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Problem Analysis and Preprocessing

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Overview

- Analysis of learning problems
  - Understanding requirements
  - Deriving a solution
  - Developing an evaluation protocol
- Data preprocessing
  - Data integration
  - Feature representation
  - Missing values
  - Feature selection

Problem Analysis

- Engineering approach to problem solving
- Understanting the requirements
  - Application goal, quality metric
  - Properties of the data, of the process that generates the data
  - Application-specific requirements
  - Locating the problem in the taxonomy of machine learning paradigms
  - Do underlying assumptions of methods match the problem requirements?
- Developing a solution
- Developing an evaluation strategy

Understanding the Problem Requirements

- Differing cultures in different industries
- E.g., automotive industry
  - 10- to 20-pages of written software requirements specifications are not uncommon
- Usual case:
  - User / customer has idea which property a good solution should have
  - Exact problem setting and requirements have to be determined in interviews.

Example: Email Service Provider

- Problem: email spam exhausts hard drives and processing capacity
- Server and storage are massive cost factors
- Legal requiements: messages that have been accepted for delivery must not be deleted

Example: Email Service Provider

- Individual mailing campaigns distributed by botnets create enormous volumes of data

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Example: Email Service Provider

- Administrators notice large campaigns, write regular expression that matches campaign
- Email server then refuses to accept messages that match these regular expressions
- Problems: campaigns have to be noticed in time, admin has to act (weekends? Holidays?)
- If legitimate messages do not arrive, number of complaint calls to call center increases

Fallbeispiel Email Service Provider

- Requirements for automatted solution?
- Evaluation metric?
- Modeling as a learning problem?
  - Type of learning problem?
  - Model space?
  - Loss function? Regularizer?

Taxonomy of Learning Problems

- Supervised: Training data contain values for variable that model has to predict
  - Classification: categorial variable
  - Regression: continuous variable
  - Ordinal regression, finite, ordered set of values
  - Rankings: ordering of elements
  - Structured prediction: sequence, tree, graph, …
  - Recommendation: Item-by-user matrix

Taxonomy of Learning Problems

- Unsupervised: discover structural properties of data
  - Clustering
  - Unsupervised feature learning: find attributes that can be used to describe the data well
  - Anomaly detection
- Control / reinforcement learning: learning to control a dynamical system
- Many further models
  - Semi-supervised learning
  - Supervised clustering
  - …

Data Availability

- Batch learning: all data available
- Online learning: data come in one at a time; incremental model updates

Data Availability

- Number of data
  - Very few?
  - So many that they have to be stored and processed distributedly?
- Number of attributes
  - Too few?
  - Too many to process?
  - Sparse (most entries zero)?
- Quality of data
  - Missing values?
  - Erroneous values? Measurement errors?

Representational Properties of the Data

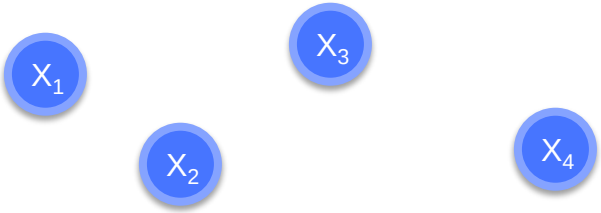
- Balanced class ratio? Rare classes?
- Class ratio representative?
- Marginal distribution $p(\boldsymbol{x})$ in the data equal to distribution at application time? (If not, learning under covariate shift)
- Values of the target attribute from the real target distribution or from an auxiliary distribution (laboratory experiments, simulation data)
- Recent data? Does the process change over time?

Data Properties

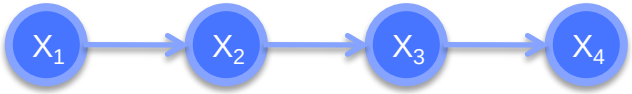
- One or several data sources?
- Credibility? Quality? Consistency?
- Availability
  - Fixed, given data set?
  - Does a data collection protocol have to be developed?

Data Dependencies

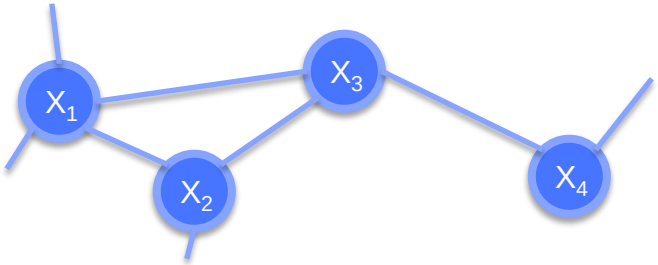
- Independent observations



- Sequences

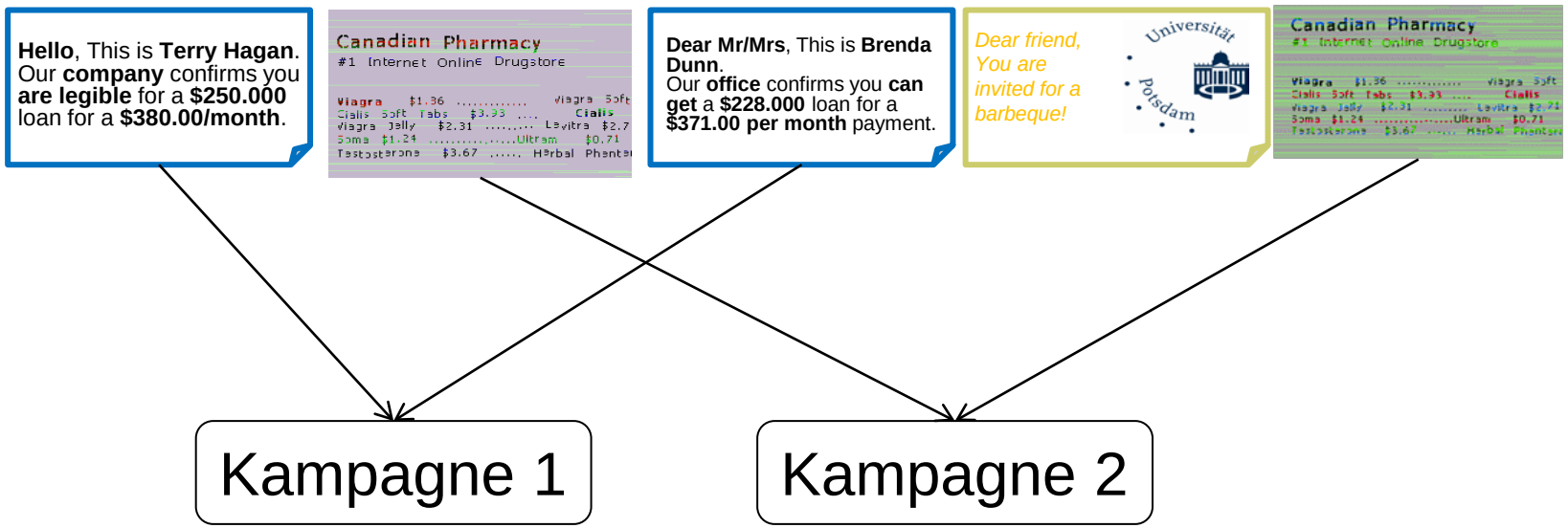


- Interdependent data



Example: Email Service Provider

- Modeled as two subsequent learning problems
  1. Campaign discovery



Example: Email Service Provider

- Modeled as two subsequent learning problems
  1. Campaign discovery
  2. Creating a regular expression for each campaign

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\S+(\S+){1,19} to start improving your life!

~C[A-Z]*FOR A FREE CONSULTATION~

(1-407-245-7320 You must |1-407-245-7320 You should |1-407-245-7320 Please)leave us a (|voice)message with your (name and |)phone number with country code if outside USA and
\S+(\S+){0,4}ll (|contact |get back to)you \S+(\S+){0,4}.

Example: Discovering Campaigns

- Unsupervised learning: cluster analysis
- Online processing of the data stream
- Optimization criterium:
  - Most likely partitioning of stream into clusters
- Instances: header and word-occurrance attributes

...	Email Header Attributes
0	Alternative
1	Beneficiary
0	Friend
...	…
1	Sterling
0	Zoo

Dear Beneficiary,

your Email address has been picked online in this years MICROSOFT CONSUMER AWARD as a Winner of One Hundred and Fifty Five Thousand Pounds Sterling…

Example: Discovering Campaigns

- Offline evaluation
  - Save all emails within a limited period of time
  - Manually partition into clusters
  - Metrics: agreement between manually and automatically generated clustering
  - False-positive rate, False-negative rate
- Online evaluation, testing
  - Find clusters during regular business operation
  - Show to admins in charge of blocking campaigns
  - Admin feedback: incomplete? Multiple campaigns? Ok to block?

