_i < 0, \rightarrow h_i = 0$$

$$\text{hash} = \sum_{i}^{H} 2^i \times h_i$$

Multiple planes, single hash value!!

```
def hash_multiple_plane(P_l,v):

    hash_value = 0

    for i, P in enumerate(P_l):
        sign = side_of_plane(P,v)
        hash_i = 1 if sign >=0 else 0
        hash_value += 2**i * hash_i

    return hash_value
```

Try it!

Summary

- Planes $\longrightarrow$ Sign of dot product $\longrightarrow$ Hash values

Approximate nearest neighbors

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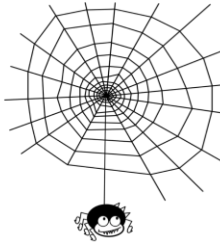
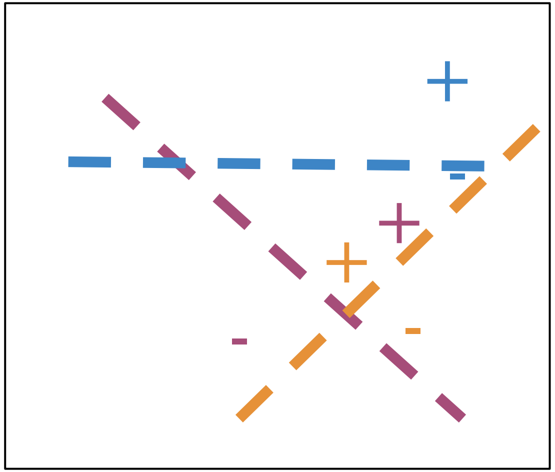
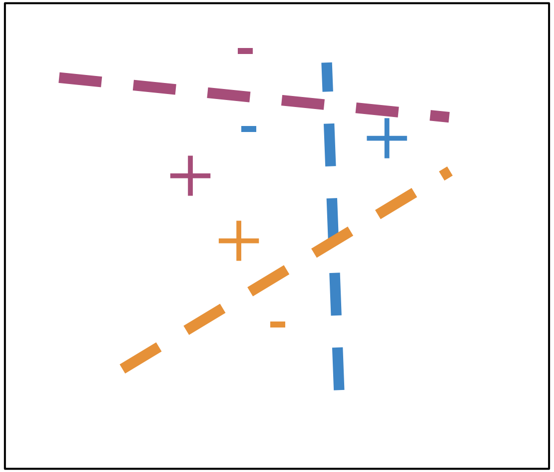
Outline

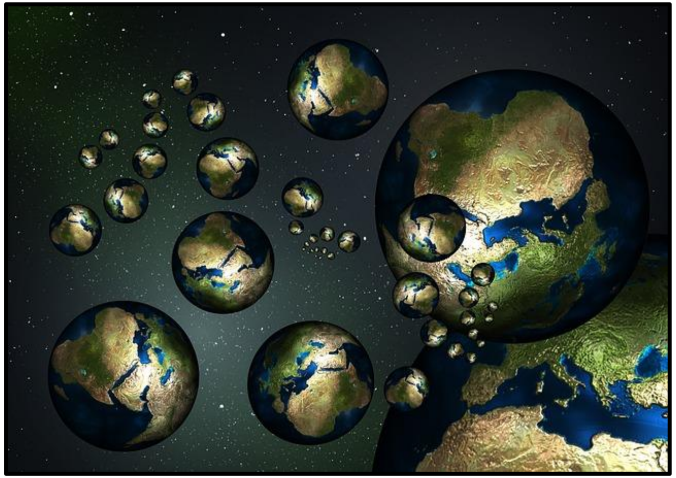
- Multiple sets of planes for approximate K-nearest neighbors



