**CS286 Solving Big Data Problems – Exam #2 Study Guide**

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**Lecture #14 – Introduction to Data Science**

**Features**

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| **Feature –** Individual, measurable property of an observation. In supervised learning, it is used for predicting the target.  **Additional Names:**   * **Predictor** * **Attribute** * **Variable**   **Vectorizing Data** – Given an observation, assign features to dimensions. | **Attribute Types**   * **Continuous** (Numeric) – **Data across a continuum**. * **Binary** – Two possible values. * **Categorical** – Finite set of possible values. * **Text** –Vocabulary or n-gram.   + **Bi-gram** – 2 consecutive words. | **Qualities of Good Features/Feature Sets**   * **Correlation** with the target (i.e. class value) * Features are **independent** * **Number of Features in Minimized** * **Number of features is much less than the number of data points**. * **Features do not leak the target** meaning they do not provide information that would not be available under normal circumstances. |

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| **Set Dimensionality**   * – Number of observations * – Number of Features   Ideally: | **Principal Component Analysis Procedure** – **Dimensionality Reduction** | |
| **Procedure**   1. **Calculate covariance matrix of the original input matrix.** 2. **Perform eigenvalue decomposition of the covariance matrix.** 3. **Look for orthogonal dimensions with the greatest variance (principal)** 4. **Project input matrix into those dimensions.**   **Relative covariance preserved across projection**. | – Representation of the total variance of the principal components.  **Number of principal components and eigenvectors equivalent to the number of dimensions in the original input matrix.**  **Since the data is mapped to new dimensions, not easy to map principal components to the original data.** |

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| **Feature Scale** | | **Target Leaks** – **Sample data has “extra” information/features not found outside the sample**. May cause the model to be unrealistically good.  **Bias**   * **Sampling Bias** – Non-representative sample * **Observer Bias** – Corrupted/invalid measurement of features * **Funding Bias** – “Fudging”/manipulating of the data.   **Simpson’s Paradox** – **Trend that appears in different groups disappears (or changes) groups are combined**. **Example**: The average of averages does not equal the average all points. |
| **Potential Issues**   * **Relative Magnitude** – **Some features may have different magnitude than others** causing those features to dominate. * **Absolute Magnitude** – When features are too large or too small, **data may be lost to overflow or underflow** respectively. | **Potential Solutions**   * **Standardization** –Transform data to measure how many standard deviations it is from the mean. * **Normalization** – Transform data such that the range is between 0 and 1. |

**Algorithms and Evaluation**

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| **Applications of Clustering**   * **Image Segmentation** * **Dendrogram (including Phylogentic Dendogram)** * **Market Segmentation** | **K-Means Clustering Algorithm**   1. **Initialize the K centroid** 2. **Assign points to the nearest centroid.** 3. **Update the centroids.** 4. **Check Stop Conditions** | **Methods for Selecting the Initial Clusters**   1. **Random** 2. **El Agha et. al. Method** 3. **All at the same point (e.g. origin)**   **Stop Condition Options**   1. **Min change of median from last iteration**. 2. Sufficiently **small intra-cluster distance** 3. Sufficiently **large intercluster distance** | **Intracluster Distance** – Distance between **points within the same cluster**. **Measures the cluster’s similarity**.  **Intercluster Distance** – **Distance between** **the centroids**. **Measures data separation between clusters.** |

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| **Naïve Bayes**   * Assumes all features are **conditionally independent.** * – A class value * – The feature. * The predicted class value is the one with the **highest Naïve Bayes probability**. | **Sensitivity/True Positive Rate**  **Specificity/True Negative Rate**  **Accuracy** | * For some domains (e.g. SPAM and cancer detection), you may use a weight function as different types of misclassification may have different costs. |

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| **K-Nearest Neighbors (KNN)**  Example Distance Metrics   * **Euclidean** * **Manhattan** * **Cosine**   **Voting Related Issues:**   * May be **problematic if class distribution is skewed**. * Cloud **use distance as a weight**. * May want to **pick an odd number for to avoid ties**. | **Types Recommendation Filtering**   * + **Item Based**   + **User Based**   **Precision** – Proportion of **top-search results that are relevant**.  **Recall** – Proportion of **relevant results that are top-scoring**. | **Underfitting** – Model is too simple for the data set.  **Overfitting** – Model is overly trained to match the training set.  **Occam’s Razor** – Most plausible explanation is the simplest one.  **Pessimistic Estimation** – Impose a penalty () in cost function based on model.   * **Smaller** – Overfitting * **Larger** – Underfitting | **Sunrise Problem**  Using existing observations the probability is one but there will be a day when it does not rise.  **Smoothing:** Use probability distributions for parameter estimates for sparse data.   * **Smaller** – Overfitting * **Larger** – Underfitting |

