Data Mining

- The Extraction of useful information from data
- The automated extraction of hidden predictive information from (large) databases
- Business, Huge data bases, customer data, mine the data
  - Also Medical, Genetic, Astronomy, etc.
- Data sometimes unlabeled – unsupervised clustering, etc.
- Focuses on learning approaches which scale to massive amounts of data
  - and potentially to a large number of features
  - sometimes requires simpler algorithms with lower big-O complexities
Data Mining Applications

- Often seeks to give businesses a competitive advantage
- Which customers should they target
  - For advertising – more focused campaign
  - Customers they most/least want to keep
  - Most favorable business decisions
- Associations
  - Which products should/should not be on the same shelf
  - Which products should be advertised together
  - Which products should be bundled
- Information Brokers
  - Make transaction information available to others who are seeking advantages
Data Mining

Basically, a particular niche of machine learning applications

- Focused on business and other large data problems
- Focused on problems with huge amounts of data which needs to be manipulated in order to make effective inferences
- “Mine” for “gems” of actionable information
Make shorter Data warehouse slide and move next two back
Data Warehouse

- Companies have large data warehouses of transactions
  - Records of sales at a store
  - On-line shopping
  - Credit card usage
  - Phone calls made and received
  - Visits and navigation of web sites, etc…

- Many/Most things recorded these days and there is potential
  information that can be mined to gain business improvements
  - For better customer service/support and/or profits

- Data Warehouse (DWH)
  - Separate from the operational data (OLTP – Online transaction processing)
  - Data comes from heterogeneous company sources
  - Contains static records of data which can be used and manipulated for
    analysis and business purposes
  - Old data is rarely modified, and new data is continually added
  - OLAP (Online Analytical Processing) – Front end to DWH allowing basic
    data base style queries
    - Useful for data analysis and data gathering and creating the task data base
The Big Picture: DBs, DWH, OLAP & DM

Operational DBs

other sources

Extract
Transform
Load
Refresh

Data Warehouse

OLAP Server

Serve

Analysis, Query, Reports, Create Data Base for Data mining

OLAP Engine

Data Storage

Front-End Tools
Data Mining Popularity

- Recent Data Mining explosion based on:
  - Data available – Transactions recorded in data warehouses
    - From these warehouses specific databases for the goal task can be created
  - Algorithms available – Machine Learning and Statistics
    - Including special purpose Data Mining software products to make it easier for people to work through the entire data mining cycle
  - Computing power available
  - Competitiveness of modern business – need an edge
Data Mining Process Model

- You will use this basic process in your group project
  1. Identify and define the task (e.g. business problem)
  2. Gather and Prepare the Data
     - Build Data Base for the task
     - Select/Transform/Derive features
     - Analyze and Clean the Data
  3. Build and Evaluate the Model(s) – Using training and test data
  4. Deploy the Model(s) and Evaluate business related Results
     - Data visualization tools
  5. Iterate through this process to gain continual improvements
     - both initially and during life of task
     - Improve/adjust features and/or machine learning approach
Data Mining Process Model - Cycle

Monitor, Evaluate, and update deployment
Data Science and Big Data

- Interdisciplinary field about scientific methods, processes and systems to extract knowledge or insights from data
  - Machine Learning
  - Statistics/Math
  - CS/Database/Algorithms
  - Visualization
  - Parallel Processing
  - Etc.

- Increasing demand in industry!
Group Projects

- Review timing and expectations
  - Progress Report
  - Time purposely available between Decision Tree and Instance Based projects to keep going on the group project
    - Gathering, Cleaning, Transforming the Data can be the most critical part of the project, so get that going early!!
    - Then plenty of time to try some different ML models and some iterations on your Features/ML approaches to get improvements
  - Final report and presentation
- Questions?
Association Analysis – Link Analysis

- Used to discover relationships in large databases
- Relationships represented as *association rules*
  - Unsupervised learning, any data set
- One example is *market basket analysis* which seeks to understand more about what items are bought together
  - This can then lead to improved approaches for advertising, product placement, etc.
  - Example Association Rule: \{Cereal\} \Rightarrow \{Milk\}

