

CSE/STAT 416

Dimensionality Reduction

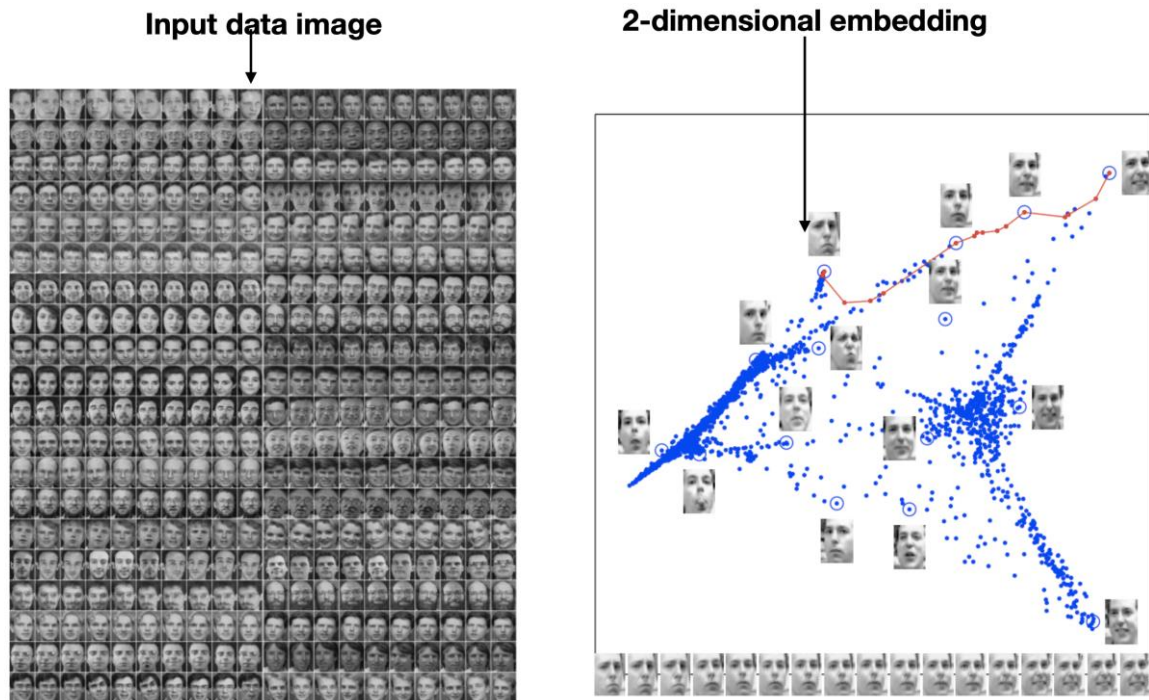
Vinitra Swamy
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Aug 10, 2020