Random planes

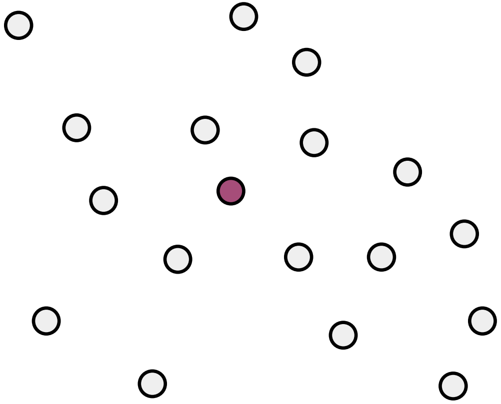




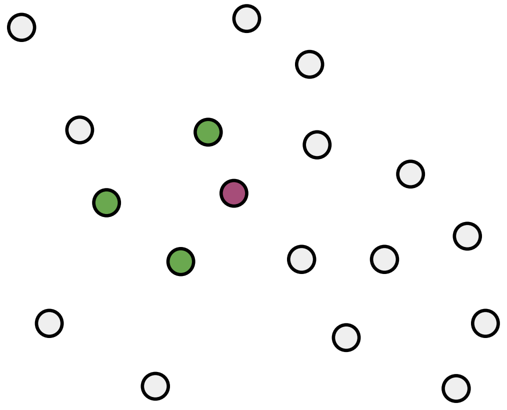


Cultural reference: Spider-Man: Into the Spider-Verse

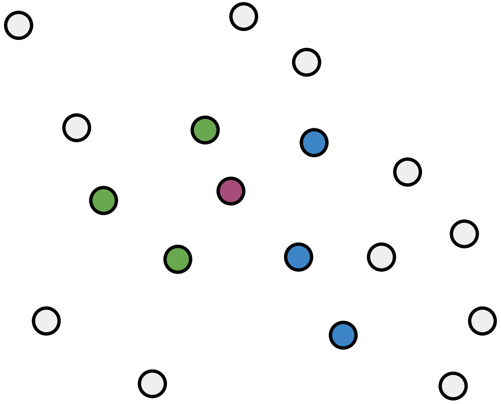
Multiple sets of random planes



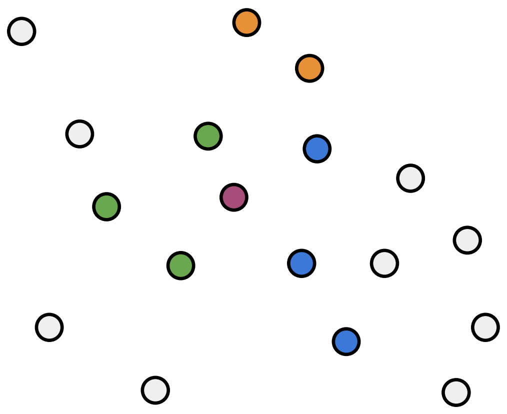
Multiple sets of random planes



Multiple sets of random planes



Multiple sets of random planes



Approximate nearest (friendly) neighbors

Make one set of random planes

```
num_dimensions = 2 #300 in assignment
num_planes = 3 #10 in assignment

random_planes_matrix = np.random.normal(
                       size=(num_planes,
                             num_dimensions))
```

```
array([[ 1.76405235  0.40015721]
       [ 0.97873798  2.2408932 ]
       [ 1.86755799 -0.97727788]])
```

```
v = np.array([[2,2]])
```

```
def side_of_plane_matrix(P,v):
          dotproduct = np.dot(P,v.T)
          sign_of_dot_product =
np.sign(dotproduct)

num_planes_matrix = side_of_plane_matrix(
                    random_planes_matrix,v)
```

```
array([[1.]
       [1.]
       [1.]])
```

See notebook for calculating the hash value!

Summary

- Multiple universes $\longrightarrow$ Locality sensitive hashing $\longrightarrow$ A. K-NN

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Searching documents

Outline

- Representation for documents
- Document search with K-nearest neighbors

Document representation

I love learning!	[?, ?, ?]
I	[1, 0, 1]
	+
love	[-1, 0, 1]
	+
learning	[1, 0, 1]
	=
I love learning!	[1, 0, 3]

Document Search

K-NN!

Document vectors

```
word_embedding = {"I": np.array([1,0,1]),
                  "love": np.array([-1,0,1]),
                  "learning": np.array([1,0,1])}

words_in_document = ['I', 'love', 'learning']

document_embedding = np.array([0,0,0])

for word in words_in_document:
        document_embedding +=

print(document_embedding)
array([1 0 3])
```

Try it!

Revisit Learning Objectives

- Transform vector
- "K nearest neighbors"
- Hash tables
- Divide vector space into regions
- Locality sensitive hashing
- Approximated nearest neighbors

Machine translation

Document search

Practice your skills in the assignment!