Lec Wed

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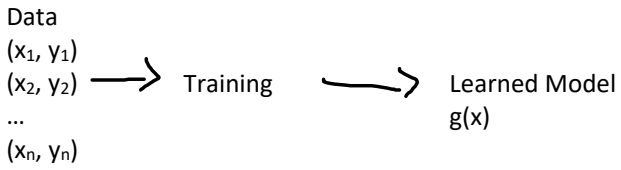
Supervised Learning uses data to learn the function that maps inputs x to outputs y



Learning the mapping (how do we train the model?)

- There's some target function f*(x) that is unknown
- Goal is to get a learned model y=f(x) that approximates f*(x) well

Key questions when designing a learning system

- Modeling
  - How to formulate application problems as machine learning problems
  - Learning Protocols (where are the data & labels coming from?)
- Representation
  - What functions should we learn (hypothesis spaces)?
  - How to map raw input to an instance space?
- Algorithms
  - What are good algorithms?
  - How to define success?
  - Computational limitations

In supervised learning,

- What is our **Instance Space**?
  - representing our inputs
  - inputs x are represented in a **feature space**
  - typically, $x \in \{0,1\}^n$ *or* $x \in R$
  - ex: for inputs being first + last names, gender/age/country of person, length of last name, whether name contains letter x, etc.
  - x, with multiple features, can be represented as a vector space where each dimension is a feature
    - so each input is represented as a vector of features
  - we may come up with a **feature template** - some way of representing features
    - ex: Abe -> [1000…00|01000…00|00001…00]
  - Finding good features is essential - they're the key to allowing the machine to understand the data
- What is our **Output Space**?
  - outputs y are represented in output space
  - different kinds of output:
    - binary classification: $y \in \{-1,1\}$
    - multiclass classification $y \in \{1,2,3, \dots, k\}$
    - regression $y \in R$
    - structured output $y \in \{1,2,3, \dots, k\}^n$
  - output space can be compositional - not only depending on individual inputs but relationships between them

Ex: Input/Output

- Disease diagnosis
  - x: properties of patient

    - y: multiclass (has disease, might have, doesn't have)
- Part-of-Speech Tagging
    - x: an English sentence
    - y: part of speech of a word in the sentence
- Face Recognition
    - x: bitmap picture of person's face
    - y: name of person, or maybe property of person (gender, ethnicity)

- What kind of **model**?
    - how many possible functions are there?
        - ex: 4 inputs, 1 output (all boolean) there are 2^{16} possible functions
    - our training data narrow down the number of possible functions that can fit our data
        - ex: continuing previous example, if we are given 7 examples, we now have 2^9 possible functions ($2^{16}/2^7 = 2^9$)
    - in general, there are $|Y|^{|X|}$ possible functions
    - the **hypothesis space** is the set of all functions we consider, usually some subset of all possible functions
    - it's possible we can't find any functions within our hypothesis space that fit all the training data, but that's okay. there will likely be a function that fits the training data well, but not fully
- Learning
    - Learning is the removal of our remaining uncertainty
    - Learning requires a good, small hypothesis space
        - generally we start with a very small class and enlarge it until it contains a hypothesis that fits the data

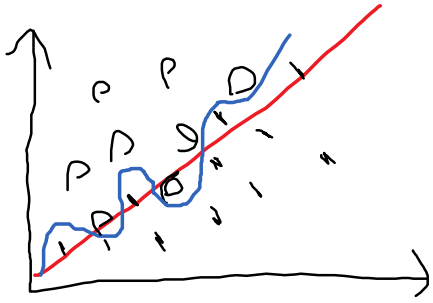
<u>General strategies for Machine Learning</u>

- Develop flexible hypothesis spaces
- Develop representation of languages for restricted classes of functions

<u>Real-World Example</u>

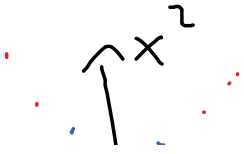
I don't know {whether, weather} to laugh or cry
How do we make this a learning problem?
Training data being correct English sentences, we represent them by a 50,000 dimensional feature vector denoting which English words are used in the sentence.
Note: outputs might be probabilities of each word, not a definitive choice of one or the other

Ex:



We want to separate the data: which is better? The blue or red function? Depends on your criteria. Blue obviously fits the training data better, but red is simpler and more general

Boolean functions can often be represented as linear functions
Ex:
$x_1 x_3 x_5 \Leftrightarrow \text{sgn}(x_1 + x_3 + x_5)$



<u>How to make functions linear</u>

$x_1 x_3 x_5 \Leftrightarrow \text{sgn}(x_1 + x_3 + x_5)$

How to make functions linear

ex: