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## Text Technologies for Data Science

INFR11145

# Text Classification

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## Lecture Objectives

- Learn about text basics of text classification
  - Definition
  - Types
  - Methods
  - Evaluation



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## Text Classification

- **Text classification** is the process of classifying documents into predefined categories based on their content.
- Input: Text (document, article, sentence)
- Task: Classify into predefined one/multiple categories
- Categories:
  - Binary: relevant/irrelevant, spam .. etc.
  - Few: sports/politics/comedy/technology
  - Hierarchical: patents

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## Classification is and is not

- **Classification** (a.k.a. “**categorization**”): a common technology in data science; studied within pattern recognition, statistics, and machine learning.
- Definition:  
the activity of **predicting** to which among a **predefined finite** set of groups (“classes”, or “categories”) a data item belongs to
- Formulated as the task of generating a hypothesis (or “classifier”, or “model”)

$$h : D \rightarrow C$$

where  $D = \{\mathbf{x}_1, \mathbf{x}_2, \dots\}$  is a domain of data items and

$C = \{c_1, \dots, c_n\}$  is a finite set of classes (the **classification scheme**)

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## Classification is and is not

- Different from clustering, where the groups (“clusters”) and their number are not known in advance
- The membership of a data item into a class must not be determinable with certainty
  - e.g., predicting whether a natural number belongs to *Prime* or *Non-Prime* is not classification
- In text classification, data items are
  - **Textual**: e.g., news articles, emails, sentences, queries, etc.
  - **Partly textual**: e.g., Web pages

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## Types of Classification

- **Binary**:  
item to be classified into one of two classes  
 $h : D \rightarrow C, C = \{c_1, c_2\}$ 
  - e.g., Spam/not spam, offensive/not offensive, rel/irrel
- **Single-Label Multi-Class (SLMC)**  
item to be classified into only one of  $n$  possible classes.  
 $h : D \rightarrow C, C = \{c_1 \dots c_n\}$ , where  $n > 2$ 
  - e.g., Sports/politics/entertainment, positive/negative/neutral
- **Multi-Label Multi-Class (MLMC)**  
item to be classified into none, one, two, or more classes  
 $h : D \rightarrow 2^C, C = \{c_1 \dots c_n\}$ , where  $n > 1$ 
  - e.g., Assigning CS articles to classes in the ACM Classification System
  - Usually be solved as  $n$  independent binary classification problems

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## Dimension of Classification

- Text classification may be performed according to several dimensions (“axes”) orthogonal to each other
- by **topic**; by far the most frequent case, its applications are global
- by **sentiment**; useful in market research, online reputation management, social science and political science
- by **language** (a.k.a. “language identification”); useful, e.g., in query processing within search engines
- by **genre**; e.g., AutomotiveNews vs. AutomotiveBlogs, useful in website classification and others;
- by **author** (a.k.a. “authorship attribution”), by native language (“native language identification”), or by gender; useful in forensics and cybersecurity
- by usefulness, e.g., product reviews
- .....

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## Rule-based classification

- An old-fashioned way to build text classifiers was via knowledge engineering, i.e., manually building classification rules
  - E.g., (Viagra or Sildenafil or Cialis) → Spam
  - E.g. (#MAGA or America great again) → support Trump
- Common type: dictionary-based classification
- Disadvantages:
  - Expensive to setup and to maintain
  - Depends on few keywords → bad coverage (recall)

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## Supervised-learning classification

- A generic (task-independent) learning algorithm is used to train a classifier from a set of manually classified examples
- The classifier learns, from these training examples, the characteristics a new text should have in order to be assigned to class  $c$
- Advantages:
  - Generating training examples cheaper than writing classification rules
  - Easy update to changing conditions (e.g., addition of new classes, deletion of existing classes, shifted meaning of existing classes, etc.)