Example: Find Regular Expression

- Instances $\boldsymbol{x}$: sets of emails (set of strings)
- Target attribute $\boldsymbol{y}$: Regular expression

I'm a cute russian lady. I'm 21 years old, weigh 55 kilograms and am 172 centimeters tall.	I'm a lonely russian lady. I'm 23 years old, weigh 47 kilograms and am 165 centimeters tall.	...	I'm a sweet russian girl. I'm 22 years old, weigh 58 kilograms and am 171 centimeters tall.

$\downarrow \quad y_\theta(\boldsymbol{x})$

y = I'm a [a-z]$^+$ russian (girl|lady). I am 2[123] years old, weigh \d$^+$ kilograms and am 1\d{2} centimeters tall.

Example: Find Regular Expression

- Training data $\{(\boldsymbol{x}_i, \boldsymbol{y}_i)\}$: Sets of strings and corresponding regular expression written by admin.

This is a nice way to make a right move and receive your due
This is a best chance to make a right move and receive your
This is a good chance to make a right move and receive your
This is a good chance to make a right move and receive your due benefits... if you are qualified but are lacking that piece of paper. Get one from us in a fraction of the time. If you want to get better - you must Contact us 24 hours a day and 7 days a week! to start improving your life! ~CALL US FOR A FREE CONSULTATION~ 1-407-245-7320 You should leave us a message with your phone number with country code if outside USA and name and we'll contact you asap.

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\S+(\S+){0,2} time.

\S+(\S+){1,19} to start improving your life!

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Example: Find Regular Expression

- Type of learning problem?

Example: Find Regular Expression

- Type of leanring problem:
  - Training data contain correct regular expressions: $\Rightarrow$ supervised learning
  - Target variable is a regular expression: discrete, structured $\Rightarrow$ Structured prediction (learning wth struvctured output spaces)

Example: Find Regular Expression

- Loss function $\ell(y_\theta(\boldsymbol{x}_i), \boldsymbol{y}_i)$: should measure how different the expressions are

Example: Find Regular Expression

- Loss function $\ell(y_\theta(\boldsymbol{x}_i), \boldsymbol{y}_i)$: should measure how different the expressions are:
  - Proportion of non-identical nodes in the syntax tree.
- Regularization: L_2

Example: Evaluation and Testing

Example: Evaluation and Testing

- Online evaluation
  - Discovered campaigns and generated regular expressions presented to admins who have to blacklist campaigns
  - Rates of acceptance, acceptance + editing, rejection of the generated expressions
  - Rate of complaint calls to the call center

Overview

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  - Deriving a solution
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- Data preprocessing
  - Data integration
  - Feature representation
  - Missing values
  - Feature selection

Data Integration

- Multiple data sources: integrate consistently; e.g., in data warehouse.
- Integration of multiple data formats.
- Schema integration: identify same / related attributes in different sources.
- Data conflicts (e.g., conversion of differing units).
- Discover redundant information (duplicate detection).

Feature Representation

- Transform attributes, depending of model structure
- For instance, linear model compute inner product of attributes and model parameters.
  - All attributes have to be numeric.
  - Larger attribute values: larger value of inner product
  - Categorial attributes, attributes without ordering, textual attributes have to be converted.

Farbe	Größe	Produktkategorie
rot	23	173
blau	23	173
grün	45	36

→

Farbe rot	Farbe blau	Farbe grün	Größe	Produktkategorie 1	…	Produktkategorie 173
1	0	0	23	0		1
0	1	0	23	0		1
0	0	1	45	0		0

Feature Representation

- Texts: TF- or TFIDF-representation
- Term-frequency vector: one dimension per term in a dictionary.
- Use all terms that appear at least 3 times in data.
- Value: number of occurances ot the term in the document.

$$\mathbf{x} \quad \begin{array}{c} \begin{pmatrix} 0 \\ 1 \\ 0 \\ \dots \\ 1 \\ 0 \end{pmatrix} \end{array} \begin{array}{l} \text{Alternative} \\ \text{Beneficiary} \\ \text{Friend} \\ \dots \\ \text{Sterling} \\ \text{Zoo} \end{array}$$

Email

Dear Beneficiary,

your Email address has been picked online in this years MICROSOFT CONSUMER AWARD as a Winner of One Hundred and Fifty Five Thousand Pounds Sterling…

Feature Representation

- Texts: TF- or TFIDF-representation
- Frequently occurring terms (and, or, not, is) carry little semantic meaning.
- Idea: assign lower weight to frequent terms.
- Inverse document frequency

$$IDF(\text{term}_i) = \log \frac{\#\text{documents}}{\#\text{documents that contain term}_\text{i}}$$

