Chapter I: Introduction

Knowledge Discovery in Databases

Luciano Melodia M.A.
Evolutionary Data Management, Friedrich-Alexander University Erlangen-Nürnberg
Summer semester 2021

Chapter I: Introduction

This is our agenda for this lecture:

- **Why data mining?**
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

Why data mining?

The explosive growth of data: from terabytes to petabytes and more.

- Data collection and availability:
  - Automated data collection tools.
  - Database systems.
  - World wide web.
  - Computerized society.
  - Digitization.
- Major sources of abundant data:
  - Business: web, e-commerce, transactions, stocks ...
  - Science: remote sensing, bioinformatics, scientific simulation ...
  - Society: news, digital cameras, social media ...
- The era of **big data** (as inflationary used buzzword).

We are drowning in data, but starving for knowledge. Necessity is the mother of invention.
For data mining it is the automated analysis of massive data sets.

Evolution of sciences I

- Before 1600, era of **empirical science**.
- 1600 — 1950s, rise of **theoretical science**.
  - Each discipline has grown a theoretical component.
  - Theoretical models often motivate experiments and generalize our understanding.
- 1950 — 1990s, rise of **computational science**.
  - Over the last 50 years most disciplines have grown a third, computational branch.
    - E.g. empirical, theoretical and computational ecology.
    - E.g. physics, linguistics or biology.
- Computational science traditionally meant simulation.
- It grew out of our inability to describe reality by closed-form mathematical models.

Evolution of sciences II

- 1990—now, rise of **data science**.
  - The flood of data from new instruments and modern simulations.
  - The ability to economically store and manage petabytes of data.
  - The internet makes all these archives world wide accessible.
  - Scientific *information management*,
    acquisition,
    organization,
    query and
    visualization scale almost linearly with amount of data.
  - **Data mining** is a major new challenge!
- For further reading:
  Jim Gray and Alex Szaly: *The World Wide Telescope: An Archetype for Online Science*,
  Communications of the ACM 45(11): 50-54, 2002.

Evolution of sciences III

- 1960s: Data collection,
  database creation,
  integrated management systems (IMS) and
  network database management systems (DBMS).
- 1970s: Relational data model, relational DBMS implementation (RDBMS).
- 1980s: RDBMS products,
  database creation,
  advanced data models (extended relational, object oriented, deductive etc.),
  application-oriented DBMS (spatial, scientific, engineering etc.).
- 1990s: Data mining,
  data warehousing,
  multimedia databases,
  web databases.
- 2000s: Stream data management and mining,
  data mining and applications,
  web technology (XML, data integration) and global information systems.

Chapter I: What is data mining?

- Why data mining?
- **What is data mining?**
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

What is data mining?

Data mining or knowledge discovery from data:

- Extraction of interesting (**non-trivial, implicit, previously unknown and potentially useful**) patterns from huge amounts of data.
- Is **data mining** a misnomer?

Alternative names:

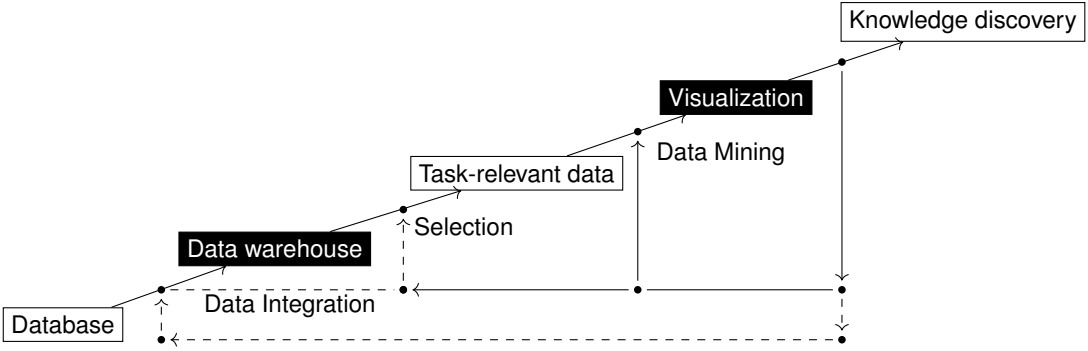
- Knowledge discovery/mining in databases (KDD).
- Knowledge extraction.
- Data/pattern analysis.
- Data archeology.
- Data dredging.
- Information harvesting.
- Business intelligence.

Watch out: Is everything **data mining**?

- Simple search and query processing is considered not to be.
- Neither are deductive expert systems.

Knowledge discovery pipeline

- This is a typical view from a typical database-systems and data-warehousing community.
- Data mining plays an essential role in the knowledge-discovery process.



