Statistics, Pattern Recognition, and Astrophysics

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October 14, 1998

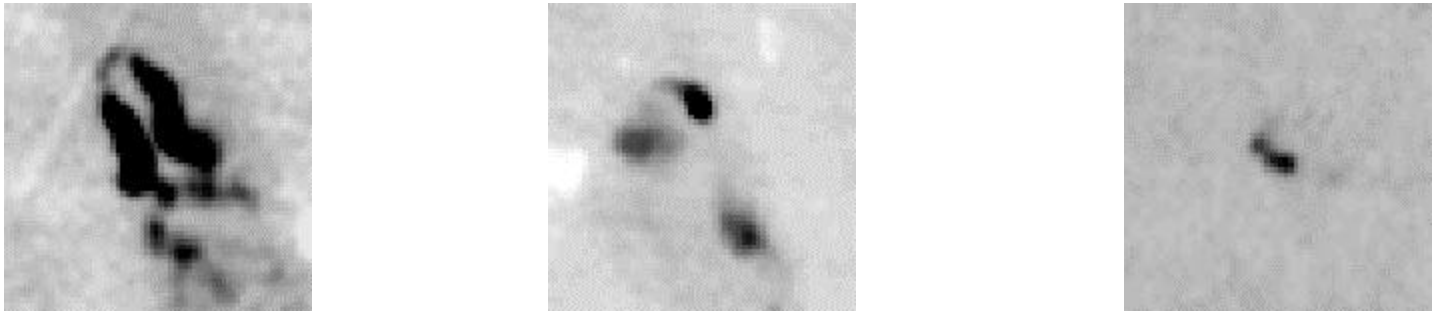
We need an effective way to deal with data overload

- Widening gap between data collection capabilities and data analysis abilities
  - Data from simulations, experiments, observations
  - Terabytes of data, soon to be petabytes
  - Complex data (images, time series data)
- Manual exploration and analysis is impractical
  - Poor utilization of resources
  - Potential loss of information

➡ Need computational tools and techniques to automate the exploration and analysis of large, complex data sets

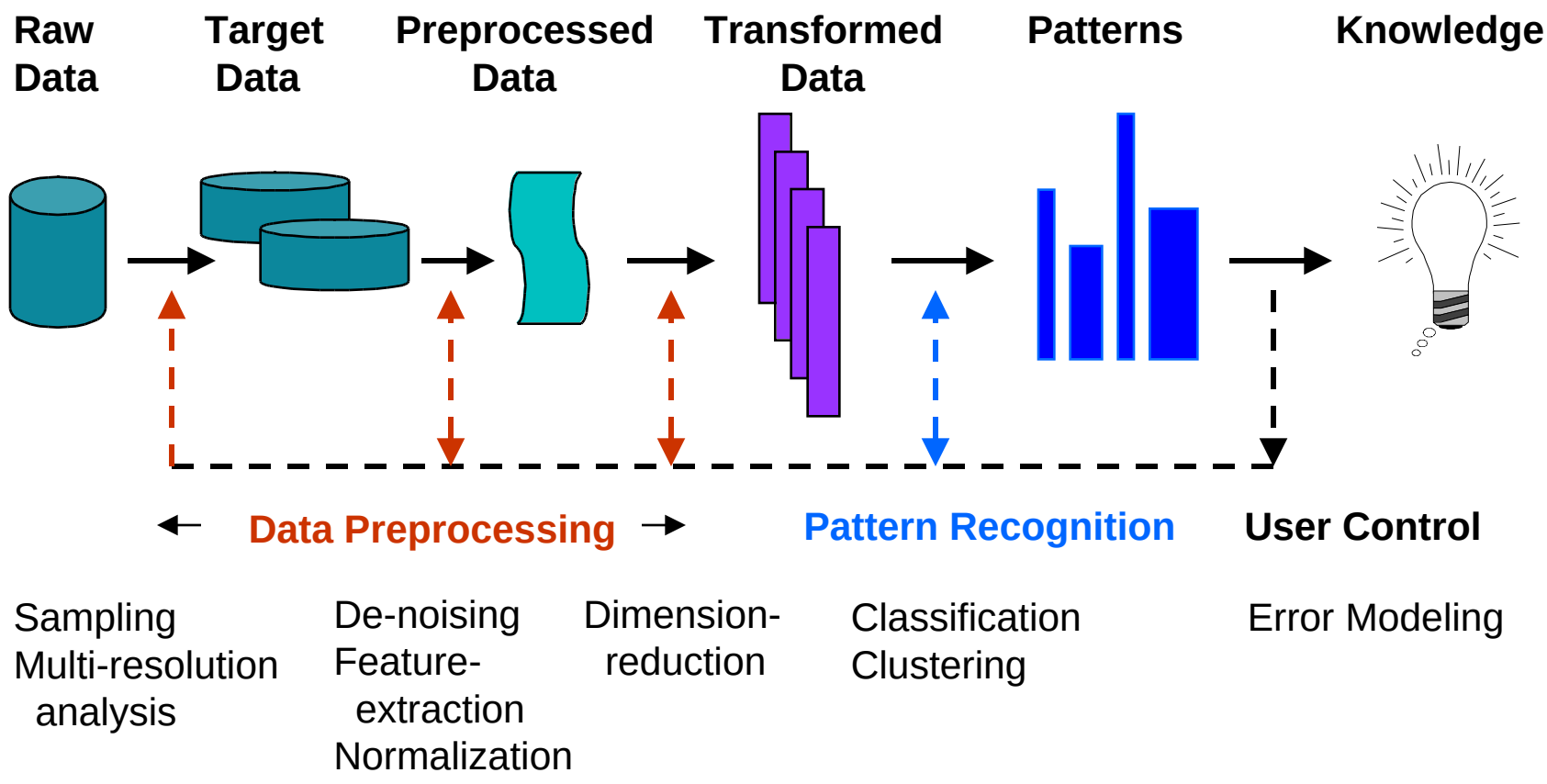
What do we mean by the terms Data Mining and Pattern Recognition?

