Naive Bayes Classification

Machine Learning and Deep Learning

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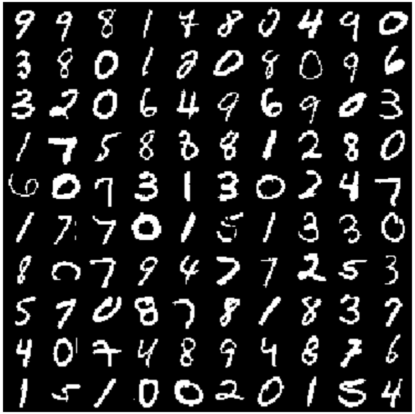
MNIST digits classification

Today we meet MNIST for the first time:



- 70000 images of handwritten images;
- available grayscale, we will use a binarized version;
- the task is to classify each image into the right digit.

Supervised learning setting

We are given a training set $\{X_i, Y_i\}_{i=1}^{n}$, with $X_i \in \mathbb{R}^m$ and $Y_i \in \mathbb{R}$ for each $i = 1, \ldots, n$.

- n is the number of training images;
- each image $X_i = \{x_i^{(1)}, \ldots, x_i^{(m)}\}$ is a vector of m pixels;
- each label Y_i is just a number among $\{1, \ldots, d\}$.

Classification using bayes rule

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- $P(Y)$ is the prior probability of the class Y;
- $P(X/Y)$ is the likelyhood of the image X under the model Y;
- $P(X)$ is the probability of the image X under the whole dataset. Does not influence the argmax so we can drop it.

Prior $P(Y)$

Finding the prior of a class Y is easy.
Simply count the number of examples of each class and divide by the number of total examples.

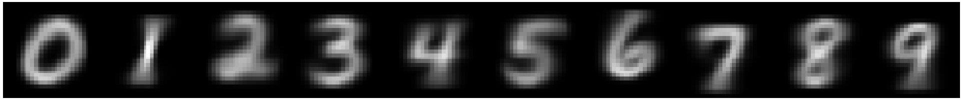
$$P(Y = c) = \frac{\sum_{i=1}^{n} \mathbf{1}\{Y_i == c\}}{n}$$

Likelyhood $P(X/Y)$

Naive assumption: all pixels are independent given the class. The probability of an image is the product of the probability of every single pixel.

$$P(X_i/Y_c) = \prod_{j=1}^{m} P(x_i^{(j)}/Y_c)$$

During training, we need to model this for each possible class:



0 medio di ogni classe

1 medio di ogni classe

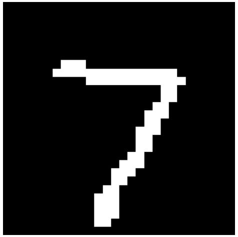
Likelyhood $P(X/Y)$

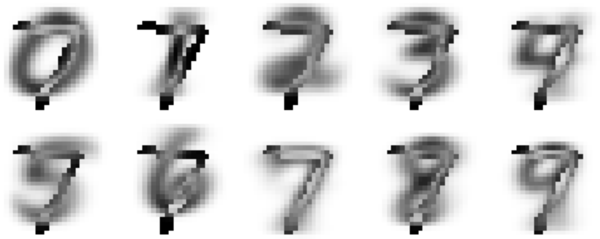
During testing, the likelihood of an image under a class is built by taking the class model (the one built before, during training) and:

- for each active pixel, account for the probability of being active given class;
- for each zero pixel, account for one minus the probability of being active given class;

immagine di inferenza, cioè da clasificare

i pixel attivi e spenti devono essere separati, quelli neri la p=1-p(pixel bianchi)





Inference

Once we can model $P(Y/X)$ for each class, we can classify an image by choosing the class that maximizes it:

$$\tilde{Y} = \arg\max_{Y} P(Y/X) = P(X/Y)P(Y)$$

Use logarithms!

All those products of probabilities can result in nothing. Use log-probabilities instead!

$$\log P(X_i/Y_c) = \sum_{j=1}^{m} \log P(x_i^{(j)}/Y_c)$$

$$\log P(Y/X) = \log P(X/Y) + \log P(Y)$$

Wrap up: algorithms

Algorithm 1 pseudocode for training

```
1: for $j = 1$ to $d$ do
2:     compute the class prior $P(Y_j)$
3:     compute a model for $P(X/Y_j)$
4: end for
```

Algorithm 2 pseudocode for inference

```
1: for $i = 1$ to $n$ do
2:     for $j = 1$ to $d$ do
3:         compute $\log P(X_i, Y_j)$
4:         compute $\log P(Y_j/X_i) = \log P(X_i, Y_j) + \log P(Y_j)$
5:     end for
6:     $Y_i = \arg\max_{Y_j} \log P(Y_j/X_i)$
7: end for
```