Data Warehousing for Social Network and Human Mobility Research and Detecting Real-World Events in Space and Time Using Feature Clustering

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Overview

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2. Background on Database Management Systems and Data Warehousing
3. Designing a Data Warehouse for Social Network and Human Mobility Research
4. Approach for Merging Noisy Data in a Scientific Data Warehouse
5. Background on Data Clustering
6. Online Cluster Analysis of Spatially Partitioned Phone Usage Data
7. Feature Clustering for Data Steering in Dynamic Data Driven Application Systems
8. Summary
Overview: Dynamic Data Driven Application Systems

Utilize simulations and models that can

▶ Incorporate newly available data online, and

▶ Steer the data collection mechanism to obtain the most useful data

Areas of application:

▶ Population movement forecasting (Schoenharl and Madey 2008)

▶ Forecasting the spread of fire: wildfire (Mendel et al., 2007), in buildings (Chaturvedi, et al., 2005)

▶ Weather (Ramakrishnan et al., 2007), hurricane (Allen, 2007) forecasting

▶ and many others.

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Overview: Wireless Phone Based Emergency Response System
Overview: Road Map

In this presentation, we will cover two aspects of the WIPER system:

- **The Historical Data Source**
  - Data partitioning aspect of the warehouse design.
  - Issues arising from the data merge.
- **Detection and Alert System**
  - Feature clustering approach for event detection.
A Data Warehouse for Social Network and Human Mobility Research
Overview: Data Warehousing

Data warehouses store long term historical data organized in such a way that it can be effectively used for analysis (traditionally decision support in a business environment).

- Data residing in a warehouse are often from different sources (departments).
- The warehouse is non-volatile: once loaded, the data are not updated.
Overview: The Phone Data

Two major components:

- **Usage data**
  - Call data: billing records of service usage initiated by customers of the company.
  - Interconnect data: billing records of service usage initiated by users that are not customers of the company and received by customers of the company.
  - Call Record Data (CDR): usage records with tower information. Four types of records:
    - MOC: record for a voice call from the originating tower
    - MTC: record for a voice call from the terminating tower
    - SOM: record for an SMS from the originating tower
    - STM: record for an SMS from the terminating tower

- **Customer data**
  - Defines the set of “in-company” users.
  - Users that are not in the customer data are “out-of-company”.

Motivation

Data used for:

- Development of the Simulation and Prediction and Detection and Alert Systems of WIPER.
- Social network and human mobility research.

Problems:

- Large (5 TB) set of flat files.
- Inefficient de-identification mechanism (phone numbers replaced by strings).
- Data preparation is time consuming, error prone, and often redundant.

Goal: Develop a repository that allows efficient extraction of relevant subsets of the data.
Gray *et al.*, 2005. Advocate for the use of database management systems instead of file formats traditionally used in scientific research.

Examples of scientific databases:
- **Bioinformatics**: INTERACT (Eilbeck, *et al.*, 1999)
- **Astronomy**: Sloan Digital Sky Survey (O’Mullane, *et al.*, 2005)
- **High Energy Physics**: BaBar (CERN) (Becla and Wang, 2005)
Design considerations: (Inmon, 2005)

- **Granularity**: Level of detail.
- **Partitioning**: Divide the data into manageable chunks.
Data Partitioning

Guided by the way in which the data has been historically used: groups of greatest interest are voice calls and “in-company” users.

Data Partitioning

1

2

3

4

5

...
Introduction of Duplicates by Merge

Intercall time for MOC records

Intercall time for MTC records

Merged intercall time

Merged intercall time (log-log)
Consider only records that haven't been matched (initially records with a value in exactly one of the two antenna fields).

Add perturbation to the start time of records having a value in only the terminating antenna field and attempt to match with records having a value in only the originating antenna field.

- Sequence of perturbation: $+1, -1, +2, -2, \cdots +60, -60$.