<table>
<thead>
<tr>
<th>Transaction ID and Info</th>
<th>Items Bought</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and (who, when, etc.)</td>
<td>{Ice cream, milk, eggs, cereal}</td>
</tr>
<tr>
<td>2</td>
<td>{Ice cream}</td>
</tr>
<tr>
<td>3</td>
<td>{milk, cereal, sugar}</td>
</tr>
<tr>
<td>4</td>
<td>{eggs, yogurt, sugar}</td>
</tr>
<tr>
<td>5</td>
<td>{Ice cream, milk, cereal}</td>
</tr>
</tbody>
</table>
Association Discovery

- Association rules are not causal, show correlations
- $k$-itemset is a subset of the possible items – \{Milk, Eggs\} is a 2-itemset
- Which itemsets does transaction 3 contain
- Association Analysis/Discovery seeks to find frequent itemsets

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Association Rule Quality

- \( t \in T \), the set of all transactions, and \( X \) and \( Y \) are itemsets
- Rule quality measured by support and confidence
  - Without sufficient support (frequency), rule will probably overfit, and also of little interest, since it is rare
  - Note \( \text{support}(X \Rightarrow Y) = \text{support}(Y \Rightarrow X) = \text{support}(X \cup Y) \)
    - Note that \( \text{support}(X \cup Y) \) is support for itemsets where both \( X \) and \( Y \) occur
  - Confidence measures reliability of the inference (to what extent does \( X \) imply \( Y \))
  - \( \text{confidence}(X \Rightarrow Y) \neq \text{confidence}(Y \Rightarrow X) \)
  - Support and confidence range between 0 and 1
  - Lift: Lift is high when \( X \Rightarrow Y \) has high confidence and the consequent \( Y \) is less common. Thus lift suggests ability for \( X \) to infer a less common value with good probability

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Association Rule Discovery Defined

- User supplies two thresholds
  - \textit{minsup} (Minimum required support level for a rule)
  - \textit{minconf} (Minimum required confidence level for a rule)

- Association Rule Discovery: Given a set of transactions \( T \), find all rules having support \( \geq \text{minsup} \) and confidence \( \geq \text{minconf} \)

- How do you find the rules?
- Could simply try every possible rule and just keep those that pass
  - Number of candidate rules is exponential in the size of the number of items

- Standard Approaches - Apriori
  - 1\textsuperscript{st} find frequent itemsets (Frequent itemset generation)
  - Then return rules within those frequent itemsets that have sufficient confidence (Rule generation)
    - Both steps have an exponential number of combinations to consider
    - Number of itemsets exponential in number of items \( m \) (power set: \( 2^m \))
    - Number of rules per itemset exponential in number of items in itemset \( (n!) \)
Apriori Algorithm

- The support for the rule $X \Rightarrow Y$ is the same as the support of the itemset $X \cup Y$
  - Assume $X = \{\text{milk, eggs}\}$ and $Y = \{\text{cereal}\}$. $C = X \cup Y$
  - All the possible rule combinations of itemset $C$ have the same support
    (# of possible rules exponential in width of itemset: $|C|!$)
      - $\{\text{milk, eggs}\} \Rightarrow \{\text{cereal}\}$
      - $\{\text{milk}\} \Rightarrow \{\text{cereal, eggs}\}$
      - $\{\text{eggs}\} \Rightarrow \{\text{milk, cereal}\}$
      - $\{\text{milk, cereal}\} \Rightarrow \{\text{eggs}\}$
      - $\{\text{cereal, eggs}\} \Rightarrow \{\text{milk}\}$
      - $\{\text{cereal}\} \Rightarrow \{\text{milk, eggs}\}$

- Do they have the same confidence?
- So rather than find common rules we can first just find all itemsets with support $\geq \text{minsup}$
  - These are called frequent itemsets
  - After that we can find which rules within the common itemsets have sufficient confidence to be kept
Support-based Pruning

- **Apriori Principle**: If an itemset is frequent, then all subsets of that itemset will be frequent
  - Note that subset refers to the items in the itemset
- If an itemset is not frequent, then any superset of that itemset will also not be frequent

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**Figure 6.3.** An illustration of the *Apriori* principle. If \( \{c, d, e\} \) is frequent, then all subsets of this itemset are frequent.