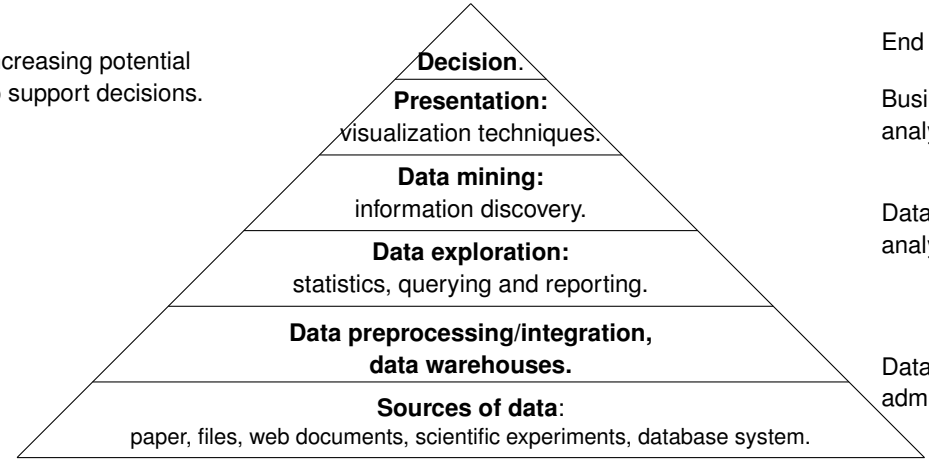
Example: a web-mining framework

Web mining usually involves:

- Data cleaning.
- Data integration from multiple sources.
- Warehousing the data.
- Data-cube construction.
- Data selection for data mining.
- Data mining.
- Presentation of the mining results.
- Patterns and knowledge to be used or stored in a knowledge base.

Data mining in business

Increasing potential
to support decisions.



End user.

Business
analyst.

Data
analyst.

Database
administration.

Example: mining vs. data exploration

- Business intelligence view:
  - Warehouse, data cube or reporting.
  - But not much mining.
- Business objects vs. data mining tools.
- Supply chain example: tools.
- Data presentation.
- Exploration.

KDD pipeline: a typical view from machine learning and statistics

- This is a view from typical machine-learning and statistics communities.

- Data integration.
- Normalization.
- Feature selection.
- Dimension reduction.

- Pattern discovery.
- Association/correlation.
- Classification.
- Clustering.
- Outlier analysis.
- ...

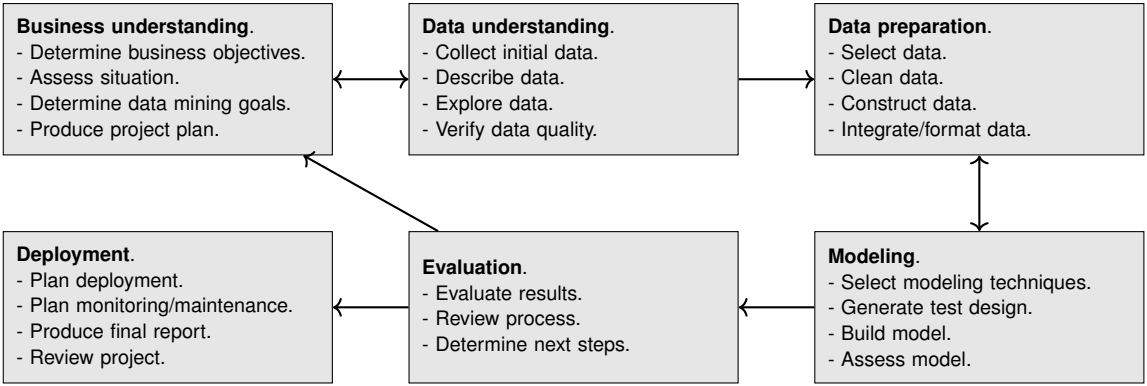
- Pattern evaluation.
- Pattern selection.
- Pattern interpretation.
- Pattern visualization.

Example: medical data mining

- **Health care and medical data mining**:
  - Often adopted such a view in statistics and machine learning.
- **Preprocessing of data**:
  - Includes feature extraction and dimension reduction.
- **Classification and/or clustering processes.**
- **Post processing for presentation**.

CRISP-DM

- **CRoss-Industry Standard Process for Data Mining**:



Chapter I: A multi-dimensional view of data mining.