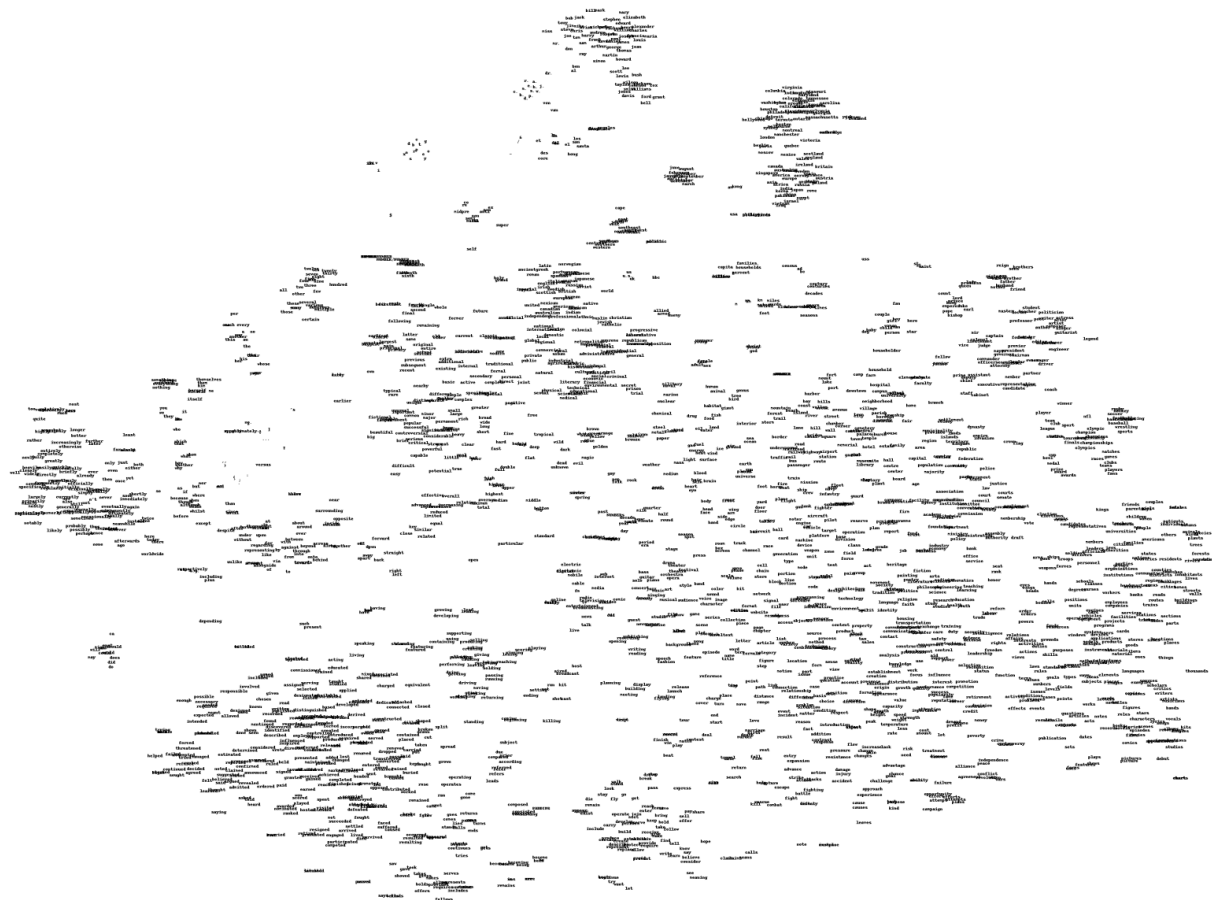
Embedding Pictures

Example: Embed high dimensional data in low dimensions to visualize the data

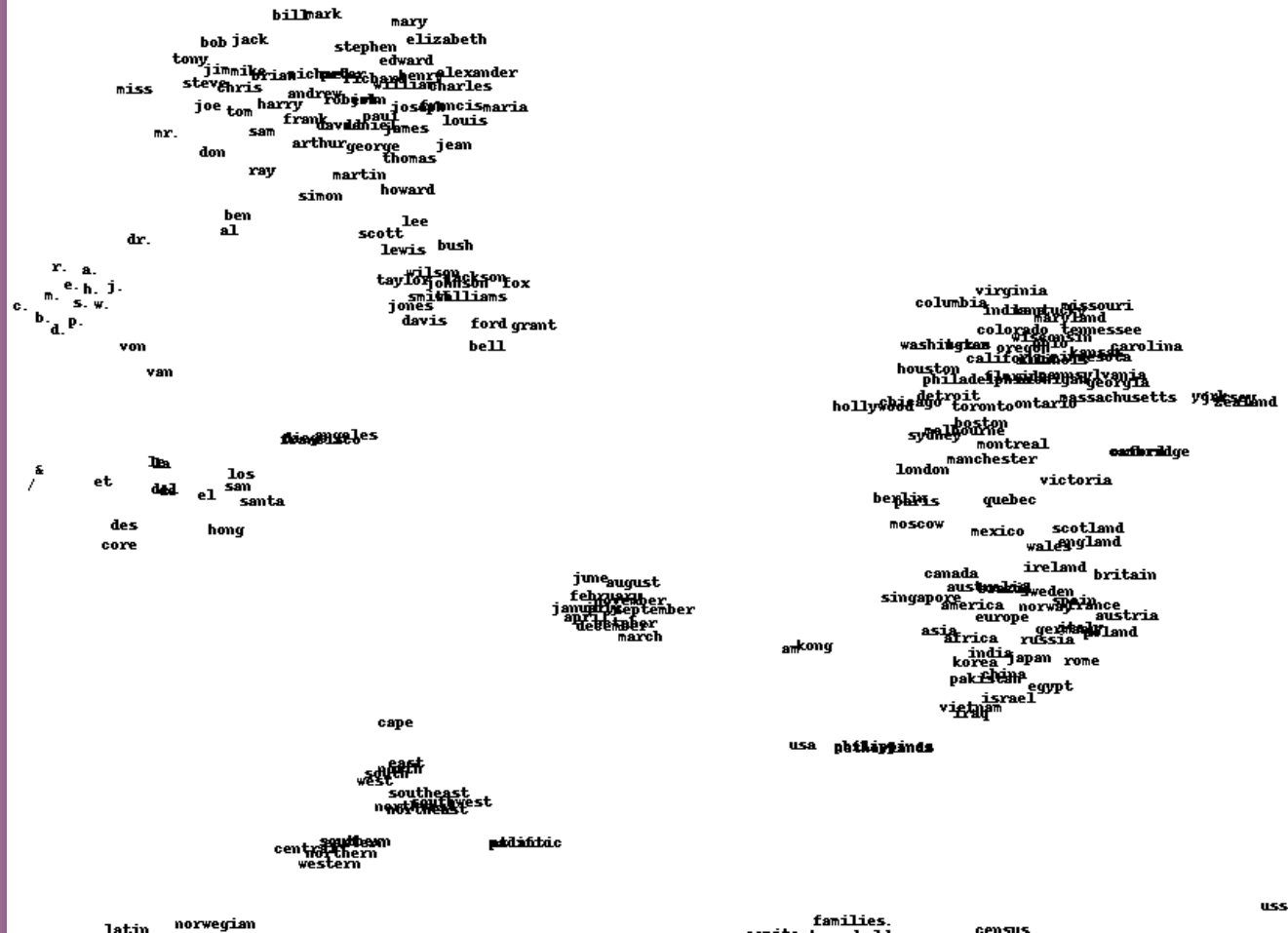
- Goal: Similar images should be near each other.



Embedding Words



Embedding Words



Dimensionality Reduction

Input data might have thousands or millions of dimensions!

Dimensionality Reduction is the the task of representing the data with a fewer number of dimensions, while keeping meaningful relations between data

- **Easier Learning:** fewer parameters, no curse of dimensionality
- **Visualization:** Hard to visualize more than 3D
- Discover “**intrinsic dimensionality**” of the data
 - High dimensional data is truly lower dimensional (i.e. redundant information)

Projections

Could do something like feature importance and find the subset of features with most meaningful information.

A popular approach is to **create new features** that are **combinations of existing features**

We can do this in the unsupervised setting when we only know x and not y !

PCA

One very popular dimensionality reduction algorithm is called **Principal Component Analysis (PCA)**.

Idea: Use a linear projection from d -dimensional data to k -dimensional data

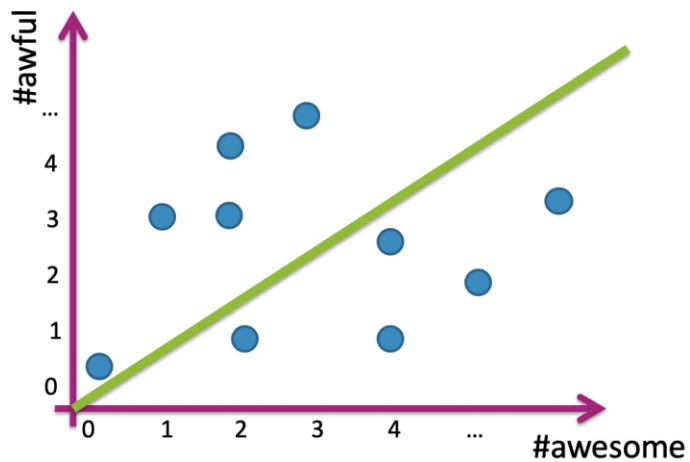
- E.g. 1000 dimension word vectors to 3 dimensions

Choose the projection that minimizes **reconstruction error**

- Idea: The information lost if you were to "undo" the projection

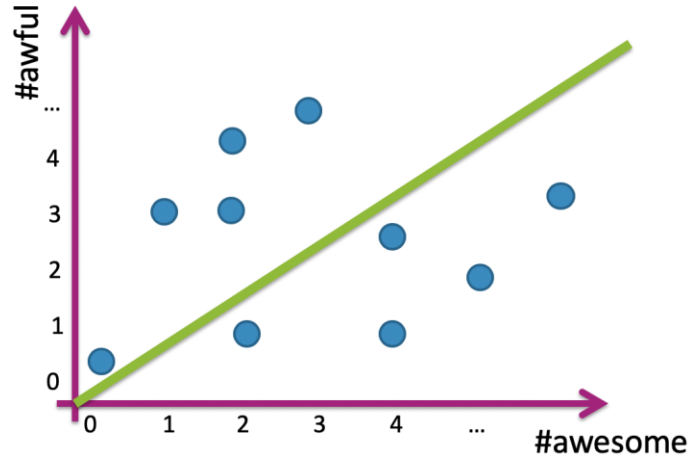
Linear Projection

Project data into 1 dimension along a line



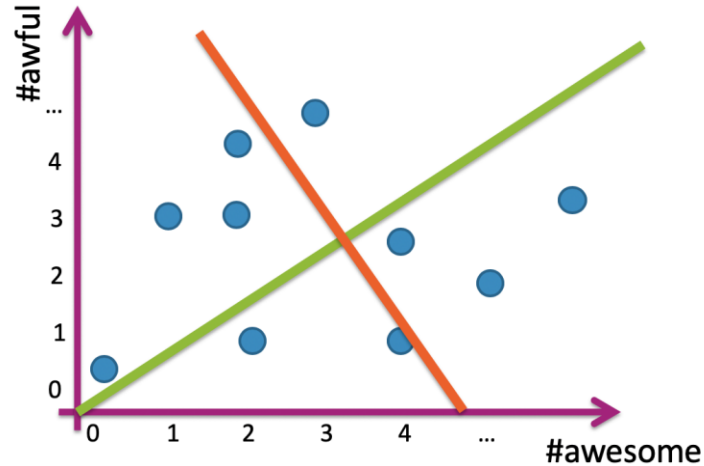
Reconstruction

Reconstruct original data only knowing the projection



Projection w/ 2 Dimensions

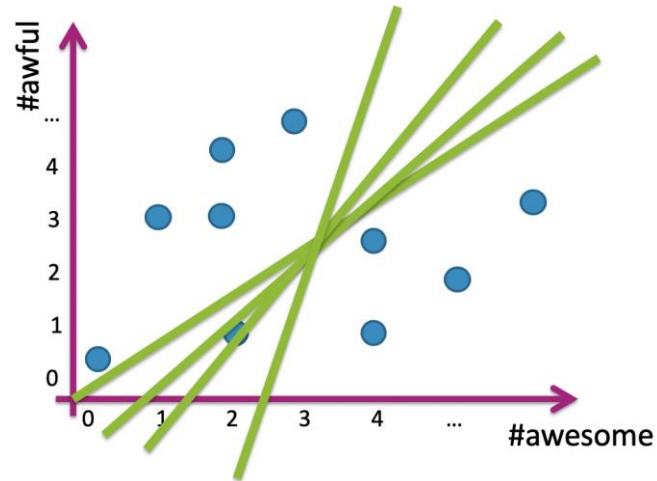
What if projected onto d orthogonal vectors?