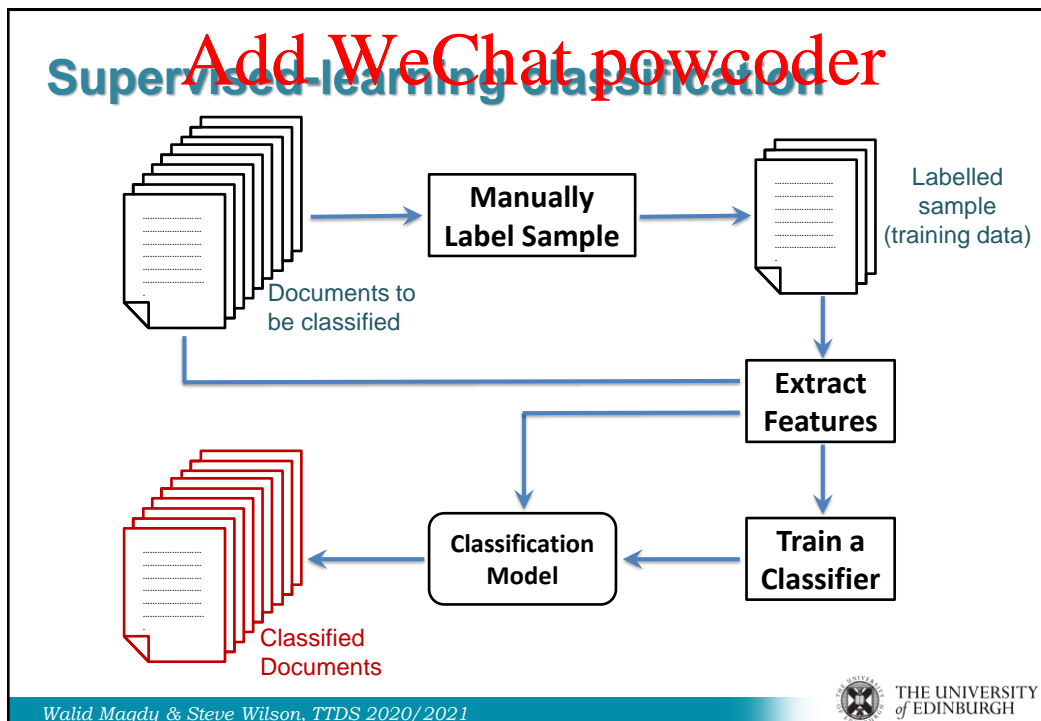
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## Extract Features

- In order to be input to a learning algorithm (or a classifier), all training (or unlabeled) documents are converted into **vectors** in a common **vector space**
- The dimensions of the vector space are called **features**
- In order to generate a vector-based representation for a set of documents  $D$ , the following steps need to be taken
  1. Feature Extraction
  2. Feature Selection or Feature Synthesis (optional)
  3. Feature Weighting

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## Step 1: Feature Extraction

- What are the features that should be different from one class to another?
- Simplest form: BOW
  - Each term in a document is a feature
  - Feature space size = vocabulary in all docs
  - Standard IR preprocessing steps are usually applied
    - Tokenisation, stopping, stemming
- Other simple features forms:
  - Word n-grams (bigrams, trigrams, ....)
    - Much larger + more sparse
  - Sometimes char n-grams are used
    - Especially for degraded text (OCR or ASR outputs)

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## Step 1: Feature Extraction

- What other text features could be used?
- Sentence structure (NLP):
  - POS (part-of-speech tags)
  - Syntactic tree structure
- Topic-based features (NLP):
  - LDA topics
  - NEs (named entities) in text
  - Links / Linked terms
- Non-textual features:
  - Average doc\sentence\word length
  - % of words start with upper-case letter
  - % of links/hashtags/emojis in text

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## Step 1: Feature Extraction

- What preprocessing to apply?
  - Case-folding? really vs Really vs REALLY
  - Punctuation? "?", "!", "@", "#"
  - Stopping? "he", "she", "what", "but"
  - Stemming? "replaced" vs "replacement"
- Other Features:
  - Start with Cap, All Cap
  - Repeated characters "congraaaaaats" "help!!!!!!!!!"
  - LIWC: Linguistic Inquiry and Word Count
- Which to choose?
  - Classification task/application

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## Step 2: Feature Selection