- Why data mining?
- What is data mining?
- **A multi-dimensional view of data mining.**
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

A multidimensional view of data mining

- **Data to be mined**:
  Database data (extended relational, object oriented, heterogeneous, legacy), data warehouse, transactional data, stream, spatiotemporal, time-series, sequence, text and web, multi-media, graphs.
- **Knowledge to be mined (or data mining functions)**:
  - Characterization, discrimination, association, classification, clustering, outlier analysis, etc.
  - Descriptive vs. predictive data mining.
  - Multiple/integrated functions and mining at multiple levels.
- **Techniques utilized**:
  Database, data warehouse (OLAP), machine learning, statistics, pattern recognition, visualization, high performance computing, etc.
- **Applications adapted**:
  Retail, telecommunication, banking, fraud analysis, bio data mining, stock market analysis, text mining, web mining, etc.

Chapter I: What kind of data can be mined?

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- **What kind of data can be mined?**
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

Data mining: on what kinds of data?

- Database oriented data sets and applications:
  - Relational database.
  - Data warehouse.
  - Transactional database.
- Advanced data sets and advanced applications:
  - Data streams and sensor data.
  - Time series data, temporal data, sequence data (incl. biosequences).
  - Structure data, graphs, social networks and multi-linked data.
  - Object-relational databases.
  - Heterogeneous databases and legacy databases.
  - NoSQL databases.
  - Spatial data and spatiotemporal data.
  - Multimedia databases.
  - Text databases.
  - The world wide web.

Chapter I: What kinds of patterns can be mined?

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- **What kinds of patterns can be mined?**
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

Data mining function: I. Generalization

Information integration and data warehous construction:

- Data cleaning.
- Transformation.
- Integration.
- Multidimensional modeling.

Data cube technology:

- Characterization (contrast data characteristics).
  E.g. dry vs. wet regions from numerical humidity values.
- Discrimination.
- Generalization.
- Summary.

Data mining function: II. Association and correlation analysis

Frequent patterns or item sets:
What items are frequently purchased together in your supermarket.

Association, correlation vs. causality:
A typical association rule: Diapers $\rightarrow$ Beer $[0.5\%, 75\%]$ (support, confidence).
Are strongly associated items also strongly correlated?

How to mine such patterns and rules efficiently in large datasets?
How to use such patterns for classification, clustering and other applications?

Data mining function: III. Classification

Classification and (class-)label prediction:
Construct models (functions) based on training examples.
Hence: "supervised".
Describe and distinguish classes or concepts for future prediction.
E.g. classify countries based on climate or classify cars based on gas mileage.
Classifying something means to predict unknown class labels.

Typical methods:
Decision trees, naive Bayesian classification, support-vector machines, neural networks, rule-based classification, pattern-based classification, logistic regression . . .

Typical applications:
Credit-card-fraud detection, direct marketing, classifying stars, diseases, web pages . . .

Data mining function: IV. Cluster analysis

Unsupervised learning: I.e. class labels are unknown.
Group data: I.e. cluster houses to find distribution patterns.

Principle:
Maximize intra class similarity and minimize inter class similarity.

What is **similarity?**

Data mining function: V. Outlier analysis

Outlier: A data object that does not comply with the general behavior of the data.

Noise or exception?
One person's garbage could be another person's treasure.

Methods:
By-product of clustering or regression analysis . . .
Useful in fraud detection or rare-events analysis.

Time and ordering: sequential pattern, trend and evolution analysis

Sequence, trend, and evolution analysis.

- Trend, time-series and deviation analysis.
  E.g., regression and value prediction (forecasting).
- Sequential-pattern mining.
  E.g. customers first buy digital camera, then buy large SD memory cards.
- Periodicity analysis.
- Motifs and biological-sequence analysis.
  Approximate and consecutive motifs.
- Similarity-based analysis.
- Mining data streams.
  Ordered, time-varying, potentially infinite (unbounded).

Structure and Network Analysis

Graph mining:
Finding frequent subgraphs (e.g. chemical compounds), trees (XML), substructures (web fragments), information-network analysis.

Social networks:

- Social networks: Actors (objects, nodes) and relationships (edges).
  E.g., author networks in CS, terrorist networks.
- Multiple heterogeneous networks.
  A person could be in multiple information networks: friends, family, classmates ...
- Links carry a lot of semantical information: link mining.

Web mining:

- Web is a big information network: from PageRank to Google.
- Analysis of web information networks.
- Web community discovery, opinion mining, usage mining ...

Evaluation of knowledge

Is all mined knowledge interesting?

- One can mine tremendous amounts of "patterns" and knowledge.
- Some may fit only certain dimension space (time, location . . .).
- Some may not be representative, may be transient . . .