Feature Representation

- TFIDF vector

$$TFIDF(\mathrm{x}) = \frac{1}{|\mathrm{x}|}\begin{pmatrix} TF(\mathrm{term}_1)\cdot IDF(\mathrm{term}_1) \\ \vdots \\ TF(\mathrm{term}_n)\cdot IDF(\mathrm{term}_n) \end{pmatrix}$$

Feature Representation

- Texts: N-Gram vectors
- In TFIDS representation, information about the ordering of the terms is lost
- N-Gram features: one attribute for each k-tuple of subsequent terms (for all $k \leq N$)

$$\begin{pmatrix} 1 \\ 1 \\ 1 \\ \dots \\ 1 \\ \dots \\ 1 \end{pmatrix}$$

Dear
Dear Beneficiary
Dear Beneficiary your

has been picked

Thousand pounds Sterling

Email

Dear Beneficiary,

your Email address has been picked online in this years MICROSOFT CONSUMER AWARD as a Winner of One Hundred and Fifty Five Thousand Pounds Sterling…

Feature Representation

- Attributes can assume greatly varying ranges of values.
- Larger absolute values will have a larger impact on th decision function
- It can be beneficial to normalize these ranges.
- This is equivalen to applying stronger regularization to the corresponding weights.

Feature Representation

- Feature normalization

  - Min/Max normalization: $$x^{new} = \frac{x - x_{\min}}{x_{\max} - x_{\min}}(x_{\max}^{new} - x_{\min}^{new}) + x_{\min}^{new}$$
  - Z-Score normalisierung: $$x^{new} = \frac{x - \mu_x}{\sigma_x}$$
  - Decimal scaling: $$x^{new} = |x| \cdot 10^a \quad a = \max_x \{i \in \mathbb{Z} | \, |x| \cdot 10^i < 1\}$$
  - Logarithmic scaling: $$x^{new} = \log_a x$$

Feature Representation

- It can be beneficial to construct complex features is such combinations cannot be found by the model.
  - With polynomial kernels, the model space contains all polynomials of the attributes, but not with linear modelks
- Feature construction
  - Combinations of elementary features, e.g., $(x_i, x_j) \rightarrow \left(x_j, \sqrt{x_i x_j}, x_i + x_j\right)$
  - Mapping of elementary features, e.g.,. $x_i \rightarrow \left(x_i, \log x_i, x_i^2\right)$

Attributes with Missing Values

- Cause of missing values
  - Missing at random (e.g., memory error, measuring fault).
  - Some values may be missing systematically, some classes may be more likely to have missing values.
  - Data integration: values may have been deleted due to inconsistencies.
  - Data aggregation: may have been aggregated or deleted for privacy.
  - …

Attributes with Missing Values

- Delete all affected instances (attributes)
  - Makes only sense if very few instances have missing values (attribute is almost always missing)
- Extend range of values to special value “missing”.
- Introduce new binary attributes “Attribute_XY_missing”.
- Estimate missing values
  - (Class-specific) mean / median imputation
  - Infer most likely values (e.g., using EM algorithm).
- Do not handle missing values (if learning algorithm can intrinsically work with missing values).

Attributes with Erroneous Values

- Identifying incorrect values
  - Binning: equidistant discretization into bins
    $\Rightarrow$ Bins with few instances may be outliers.
  - Clustering $\Rightarrow$ Clusters with one or few instances may be outliers.
  - Active learning/labeling: inconsistencies between data and model
    $\Rightarrow$ query human for correct label.
- Handling of erroneous values
  - Smoothing of numeric values (e.g., regression, moving average).
  - Treat as missing value / delete instance
  - ...

Feature Selection

- Selecting a subset of attributes can lead to better result.
- Dimensionality reduction.
- Plenty of approaches to feature selection.
  - For instance, principal component analysis
  - Forward-/Backward-selection
- Evaluation with training/test or n-fold cross validation
  - Train models with varying feature subsets on training set
  - Evaluate on testing set.

Feature Selection

- Feature selection for linear models; e.g.,
  - Train linear model,
  - Delete attributres with smalles weights,
  - Train linear model again,
  - Evaluate on test set,
  - Reiterate until optimum is reached.

Problem Analysis, Data Preprocessing

- Machine learning is an engineering science.
  - Analyze problem, understand requirements,
  - Map to known paradigms, refer to state of the art.
  - Derive a solution, and evaluation protocol.
- Data preprocessing can make difference between a model that works great and one that works not at all
  - Data integration,
  - Engineering of good features,
  - Handling of missing, erroneous values,
  - Feature selection