Which Line?

Given a dataset, how do we choose which line to project on?

Extreme Example



PCA Visualized

This process can work with any dimension data (go from d dimensions to k dimensions).

PCA Explained Visually:

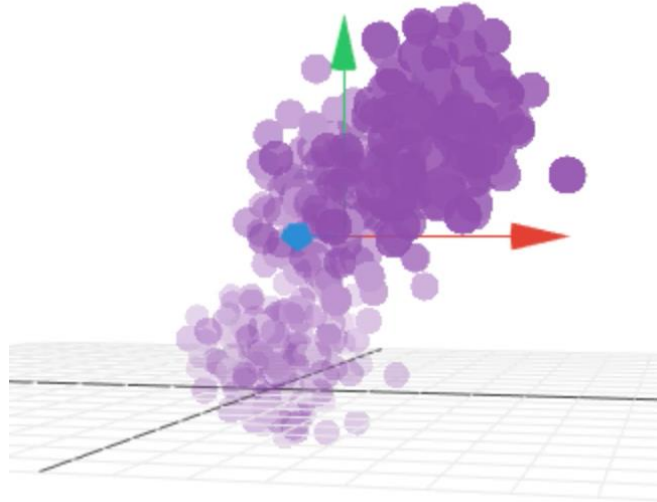
<http://setosa.io/ev/principal-component-analysis/>

Think 

1 min

Assume we were trying to reduce the dimension of 3d data to 2d data, which of the following would be the result of PCA?

Assume we are using the data from the visual demo and take pc1 and pc2 as the principal components.

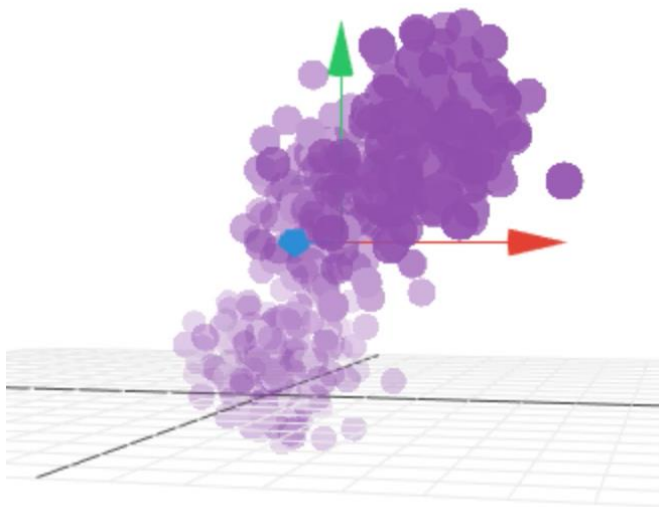


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1:00

Assume we were trying to reduce the dimension of 3d data to 2d data, which of the following would be the result of PCA?

Assume we are using the data from the visual demo and take pc1 and pc2 as the principal components.



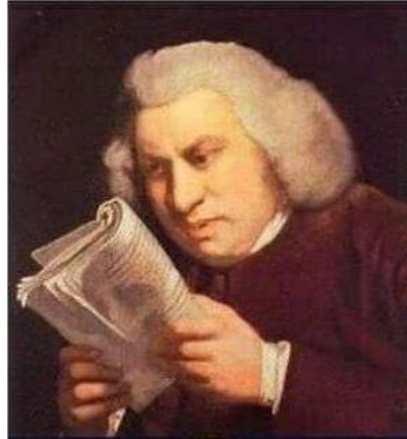
2:00



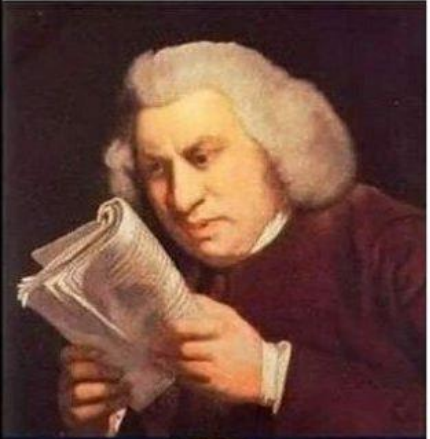
Brain Break

Another explanation about PCA

Studying PCA
for first time



Studying PCA for
100th time



PCA Algorithm

Input Data: An $n \times d$ data matrix X

- Each row is an example

1. Recenter Data: Subtract mean from each row

$$X_c \leftarrow X - \bar{X}[1:d]$$

2. Compute spread/orientation: Compute covariance matrix Σ

$$\Sigma[t, s] = \frac{1}{n} \sum_{i=1}^n x_{c,i}[t] x_{c,i}[s]$$

3. Find basis for orientation: Compute eigenvectors of Σ

- Select k eigenvectors u_1, \dots, u_k with largest eigenvalues

4. Project Data: Project data onto principal

$$z_i[1] = u_1^T x_{c,i} = u_1[1]x_{c,i}[1] + \dots + u_1[d]x_{c,i}[d]$$

...

$$z_i[k] = u_k^T x_{c,i} = u_k[1]x_{c,i}[1] + \dots + u_k[d]x_{c,i}[d]$$

Reconstructing Data

Using principal components and the projected data, you can reconstruct the data in the original domain.

$$\hat{x}_i[1:d] = \bar{X}[1:d] + \sum_{j=1}^k z_i[j] u_j$$

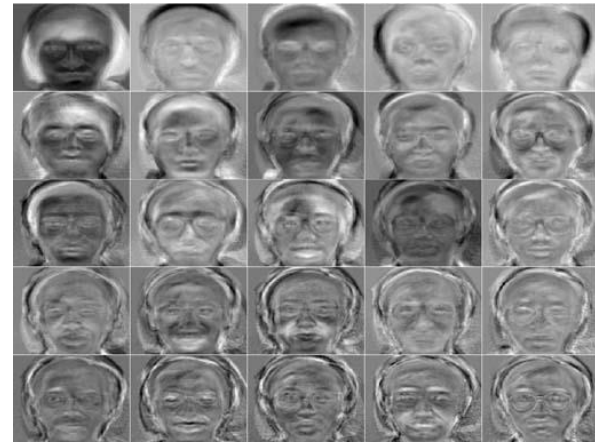
Example: Eigenfaces

Apply PCA to face data

Input Data



Principal Components



Reconstructing Faces

Depending on context, it may make sense to look at either original data or projected data.

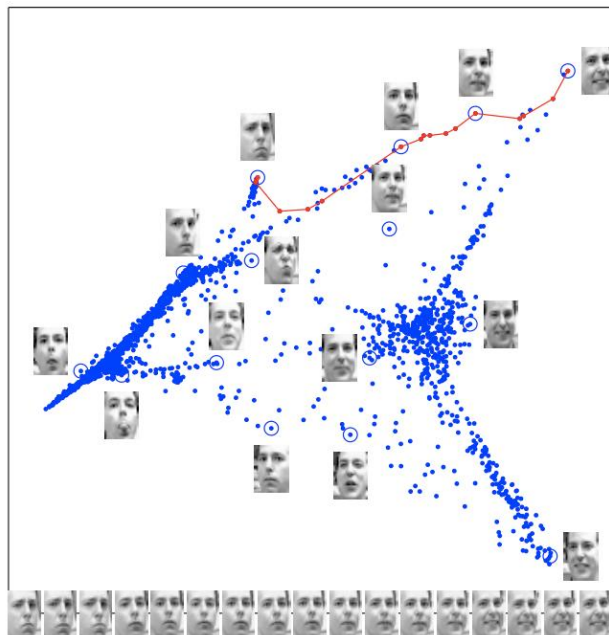
In this case, let's see how the original data looks after using more and more principal components for reconstruction.