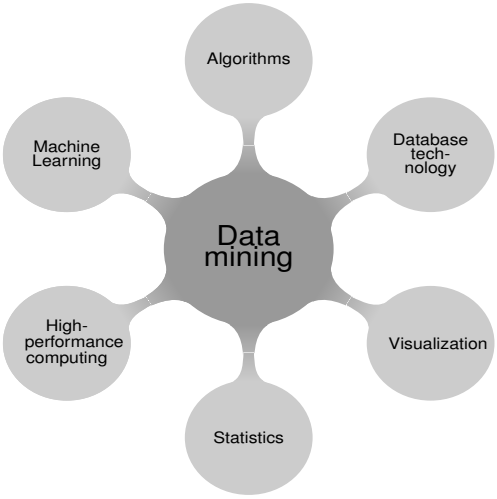
Evaluation of mined knowledge $\rightarrow$ directly mine only interesting knowledge?

- Descriptive vs. predictive.
- Coverage.
- Typically vs. predictive.
- Accuracy.
- Timeliness.
- . . .

Chapter I: What technologies are used?

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- **What technologies are used?**
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- Summary.

Data mining: confluence of multiple disciplines



Why confluence of multiple disciplines?

Tremendous amount of data:

- Algorithms must be highly scalable to handle also terabytes of data.

High dimensionality of data:

- DNA microarrays may have tens of thousands of dimensions.
  Collections of microscopic DNA spots attached to a solid surface.

High complexity of data:

- Data streams and sensor data.
- Time-series data, temporal data, sequence data.
- Structure data, graphs, social networks, and multi-linked data.
- Heterogeneous databases and legacy databases.
- Spatial, spatiotemporal, multimedia, text and web data.
- Software programs, scientific simulations.

New and sophisticated applications.

Chapter I: What kinds of applications are targeted?

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- **What kinds of applications are targeted?**
- Major issues in data mining.
- A brief history of data mining.
- Summary.

Applications of data mining

Web-page analysis:
From web-page classification, clustering to PageRank and HITS algorithms.
HITS stands for Hyperlink-Induced Topic Search.

Collaborative analysis and recommender systems.
Basket-data analysis for targeted marketing.
Biological and medical data analysis:
Classification, cluster analysis (microarray data analysis), biological sequence analysis, biological network analysis.

Data mining and software engineering:
E.g. IEEE Computer, Aug. 2009 issue.
From major dedicated data mining systems/tools:
E.g. SAS, MS SQL-Server Analysis Manager, Oracle Data-Mining Tools.

Chapter I: Major issues in data mining.

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- **Major issues in data mining.**
- A brief history of data mining.
- Summary.

Major issues in data mining (I)

Mining methodology:

- Mining various and new kinds of knowledge.
- Mining knowledge in multi-dimensional space.
- Data mining: An interdisciplinary effort.
- Boosting the power of discovery in a networked environment.
- Handling noise, uncertainty, and incompleteness of data.
- Pattern evaluation and pattern- or constraint-guided mining.

User interaction:

- Interactive mining.
- Incorporation of background knowledge.
- Presentation and visualization of data mining results.

Major issues in data mining (II)

Efficiency and scalability:

- Efficiency and scalability of data-mining algorithms.
- Parallel, distributed, stream and incremental mining methods.

Diversity of data types:

- Handling complex types of data.
- Mining dynamic, networked and global data repositories.

Data mining and society:

- Social impacts of data mining.
- Privacy-preserving data mining.
- Invisible data mining.

Chapter I: A brief history of data mining.

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- **A brief history of data mining.**
- Summary.

A brief history of data mining society

- **1989 IJCAI Workshop on Knowledge Discovery in Databases:**
  Knowledge Discovery in Databases (G. Piatetsky-Shapiro and W. Frawley, 1991).
- **1991-1994 Workshops on Knowledge Discovery in Databases:**
  Advances in Knowledge Discovery and Data Mining (U. Fayyad, G. Piatetsky-Shapiro, P. Smyth and R. Uthurusamy, 1996).
- **1995-1998 International Conferences on Knowledge Discovery in Databases and Data Mining (KDD'95-98):**
  Journal of Data Mining and Knowledge Discovery (1997).
- **ACM SIGKDD conferences since 1998 and SIGKDD Explorations.**
- **More conferences on data mining:**
  PAKDD (1997), PKDD (1997), SIAM-Data Mining (2001), (IEEE) ICDM (2001), etc.
- **Journal ACM Transactions on KDD starting in 2007**.