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| **Cross Validation**   * Leave out. * Train on the points. Use the points to estimate the out of sample error. * Repeat this process until all points have appeared in the training set exactly once. * **Example:** **Leave-1-Out**. Generate and train models. Using this approach, the error is: * **Cross validation can be repeated with different model parameters. Select the model with the lowest cross validation error.** | **-Fold Cross Validation** – Divide the training set into equally sized pieces. Example: means each testing set is size .  **Downside of Leave-One-Out** – Computationally expensive. |  |

**Lecture #15 – Introduction to Machine Learning**

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| **Machine Learning** – A **subfield of computer science** that deals with the construction and **study of systems that can learn from data rather than follow explicitly programmed instructions** | **Neuron** – A brain cell.  **Dendrite** – Appendages that stick out from a neuron.  **Axon** – Long chain that connects two neurons’ dendrites. Carries the electrical signal between two cells.  **Synapses** – Small cleft or separation between two neurons. | * **When neuron A repeatedly participates in firing neuron B, the strength of the action from A to B increases.** *Cells that fire together wire together.*   + **If they fire separately, the weight decreases.** * **Synaptic Strength** – Can be modeled as a set of weights. * **Hebbian Learning** – Changing of the weights between the neurons in the brain. | **Single Layer Perceptron (SLP) / Artificial Neuron** |

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| **Activation Function** –Defines the relation between the summed input to the perceptron and the perceptron’s output.  **Perceptron’s can be taught to recognize a binary pattern** (e.g. 0 or 1) | **Rosenblatt Perceptron Learning Algorithm**  **Step #1**: Initialize weights and perceptron thresholds (e.g. randomly).  **Step #2**: For each input () and expected/desire output (), do the following:   * + Calculate the net signal via:   + Calculate the perceptron’s output:   + Compute the error (one of the set ):   + Update the weights   **Step #3**: If stop condition met, then terminate, else repeat step #2. | **Sigmoid Activation Function**  **Benefits of the Sigmoid Function:**   * **Good approximation of the step function** * **Permits a continuous output** * **Solves noise saturation for large signals.** * **Solves noise attenuation for small signals.** * **Has a simple first order derivative.** |

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| **Sigmoid Function** | **Deficiency of the Perceptron** – Cannot solve all functions. **Example**: XOR.   * Discovered by **Minsky and Papert**.   **Perceptron Functions must be linearly separable.** | **Multilayer Perceptron** | **Multilayer Perceptron:** Developed by **Werbos**  **Two Stages: Repeat until convergence**   * **Forward Pass** – Use the inputs to **calculate the outputs and deltas for each neuron**. * **Reverse Pass** – **Adjust the weights by fractions () of the deltas**. Done via **back propagation layer to layer**.   **Multilayer perceptrons are trained to recognize patterns**. **Example**: Handwriting recognition.  **Can compute XOR.** |

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| |  |  |  | | --- | --- | --- | | **Algorithm Name** | **Year Published** | **Author** | | Decision Tree | 1986 | Quinlan | | Support Vector Machine | 1995 | Vapnik and Cortes | | Boosting | 1998 | Freund and Shapire | | Random Forest | 2001 | Breiman | | Deep Learning | 2005 | Hinton et. al | |  |

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| **Single Layer Perceptrons can learn linearly separable functions only.**  **Multilayer perceptrons can learn linearly and non-linearly separable functions.** | **Supervised learning has input-output pairs during the training phase** (i.e. labeled data).  **Unsupervised learning does not have outputs** (i.e. unlabeled data). | **Classification Problems** – Have a finite set of outputs.  **Regression Problems** – Do not have a finite set of outputs. |

**Lecture #17 – Classification**

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| **Classification** – A supervised machine learning algorithm. Distinguishes objects of one class from another. Emulates human decision making.  **Example of Classification:**   * Credit card fraud detection * Credit approval   **Example of Regression:**   * Credit card profitability. | **Feature Extractor** – Given an input object, builds/extracts the set of features.  **Machine Learning Algorithm** – Generates the classifier model.  **Classifier Model** – Given an input, predicts a class label/value. | **Feature / Predictor Attribute Types**   * **Continuous** – Decimal or floating point.   + **Example:** 0.1 * **Categorical** – Predefined, finite set of values.   + **Example:** { true, false } * **Work-like** – Large set of defined values.   + **Example:** English dictionary * **Text-Like** – Sequence of word-like objects.   + **Example:** Email message subject. |