- Each image shows additional 8 principal components



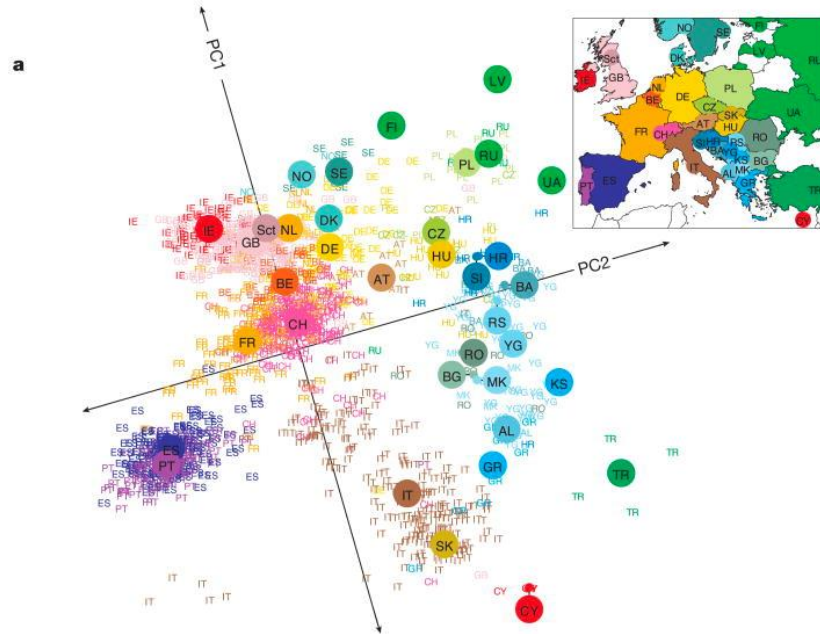
Embedding Images

Other times, it does make sense to look at the data in the projected space! (Usually if $k \leq 3$)



Example: Genes

Dataset of genes of Europeans (3192 people; 500,568 loci) and their country of origin, ran PCA on the data and plotted 2 principal components.



Think 

1 min

Using the PCA algorithm described in class on this gene data is an example of a:

- Supervised Learning Problem
- Unsupervised Learning Problem
- Neither
- I'm not sure

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A digital timer showing 1:00 in white text on a black background, which is part of a larger colorful abstract graphic.

Pair 

2 min

Using the PCA algorithm described in class on this gene data is an example of a:

- Supervised Learning Problem
- Unsupervised Learning Problem
- Neither
- I'm not sure

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A digital timer showing 2:00 in white text on a black background, which is part of a larger colorful abstract graphic.

Scaling Up

Covariance matrix Σ can be very large with high-dimensional data

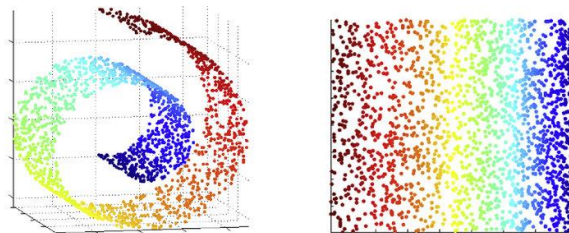
- $\Sigma \in \mathbb{R}^{d \times d}$ which can be quite large for 10,000 features
- This means finding the principal components will be slow

In practice, you can use the Singular Value Decomposition (SVD)

- Can be used to find the k eigenvectors with largest eigenvalue
- Very fast implementations available
- Don't care if you know what SVD is, but you will likely use it in practice if you are doing anything with PCA.

PCA Failure Modes

PCA assumes there is a lower dimensional **linear subspace** that represents the data well. Works some times, but can fail in practice.