- Number of distinctive features = feature space = length of feature vector.
- Vector can be of length  $O(10^6)$ , and might be sparse
  - High computational cost
  - Overfitting
- What are the most important features among those?
  - e.g. Reduce  $O(10^6)$  to  $O(10^4)$
- For each class, find the top representative  $k$  features for it → get the Union over all classes → reduced feature space

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## Step 2: Feature Selection Functions

- Document frequency
  - % of docs in class  $c_i$  that contain the term  $t_k$
  - Very basic measure. Will select stop words as features
$$\#(t_k, c_i) = P(t_k | c_i)$$

- Mutual Information
  - How term  $t_k$  appear in class  $c_i$  compared to other classes
  - Highly used in feature selection in text classification

$$MI(t_k, c_i) = \sum_{c \in \{c_i, \bar{c}_i\}} \sum_{t \in \{t_k, \bar{t}_k\}} P(t, c) \cdot \log_2 \frac{P(t, c)}{P(t) \cdot P(c)}$$

- Pearson's Chi-squared ( $\chi^2$ )
  - used more in comparisons between classes

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## Step 2: Feature Selection Functions

Function	Denoted by	Mathematical form
Document frequency	$\#(t_k, c_i)$	$P(t_k c_i)$
DIA association factor	$z(t_k, c_i)$	$P(c_i t_k)$
Information gain	$IG(t_k, c_i)$	$\sum_{c \in \{c_i, \bar{c}_i\}} \sum_{t \in \{t_k, \bar{t}_k\}} P(t, c) \cdot \log \frac{P(t, c)}{P(t) \cdot P(c)}$
Mutual information	$MI(t_k, c_i)$	$\log \frac{P(t_k, c_i)}{P(t_k) \cdot P(c_i)}$
Chi-square	$\chi^2(t_k, c_i)$	$\frac{[Tr] \cdot [P(t_k, c_i) \cdot P(\bar{t}_k, \bar{c}_i) - P(t_k, \bar{c}_i) \cdot P(\bar{t}_k, c_i)]^2}{P(t_k) \cdot P(\bar{t}_k) \cdot P(c_i) \cdot P(\bar{c}_i)}$
NGL coefficient	$NGL(t_k, c_i)$	$\frac{\sqrt{[Tr] \cdot [P(t_k, c_i) \cdot P(\bar{t}_k, \bar{c}_i) - P(t_k, \bar{c}_i) \cdot P(\bar{t}_k, c_i)]}}{\sqrt{P(t_k) \cdot P(\bar{t}_k) \cdot P(c_i) \cdot P(\bar{c}_i)}}$
Relevancy score	$RS(t_k, c_i)$	$\log \frac{P(t_k c_i) + d}{P(\bar{t}_k \bar{c}_i) + d}$
Odds Ratio	$OR(t_k, c_i)$	$\frac{P(t_k c_i) \cdot (1 - P(t_k \bar{c}_i))}{(1 - P(t_k c_i)) \cdot P(t_k \bar{c}_i)}$

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## Step 2: Feature Synthesis

- **Matrix decomposition techniques** (e.g., PCA, SVD, LSA) can be used to synthesize new features that replace the features discussed above
- These techniques are based on the principles of **distributional semantics**, which states that the semantics of a word “is” the words it co-occurs with in corpora of language use
  - **Pros**: the synthetic features in the new vector representation do not suffer from problems such as polysemy and synonymy
  - **Cons**: computationally expensive
- **Word embeddings**: the new wave of distributional semantics, modern approaches are based on neural networks
- PCA: Principle component analysis
- SVD: Singular value decomposition
- LSA: latent semantic analysis

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## Step 2: Feature Synthesis

- Deep learning?
- Language modelling “features”
  - Tokenize text and pass to neural network layer
    - E.g., recurrent layer, convolutional layer, self-attention layer
  - Stack on 3+ more layers
  - Train a model to predict the next word (or a missing word) given previous words
  - Penultimate layer of network can be used to generate features for other language-based tasks
  - Basis for many state-of-the-art text classifiers
    - BERT, GPT, Electra, XLNet, etc.