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| **Bayes Theorem**   * **Can be used to prove the Monty Hall problem.** | **Assumptions of Naïve Bayes**   1. **Input data is labeled.** 2. **Predictors are in -dimensional space.** 3. **Target is a set of categorical values** 4. **Class C is dependent on the set of input attributes.** 5. **All features are conditionally independent.** | **Naive Bayes may not be Bayesian** since it simplifies the problem by the independence assumption.  **Bag of Words** – Transform a text input into an unordered set of words. | **Calculating Conditional Probability**   * – Number of elements of class * – Number of elements of class with attribute * – Number of classes. |

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| **Sequence of Mahout Commands**   * **mahout seqdirectory** * **mahout seq2sparse** * **mahout split** * **mahout trainnb** * **mahout testnb** |  |  |  |

**Lecture #13a – HBase**

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| **Relational Database** – A datastore that whose **type and structure is defined before storage**. Uses SQL.  **Deficiencies of Relational Databases**   * **Do not scale horizontally.** * **Sharding is difficult to manage (join and transactions do not scale across shards)** | **HBase** – A distributed database where puts and gets are accessed via a key.  **Table Splits** – Occur automatically as the table grows.  **Horizontal Partitioning** – Putting rows into different tables. HBase uses **key ranges/regions** to **define the horizontal partitions (shards)**. | **Row Key** – Used to store and access data.  **Column Family** – Used to group and store similar data (i.e. **subcolumns – column qualifiers**). Attributes of column families include:   * **Number of versions** * **Time to Live (TTL)** * **Compression** * **Key in memory or preserve to disk.**   **Column family are separated into different files** |

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| **Pros of HBase:**   * **Scalable to handle data volume and velocity.** * **Fast reads and writes by key.**   **Cons of HBase:**   * **Does not support joins** * **Good schema design is needed to achieve the best performance.** | Data is stored in a key-value model.  **Information Required to Access**  **a Single Cell Value in HBase**   * **Row Key** * **Column Family** * **Column Qualifier** (i.e. subcolumn name) * **Timestamp/Version** | **Version in HBase**   * **Each put and delete adds a new version/cell**. * Stores last 3 versions by default. * **Version** – **Stored as a long which is the current time in milliseconds** (if no specific version is specified) | **Table Physical View**   * Stored as a **sorted map**. * Ordered by **row key and column qualifier in ascending order**. * **Ordered by version/timestamp in descending order**. |

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| **Basic Table Operations**   * **Create table and defining of column families is done before data is imported.**   **Basic CRUD Operations**   * **Put** – Insert data into rows (both create and update) * **Get** – Access data from one row * **SCAN** – Access data from a range of rows * **Delete** – Delete a row or a range of rows/columns. | **Region** – Another name for a **key range**. All key **range is contiguous**.  **Region Server** – Serve data for reads from or writes to a particular region/key range.  **Write Ahead Log** (**WAL**) – Disk commit log used for recovery.   * **Primary Role:** Durability (log on disk) * Updates appended sequentially   **Block Cache** – Read cache. Uses the Least Recently Used (**LRU**) paradigm for block eviction. | **Memstore** – Write cache.   * **In memory**. * **Sorted set of key-value pairs**. Updates quickly stored since in memory. * **One memstore for each column family**.   **HFile** – Sorted key-value pairs on disk.   * Ideally one per column family.   **HBase Region Flush** – All contents of memstore flushed to an HFile on disk.   * Since Memstore is store, HFile is also sorted. | **Minor Compaction** – Merge multiple, small HFiles into fewer larger ones.  **Major Compaction** – Merge all HFiles into one large HFile with all records marked for deletion removed. |

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| **Data Model for Fast Writes and Reads**   * Layout on physical disk is predictable minimizing disk seek. * Fast access since get and put is by row key. * **Since tables are sorted, scan of a key range is fast**. | **Creation of a Key Region** – Table starts as a single range. **When a region becomes too large, it splits** into two child regions.  **Region Server** – Initiates a region split. The child/daughter regions are opened on the same server. | **HBase Use Case #1** – **High Velocity and Volume Writes.**   * **Examples:** Stock ticker, sensors, log files, system metrics. **Real time monitoring**.   **HBase Use Case #2** – Information exchange with **high volume read and write**.   * **Examples**: Email, chat, Facebook. | **HBase Use Case #3** – **High volume read.**   * Examples: Content serving, web application back end, search index, online pre-computer view, online catalog. |