May want to look into non-linear dimensionality reduction

- Manifold learning
- Popular: SDD Maps, Isomap, LLE, t-SNE

PCA Recap

Dimensionality Reduction

- Why and when it's important

Principal Component Analysis (PCA)

- High level intuition for what the algorithm is doing
- Goal: Minimizing reconstruction error



Brain Break

DEEP LEARNING



CSE/STAT 416

Recommender Systems

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Personalization

Personalization is transforming our experience of the world

Youtube

Netflix

Amazon

Spotify

Facebook

Many more...

Almost all have share a common trait where there are users that use the system and items that we want the user to look at.

A recommender system recommends items to a user based on what we think will be the most “useful” for the user.

Recommender System Challenges

Types of Feedback

Explicit - User tells us what she likes



Implicit – We try to infer what she likes from usage data



Top-k vs Diverse Outputs

Top-k recommendations might be very redundant

- Someone who likes Rocky I also will likely enjoy Rocky II, Rocky III, Rocky IV, Rocky V

Diverse Recommendations

- Users are multi-faceted & we want to hedge our bets
- Maybe recommend: Rocky II, Always Sunny in Philadelphia, Robin Hood

Cold Start

When a new movie comes into our system, we don't know who likes it! This is called the **cold start** problem.

Generally, to solve we will need “side information”

- Genre, actors, if it's a sequel

Could also try to test users to see if they like it to learn quickly

That's So Last Year

Interests change over time

- Is it 1967?
- Or 1977?
- Or 1998?
- Or 2011?

Models need flexibility to adapt to users

- Macro scale
- Micro scale (fads)



Scalability

For N users and M movies, some approaches take $\mathcal{O}(N^3 + M^3)$ time. This can be prohibitively slow for billions of users.

Big focus has been on:

- Efficient implementations
- Exact or faster approximate methods as needed

Popularity

Solution 0

Popularity

Simplest Approach: Recommend whatever is popular

- Rank by global popularity (i.e. Avengers Endgame)

Limitations

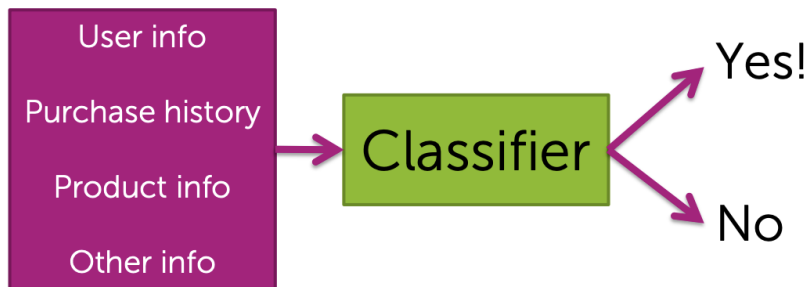
- No personalization
- Feedback loop

Classification Model

Solution 1

Learn a Classifier

Train a classifier to learn whether or not someone will like an item

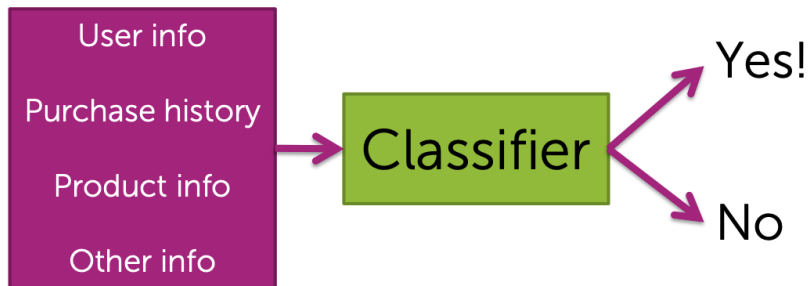


Pros

- Personalized
- Features can capture context (time of day, recent history, ...)
- Can even handle limited user history (age of user, location, ...)

Learn a Classifier

Train a classifier to learn whether or not someone will like an item



Cons

- Features might not be available or hard to work with
- Often doesn't perform well in practice when compared to more advanced techniques like **collaborative filtering**