**Figure 6.4.** An illustration of support-based pruning. If \( \{a, b\} \) is infrequent, then all supersets of \( \{a, b\} \) are infrequent.
Example transaction DB with 5 items and 10 transactions

- Minsup = 30%, at least 3 transaction must contain the itemset
- For each itemset at the current level of the tree (depth $k$) go through each of the $n$ transactions and update tree itemset counts accordingly
- All 1-itemsets are kept since all have support $\geq 30\%$
Generate level 2 of the tree (all possible 2-itemsets)

- Normally use lexical ordering in itemsets to generate/count candidates more efficiently
  - (a,b), (a,c), (a,d), (a,e), (b,c), (b,d), ..., (d,e)
  - When looping through \( n \) transactions for (a,b), can stop if \( a \) not first in the set, etc.

Number of tree nodes will grow exponentially if not pruned

Which ones can we prune assuming \( \text{minsup} = .3 \)?
- Generate level 2 of the tree (all possible 2-itemsets)
- Use lexical ordering in itemsets to generate/count candidates more efficiently
  - (a,b), (a,c), (a,d), (a,e), (b,c), (b,d), ..., (d,e)
  - When looping through $n$ transactions for (a,b), can stop if a not first in the set, etc.
- Number of tree nodes will grow exponentially if not pruned
- Which ones can we prune assuming minsup = .3?
Generate level 3 of the tree (all 3-itemsets with frequent parents)

Before calculating the counts, check to see if any of these newly generated 3-itemsets, contain an infrequent 2-itemset. If so we can prune it before we count since it must be infrequent

- A $k$-itemset contains $k$ subsets of size $k-1$
- It's parent in the tree is only one of those subsets
- Are there any candidates we can delete?
Apriori: Breadth First Search

1: \( \{a, d, e\} \)
2: \( \{b, c, d\} \)
3: \( \{a, c, e\} \)
4: \( \{a, c, d, e\} \)
5: \( \{a, e\} \)
6: \( \{a, c, d\} \)
7: \( \{b, c\} \)
8: \( \{a, c, d, e\} \)
9: \( \{c, b, e\} \)
10: \( \{a, d, e\} \)

- The item sets \( \{b, c, d\} \) and \( \{b, c, e\} \) can be pruned, because
  - \( \{b, c, d\} \) contains the infrequent item set \( \{b, d\} \) and
  - \( \{b, c, e\} \) contains the infrequent item set \( \{b, e\} \).
**Apriori: Breadth First Search**

1: \{a, d, e\}
2: \{b, c, d\}
3: \{a, c, e\}
4: \{a, c, d, e\}
5: \{a, e\}
6: \{a, c, d\}
7: \{b, c\}
8: \{a, c, d, e\}
9: \{c, b, e\}
10: \{a, d, e\}

- Only the remaining four item sets of size 3 are evaluated.
Apriori: Breadth First Search

1: \{a, d, e\}
2: \{b, c, d\}
3: \{a, c, e\}
4: \{a, c, d, e\}
5: \{a, e\}
6: \{a, c, d\}
7: \{b, c\}
8: \{a, c, d, e\}
9: \{c, b, e\}
10: \{a, d, e\}

- Minimum support: 30%, i.e., at least 3 transactions must contain the item set.
- Infrequent item set: \{c, d, e\}.
Apriori: Breadth First Search

1: \{a, d, e\}
2: \{b, c, d\}
3: \{a, c, e\}
4: \{a, c, d, e\}
5: \{a, e\}
6: \{a, c, d\}
7: \{b, c\}
8: \{a, c, d, e\}
9: \{c, b, e\}
10: \{a, d, e\}

- Generate candidate item sets with 4 items (parents must be frequent).
- Before counting, check whether the candidates contain an infrequent item set.
Frequent itemsets are: \{a, c\}, \{a, c, d\}, \{a, c, e\}, \{a, d\}, \{a, d, e\}, \{a, e\}, \{b, c\}, \{c, d\}, \{c, e\}, \{d, e\}

- The item set \{a, c, d, e\} can be pruned, because it contains the infrequent item set \{c, d, e\}.
- Consequence: No candidate item sets with four items.
- Fourth access to the transaction database is not necessary.
Rule Generation

- Frequent itemsets were: \{a,c\}, \{a,c,d\}, \{a,c,e\}, \{a,d\}, \{a,d,e\}, \{a,e\}, \{b,c\}, \{c,d\}, \{c,e\}, \{d,e\}

- For each frequent itemset generate the possible rules and keep those with confidence $\geq$ minconf

- First itemset \{a,c\} gives possible rules
  - \{a\} $\Rightarrow$ \{c\} with confidence 4/7 and
  - \{c\} $\Rightarrow$ \{a\} with confidence 4/7

- Second itemset \{a,c,d\} leads to six possible rules

- Just as with frequent itemset generation, we can use pruning and smart lexical ordering to make rule generation more efficient
  - Project? – Search pruning tricks (312) vs ML
Illustrative Training Set
Would if we had real valued data?
What are steps for this example?