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## Step 3: Feature Weighting

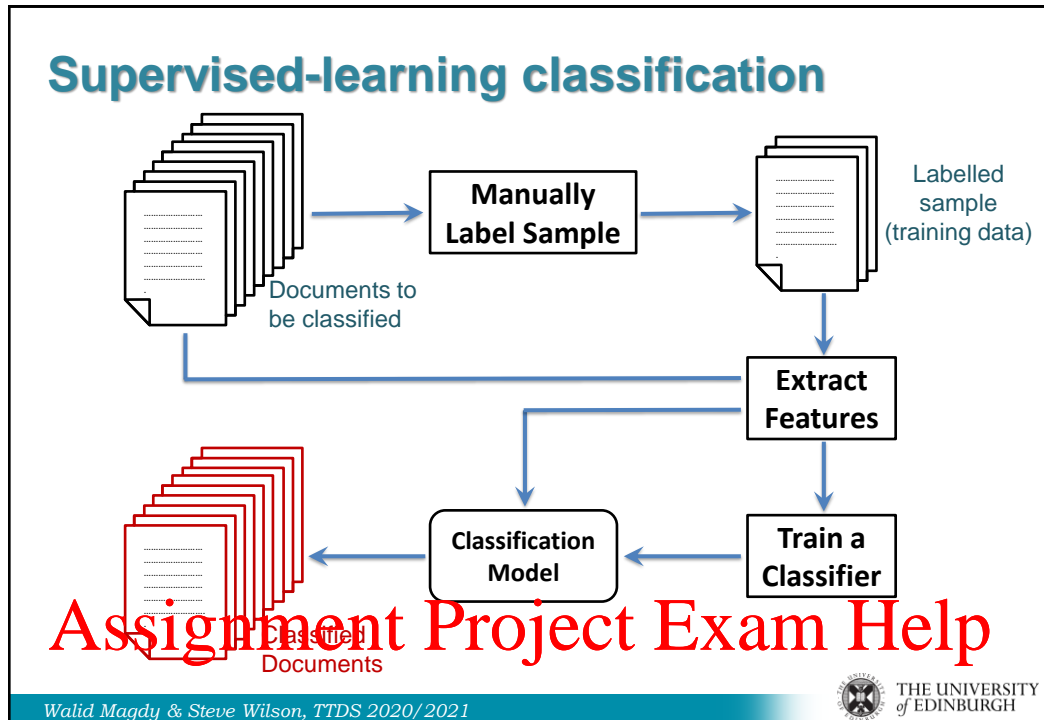
- Attributing a value to feature  $t_k$  in document  $d_i$   
This value may be
  - **binary** (representing presence/absence of  $t_k$  in  $d_i$ );
  - **numeric** (representing the importance of  $t_k$  for  $d_i$ );  
obtained via feature weighting functions in the following two classes:
    - **unsupervised**: e.g., tfidf or BM25,
    - **supervised**: e.g.,  $tf * MI$ ,  $tf * \chi^2$
- The similarity between two vectors may be computed via **cosine similarity**; if these vectors are pre-normalized, this is equivalent to computing the dot product between them

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### Training a Classifier

- For **binary** classification, essentially any supervised learning algorithm can be used for training a classifier; classical choices include
  - Support vector machines (SVMs)
  - Random forests
  - Naïve Bayesian methods
  - Lazy learning methods (e.g., k-NN)
  - Logistic Regression
  - ....
- The “**No-free-lunch principle**” (Wolpert, 1996) → *there is no learning algorithm that can outperform all others in all contexts*
- Implementations need to cater for
  - the very high dimensionality
  - the sparse nature of the representations involved

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## Training a Classifier

- For **Multiclass classification**, some learning algorithms for binary classification are “SLMC-ready”; e.g.
  - Decision trees
  - Random forests
  - Naive Bayesian methods
  - Lazy learning methods (e.g., k-NN)
  - Neural networks
- For other learners (notably: SVMs) to be used for SLMC classification, combinations / cascades of the binary versions need to be used
  - e.g. multi-class classification SVM
  - Could be directly used for MLMC as well

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## Parameter Optimisation of Classifier