- **Data Mining**: Uncovering patterns, associations, anomalies, and statistically significant structures in data
- **Pattern Recognition**: Characterization of patterns in data
- **Pattern**: Arrangement or ordering with an underlying structure
- **Feature**: An extractable measurement or attribute



Images of Radio Emitting Galaxies with Bent-Double Morphology

Data Mining: Key steps in an iterative and interactive process

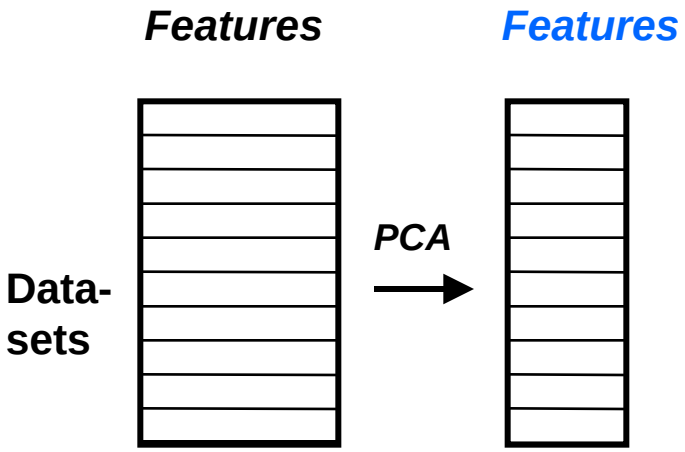


Our research plan for scaling data mining to large and complex data sets

- **Data pre-processing**
  - Implement effective image processing algorithms
  - Investigate the use of multi-resolution analysis
  - Research methods for dimension reduction
- **Pattern recognition algorithms**
  - Consider different algorithms for an application
  - Implement in an object-oriented framework
  - Research ways of making them more effective and efficient
  - Examine accuracy versus computational effort issues
- **Parallel implementation**

Data pre-processing: a time-consuming but critical first step

- **Extraction of features**: image processing and wavelets
  - De-noising
  - Multi-resolution analysis
- **Dimension reduction**: identification of key features
  - Features with greatest variance
  - Principal component analysis

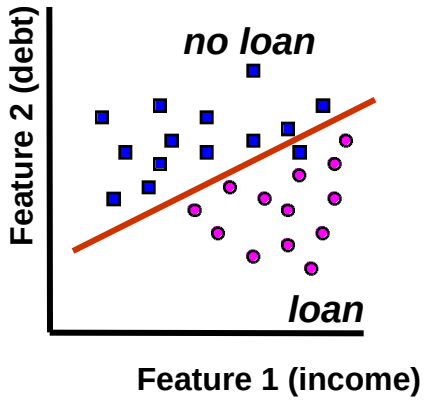


$$A = U\Sigma V^T$$

Pattern Recognition: need for scalable classification and clustering algorithms

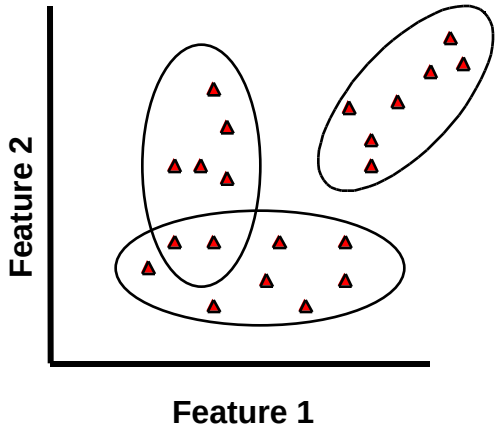
Classification: learn a function to map a data item into one of several predefined classes