Risk Assessment for Loan Applications

<table>
<thead>
<tr>
<th>Client #</th>
<th>Credit History</th>
<th>Debt Level</th>
<th>Collateral</th>
<th>Income Level</th>
<th>RISK LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bad</td>
<td>High</td>
<td>None</td>
<td>Low</td>
<td>HIGH</td>
</tr>
<tr>
<td>2</td>
<td>Unknown</td>
<td>High</td>
<td>None</td>
<td>Medium</td>
<td>HIGH</td>
</tr>
<tr>
<td>3</td>
<td>Unknown</td>
<td>Low</td>
<td>None</td>
<td>Medium</td>
<td>MODERATE</td>
</tr>
<tr>
<td>4</td>
<td>Unknown</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
<td>HIGH</td>
</tr>
<tr>
<td>5</td>
<td>Unknown</td>
<td>Low</td>
<td>None</td>
<td>High</td>
<td>LOW</td>
</tr>
<tr>
<td>6</td>
<td>Unknown</td>
<td>Low</td>
<td>Adequate</td>
<td>High</td>
<td>LOW</td>
</tr>
<tr>
<td>7</td>
<td>Bad</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
<td>HIGH</td>
</tr>
<tr>
<td>8</td>
<td>Bad</td>
<td>Low</td>
<td>Adequate</td>
<td>High</td>
<td>MODERATE</td>
</tr>
<tr>
<td>9</td>
<td>Good</td>
<td>Low</td>
<td>None</td>
<td>High</td>
<td>LOW</td>
</tr>
<tr>
<td>10</td>
<td>Good</td>
<td>High</td>
<td>Adequate</td>
<td>High</td>
<td>LOW</td>
</tr>
<tr>
<td>11</td>
<td>Good</td>
<td>High</td>
<td>None</td>
<td>Low</td>
<td>HIGH</td>
</tr>
<tr>
<td>12</td>
<td>Good</td>
<td>High</td>
<td>None</td>
<td>Medium</td>
<td>MODERATE</td>
</tr>
<tr>
<td>13</td>
<td>Good</td>
<td>High</td>
<td>None</td>
<td>High</td>
<td>LOW</td>
</tr>
<tr>
<td>14</td>
<td>Bad</td>
<td>High</td>
<td>None</td>
<td>Medium</td>
<td>HIGH</td>
</tr>
</tbody>
</table>
Running Apriori (I)

Choose \textit{MinSupport} = .4 and \textit{MinConfidence} = .8

1-Itemsets (Level 1):
- (CH=Bad, .29) (CH=Unknown, .36) (CH=Good, .36)
- (DL=Low, .5) (DL=High, .5)
- (C=None, .79) (C=Adequate, .21)
- (IL=Low, .29) (IL=Medium, .29) (IL=High, .43)
- (RL=High, .43) (RL=Moderate, .21) (RL=Low, .36)
Running Apriori (II)

1-Itemsets = \{(DL=Low, .5); (DL=High, .5); (C=None, .79); (IL=High, .43); (RL=High, .43)\}

2-Itemsets = \{(DL=High + C=None, .43)\}

3-Itemsets = {} 

Two possible rules:

- DL=High ⇒ C=None
- C=None ⇒ DL=High

Confidences:

- Conf(DL=High ⇒ C=None) = .86 Retain
- Conf(C=None ⇒ DL=High) = .54 Ignore
Summary

- Association Analysis useful in many real world tasks
  - Not a classification approach, but a way to understand relationships in data and use this knowledge to advantage
- Also standard classification and other approaches
- Data Mining continues to grow as a field
  - Data and features issues
    - Gathering, Selection and Transformation, Preparation, Cleaning, Storing
  - Data visualization and understanding
  - Outlier detection and handling
  - Time series prediction
  - Web mining
  - etc.