- Most classifiers has some parameters to be optimized: (we will usually refer to the ones we set manually as “hyperparameters” to distinguish from the “learned” parameters/weights of the model)
  - The  $C$  parameter in soft-margin SVMs
  - The  $r, d$  parameters of non-linear kernels
  - Decision threshold for binary SVM
- Optimising the hyperparameters on test data is cheating!
- Data Split:  
Usually labelled data would be split into **three parts**
  - **Training**: used to train the classifier (typically **80%** of the data)
  - **Validation**: used to optimise hyperparameters. Apply the classifier on this data with different values of the hyperparameters and report the one that achieves the highest results (usually **10%** of the data)
  - **Test**: used to test the performance of the trained classifier with the optimal hyperparameters on these unseen data (usually **10%** of the data)

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## Cross-Validation

- Sometimes the amount of labelled data in hand is limited (e.g. 200 samples). Having evaluation of a set of 20 samples only might be misleading
- Cross-validation is used to train the classifier with all data and test on all data without being cheating
- Idea:
  - Split the labelled data into  $n$  folds
  - Train classifier on  $n-1$  fold and test on the remaining one
  - Repeat  $n$  times
- 5-fold cross validation
 

Training	Test
----------	------
- Extreme case: LOOCV

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## Evaluation

- Efficiency / Effectiveness
- Baselines
- Efficiency:
  - Speed in learning
    - SVM with linear kernel is known to be fast
    - DNNs are known to be much slower (specially with large # layers)
  - Speed in classification
    - K-NNs are known to be one of the slowest
  - Speed in feature extraction
    - BOW vs POS vs Link analysis features
- Effectiveness:
  - Global effectiveness measures
  - Per class effectiveness measures

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## Evaluation: Baselines

- There are standard methods for creating baselines in text classification to compare your classifier with
- Most popular/simplest baselines
  - Random classification
    - Classes are assigned randomly
    - How much better is the classifier doing than random?
  - Majority class baseline
    - Assign all elements to the class that appears the most
    - How much better you are doing than if you always picked the same thing output regardless of input?
  - Simple algorithm, e.g. BOW
    - Usually used when you introduce new interesting features

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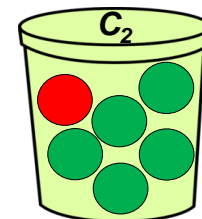
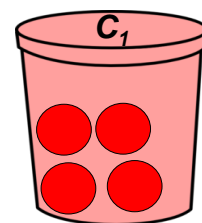
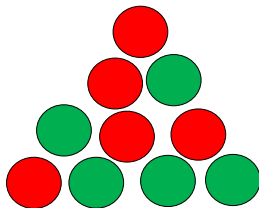
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## Evaluation: Binary Classification

- Accuracy:
  - How many of the samples are classified correctly?
- $A = 9/10 = 0.9$



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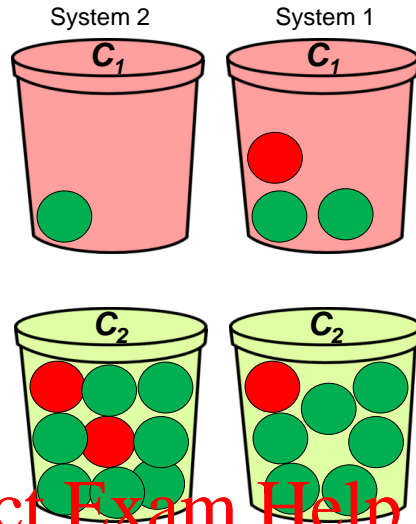
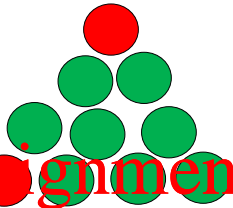


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## Evaluation: Binary Classification

- $A = 7/10 = 0.7$  System 1
- $A = 7/10 = 0.7$  System 2
- When classes are highly unbalanced
  - Precision/recall/F1 for the rare class
  - e.g. Spam classification (detection)