- Neural networks
  - Genetic algorithms
  - Simulated annealing



Clustering: a task that identifies a finite set of clusters to describe the data

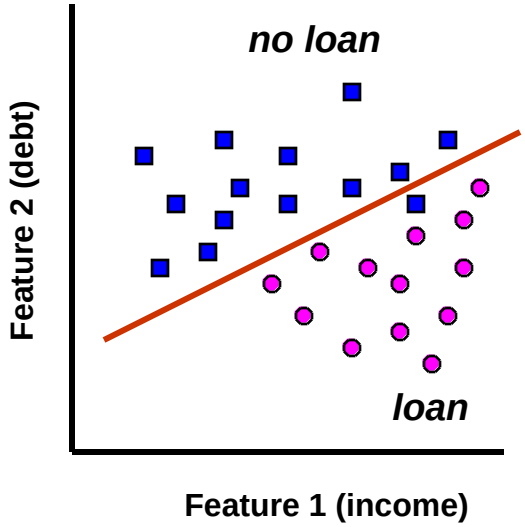
- Graph theoretic techniques
  - Hypergraph partitioning
  - Promising for high dimensional data



Pattern Recognition: need for efficient, accurate, and scalable classifiers

Classification: learning a function that maps a data item into one of several pre-defined classes

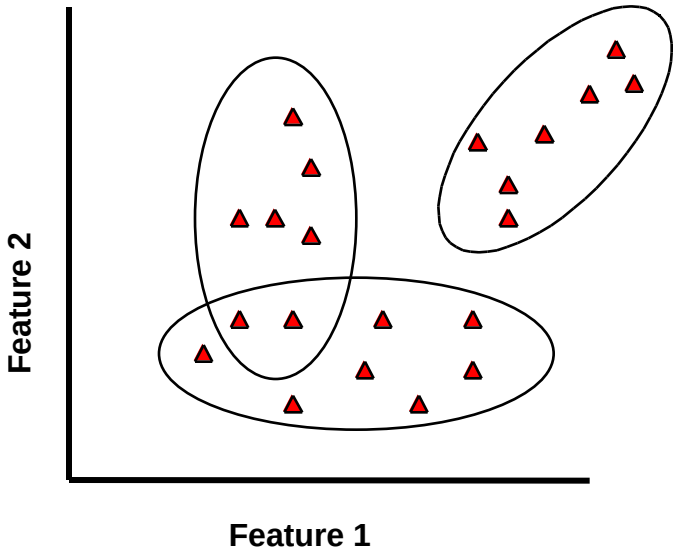
- Neural networks: avoid local minima
  - Genetic algorithms
  - Simulated annealing
- Decision trees
  - attribute selection
  - tree pruning
- Hybrid algorithms
  - techniques for combining classifiers



Pattern Recognition: need for scalable and interpretable clustering algorithms

Clustering: a descriptive task that seeks to identify a finite set of clusters to describe the data

- Implement known techniques
  - k-means
  - fuzzy k-means
  - k-nearest-neighbors
- Graph theoretic techniques
  - hypergraph partitioning
  - initial promise for high dimensional data



Applied statistics plays an important role in large-scale data mining

- Sampling
- Knowledge discovery and existence of low probability classes
- Principal component analysis
  - number of principal components
  - dynamic updating
  - non-linear techniques
- Error modeling
  - how do errors in data affect the interpretations drawn from it?
  - can the user control the accuracy of the results?

Large-scale pattern recognition can benefit several applications

- Visualization
- Computational steering
- Computer Security
- Verification and validation
- Global climate modeling
- Astrophysics (MACHO and FIRST)
- ...

➡ **A capability for large-scale pattern recognition will strengthen our ability to perform science by providing an effective way to cope with data overload.**

Sapphire: a multi-disciplinary endeavor

- Core Team (CASC)
  - C. Kamath (PI), C. Baldwin, R. Musick
- Collaborators
  - C. Alcock (IGPP), M. Aufderheide (B Division), R. Becker (UC Davis/LLNL)
- Faculty and students
  - G. Bebis, M. Giamporcaro, R. Karchin, I. Kirby

➡ For more information

http://www.llnl.gov/CASC/sapphire

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UCRL-MI-132093: This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48