**Lecture #13b – Recommendation**

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| **Input to Recommender Systems** – Interactions between users and items.  **Output of Recommender Systems** – Suggestions of additional interactions.  **Common Examples:** Movies, music, restaurant choices, sale items at stores | **Basis of Recommendation** – *Behavior of a crowd use us understand what individuals will do.*  **Popular Items** – Co-occur with everything making them not very useful for recommendation.  ***Anomalous* Co-Occurrence** – Far more useful for recommendation. **They are the source indicators of preference**. | **History Matrix** – Constructed from the log files to show the history of the users for the items.   * **Users by items**   **Co-occurrence Matrix** – Quantifies how often two items appear together.   * **Items by items**   **Indicator Matrix** – Represent anomalous (i.e. interesting) co-occurences.   * **Items by items** | **Log Likelihood Ratio (LLR)** – Can be helpful to judge with co-occurrences can be used with confidence as indicators of preference. |

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|  | **Bottom right is anomalous co-occurrence.**  Consistently appear together or separate. | **User-Based Filtering** – Recommend items by finding similar users. Harder to scale.  **Item-Based Filtering** – Calculate similarity between items and make recommendations. This can be done offline. |

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| **Dithering** – **Random re-ordering of recommendation results**. This makes for more off-line computation, but generally makes results better.   * Helps test relevancy of new items that would otherwise go unviewed. | * – Matrix of User search queries   + Matrix is by * – Gives a matrix of by   + **Query Co-occurrence Matrix**   + This enables query recommendation. * – Matrix of User video views   + **Video View Co-occurrence Matrix**   + Matrix is by * – Gives a matrix of by   + This enables recommendations in the form “*you may like these videos*.” * – **Gives query and video view co-occurrence**. ***Just like a search engine.*** |  |

**Lecture #16a – Introduction to Recommendation**

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| **Recommendation** – Class of machine learning that seeks to predict a user’s preference for or rating of an item.  **Two Main Approaches**  **for Recommendation**   * **Collaborative Filtering** * **Content-based Filtering** | **User Based Filtering** – Recommendation are based on similarity to other users.  **Item-based Filtering** – Recommendations are made based on similarity to other items. | **Similarity Metrics**   * **Pearson Correlation** – Ratio of co-variance to product of standard deviations.   + **-1** – Inversely Proportional   + **0** – No correlation   + **1** – Directly proportional * **Euclidean Distance** – Coordinates indicate item preference. Smaller distance means more similarity. | **Tanimoto Coefficient** – Ratio of intersection to union.   * + Between 0 and 1. Bigger is more similar. |

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| **Collaborative-Based Filtering** – **Deductive**. Needs user-item history to start to learn item associations.   * + **Example:** last.fm   **Content Based Filtering** – **Inductive**. Relies on domain specific know to construct association between users and items.   * + **Example:** Pandora | **Challenges of Collaborative Filtering**   * **Cold Start** – No user history means no associations on day 1. * **Scale** – Huge number of products of items and users means lots of computation. * **Sparsity** – Most users express very little behavior with very few items and no behavior with the vast majority of items. | **Neighborhood** – A group of similar users.  **Types of Neighborhoods:**   * **Fixed Size** – Cardinality (size) of the neighborhood is fixed in advance. * **Threshold-based** – Cardinality is dependent based on a threshold of similarity that is fixed in advance. | **Precision** – Proportion of top-scoring results that are relevant.  **Recall** – Proportion of relevant results that are top-scoring. |

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| **Methods for Improving Recommender Performance**   * **Change Model Type**   + User Based   + Item Based   + Content Based * **Change Distance Metric**    + Euclidean   + Tanimoto   + LogLikelihood Ratio (LLR) * **Model Parameters**   + K in KNN | **Apriori Algorithm** – Used to determine what people buy or use together.   * + Can be used for recommendation.   **KNN Algorithm** – Can be used for both classification and recommendation.  **Two Main Algorithms for Recommendation Engine**   * **Collaborative Filtering** * **Matrix Factorization** | **Fundamental Problem of Collaborative Filtering** – Finding a distance metric.  **Base Idea of Collaborative Filtering** – Like KNN. Make decisions based off similar things (e.g. items, users, etc.). (**Use collaboration from others to make recommendations**) | **ALS** – Inspired by matrix factorization but has almost nothing to do with it.   * More similar to neural networks. * Can be random or unstable, but it works fine for some cases. |