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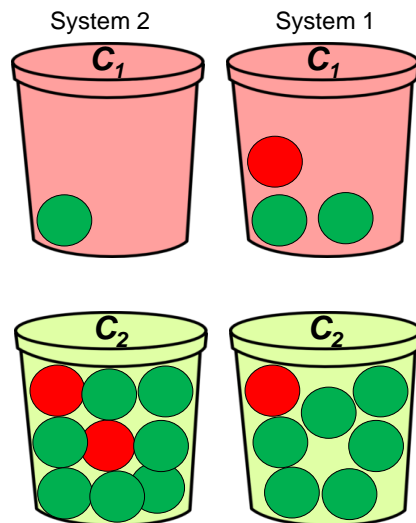
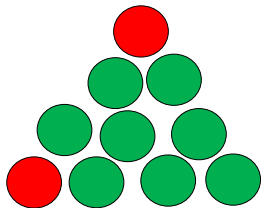


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## Evaluation: Binary Classification

	System 1	System 2
		
Precision	$1/3 = 0.33$	$0/1 = 0$
Recall	$1/2 = 0.5$	$0/2 = 0$
F1	0.4	0



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## Evaluation: Multi-class

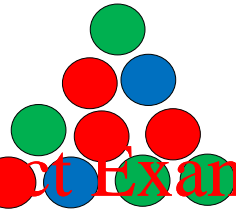
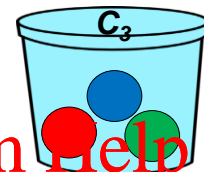
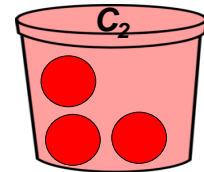
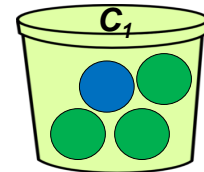
- Accuracy =  $(3+3+1)/10 = 0.7$
- Good measure when
  - Classes are nearly balanced
- Preferred:
  - Precision/recall/F1 for each class

			
P	0.75	1	0.333
R	0.75	0.75	0.5
F1	0.75	0.86	0.4

- **Macro-F1**

$$= (0.75 + 0.86 + 0.4) / 3$$

$$= 0.67$$



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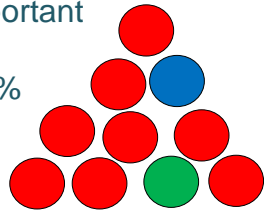
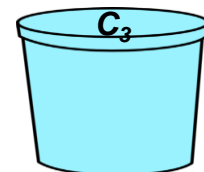
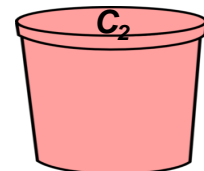
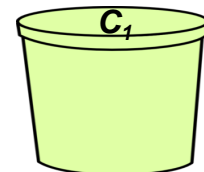
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## Evaluation: Multi-class

- Majority class baseline
- Accuracy = 0.8
- Macro-F1 = 0.296
- **Macro-F1:**
  - Should be used in binary classification when two classes are important
  - e.g.: males/females while distribution is 80/20%



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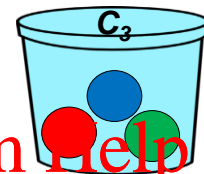
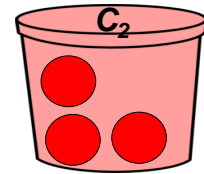
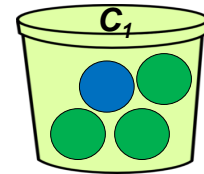
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## Error Analysis

- **Confusion Matrix**  
How classes get confused?

			
	3	0	1
	0	3	1
	1	0	1



- Useful:
  - Find classes that get confused with others
  - Develop better features to solve the problem

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## Summary

- Text Classification tasks
- Feature extraction/selection/synthesis/weighting
- Learning algorithms
- Cross-validation
- Baselines
- Evaluation measures
  - Accuracy/precision/recall/Macro-F1

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## Resources

- *Fabrizio Sebastiani*  
**Machine Learning in Automated Text Categorization**  
*ACM Computing Surveys*, 2002  
Link: <https://arxiv.org/pdf/cs/0110053>
- *Yoav Goldberg*  
**A Primer on Neural Network Models for Natural Language Processing**  
Link: <https://arxiv.org/abs/1510.00726>

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