Fields matched at each step are removed from consideration:

- Match records with smallest possible perturbation.
- Match each record only once.
Results

Intercall time for MOC records

Intercall time for MTC records

Merged intercall time

Merged intercall time (corrected)
Results
Consequences

- In many cases, these duplicates can be ignored, e.g.
  - Building graphs with edges weighted by total duration or cost (Onnela et al, 2007).
  - Generating user trajectories (González et al, 2008).
- Can be problematic when generating time series of call activity.
Summary

- Data warehouse contains 14 months of data.
- Data loading process in highly automated:
  - Two scripts: customer and usage data
  - Each script:
    - validates fields
    - loads the initial tables
    - replaces user strings with integers
    - integrates the various record types
    - usage script partitions the records
- Data extract from the warehouse is in use for a social network study
  - Comparable data extraction from text files takes weeks: code is written to identify relevant users, replace user ID strings, filter data.
  - One year of data can be extracted in one day using a single SQL query.
Detecting Real-World Events in Space and Time Using Feature Clustering
Data Clustering Model

Detection and Alert System

Upon event detection, initiate simulations for a particular area.

Simulation and Prediction System
Key Observation: Certain Events Cause Localized Changes in Call Activity
Clustering

Let $D$ be an $n \times m$ matrix:
- $n$ is the number of observations
- $m$ is the number of features per observation
- In this case, features are the call activity at each spatial area (postal code, tower). Data item is recorded every 10 minutes.

Goal: partition the $n$ rows $D$ into a natural grouping.
- Minimize intra-cluster distance.
- Maximize inter-cluster distance.

We want to cluster the time series, so we transpose $D$ before clustering; this is called feature clustering.
Related Work

  - Correlation dissimilarity: sufficient statistics require quadratic space with respect to the number of features.
- Aggarwal et al. (2003).
  - If entire history is used, stale data dominates results.
Approach

Dataset:
- Aggregate records based on spatial area: postal code or tower.
- Time series: number of calls in 10 minute intervals for each spatial area.

Clustering:
- Single link clustering over a 1 day sliding window.

Event Detection:
- Outliers are detected by examining maximum distance between clusters.
- Baseline is computed using the maximum distance between clusters over the 2 months of data.

Two events:
- An explosion.
- Celebration following a sports victory.
Results: Bombing

Figure: The maximum distance between clusters for a 12 hour window around the bombing with the mean and ± 1 standard deviation over 2 months. The bombing occurs between time = 0 and time = 0.5 (conflicting news reports)
Results: Bombing

Cluster Dendrogram at Time = 0

Cluster Dendrogram at Time = 1

Cluster Dendrogram at Time = 2
Results: Celebration

Figure: The maximum distance between clusters for a 12 hour window around the celebration with the mean and ± 1 standard deviation over 2 months. Important events are: at approximately time −1 the sporting event ends, at time = 0, the crowd has gathered to meet the team, and at approximately time = 1 the team leaves the celebration.
Results: Celebration

Cluster Dendrogram at Time = -1

Cluster Dendrogram at Time = 0

Cluster Dendrogram at Time = 1
In cases where events cause localized changes in call activity, we can use feature clustering to detect the events and their approximate location.

This achieves our goals of automating event detection and constraining the area that must be simulated by the Simulation and Prediction System.
Summary
Summary of Research

Two components:

- Historical Data Source. Data repository for:
  - development of WIPER system components
  - social network and human mobility research
- Feature clustering algorithm for event detection
  - In cases where event causes a localized change in call activity, the event and it’s approximate location can be identified.
First Author Publications


First Author Publications


Publication Plan

- Data warehouse implementation (Chapters 3, 4): Planned submission to the International Journal of Data Warehousing and Mining, pending revision.

- Feature clustering approach for event detection (Chapter 7): Planned submission to IEEE Transactions on Pattern Analysis and Machine Intelligence, pending revision.
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