Conferences and Journals on Data Mining (I)

KDD Conferences:

- ACM SIGKDD Int. Conf. on Knowledge Discovery in Databases and Data Mining (KDD).
- SIAM Data Mining Conf. (SDM).
- (IEEE) Int. Conf. on Data Mining (ICDM).
- European Conf. on Machine Learning and Principles and Practices of Knowledge Discovery and Data Mining (ECML-PKDD).
- Pacific-Asia Conf. on Knowledge Discovery and Data Mining (PAKDD).
- Int. Conf. on Web Search and Data Mining (WSDM).

Conferences and Journals on Data Mining (II)

Other related conferences:

- DB conferences: ACM SIGMOD, VLDB, ICDE, EDBT, ICDT, ...
- Web and IR conferences: WWW, SIGIR, WSDM, ...
- ML conferences: ICML, NIPS, ICLR ...
- PR conferences: CVPR, ICPR ...

Journals:

- Data Mining and Knowledge Discovery (DAMI or DMKD).
- IEEE Trans. On Knowledge and Data Eng. (TKDE).
- KDD Explorations.
- ACM Trans. on KDD.

Where to Find References? DBLP, CiteSeer, Google (I)

Data mining and KDD (SIGKDD: CD-ROM):

- Conferences: ACM-SIGKDD, IEEE-ICDM, SIAM-DM, PKDD, PAKDD, etc.
- Journal: Data Mining and Knowledge Discovery, KDD Explorations, ACM TKDD.
- KDnuggets: `www.kdnuggets.com`.

Database systems (SIGMOD: ACM SIGMOD Anthology CD-ROM):

- Conferences: ACM-SIGMOD, ACM-PODS, VLDB, IEEE-ICDE, EDBT, ICDT, DASFAA.
- Journals: IEEE-TKDE, ACM-TODS/TOIS, JIIS, J. ACM, VLDB J., Info. Sys., etc.

AI & Machine Learning:

- Conferences: Machine learning (ML), AAAI, IJCAI, COLT (Learning Theory), CVPR, NIPS, etc.
- Journals: Machine Learning, Artificial Intelligence, Knowledge and Information Systems, IEEE-PAMI, etc.

Where to Find References? DBLP, CiteSeer, Google (II)

Web and IR:

- Conferences: SIGIR, WWW, CIKM, etc.
- Journals: WWW: Internet and Web Information Systems.

Statistics:

- Conferences: Joint Stat. Meeting, etc.
- Journals: Annals of Statistics, etc.

Visualization:

- Conferences: CHI, ACM-SIGGraph, etc.
- Journals: IEEE Trans. Visualization and Computer Graphics, etc.

Chapter I: Summary.

- Why data mining?
- What is data mining?
- A multi-dimensional view of data mining.
- What kind of data can be mined?
- What kinds of patterns can be mined?
- What technologies are used?
- What kinds of applications are targeted?
- Major issues in data mining.
- A brief history of data mining.
- **Summary.**

Summary

Data mining:
Discovering interesting patterns and knowledge from massive amounts of data.

A natural evolution of database technology:
In great demand, with wide applications.

KDD pipeline includes:
Data cleaning, data integration, data selection, transformation, data mining, pattern evaluation and knowledge presentation.

Mining can be performed in a variety of data.
Data-mining functionalities:
Characterization, discrimination, association, classification, clustering, outlier and trend analysis, etc.

Data-mining technologies and applications.
Major issues in data mining.

References I

- S. Chakrabarti: *Mining the Web: Statistical Analysis of Hypertext and Semi-Structured Data*. Morgan Kaufmann, 2002.
- T. Dasu and T. Johnson: *Exploratory Data Mining and Data Cleaning*. John Wiley & Sons, 2003.
- R. Duda, P. E. Hart and D. Stork: *Pattern Classification*. 2ed., Wiley-Interscience, 2000.
- U. Fayyad, G. Piatetsky-Shapiro, P. Smyth and R. Uthurusamy: *Advances in Knowledge Discovery and Data Mining*. AAAI/MIT Press, 1996.
- U. Fayyad, G. Grinstein and A. Wierse: *Information Visualization in Data Mining and Knowledge Discovery*, Morgan Kaufmann, 2001.
- J. Han, M. Kamber and J. Pei: *Data Mining: Concepts and Techniques*. Morgan Kaufmann, 3rd ed., 2012.
- D. Hand, H. Mannila and P. Smyth: *Principles of Data Mining*. MIT Press, 2001.
- T. Hastie, R. Tibshirani and J. Friedman: *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. 2nd ed., Springer-Verlag, 2009.

References II

- B. Liu: *Web Data Mining*. Springer 2006.
- T. M. Mitchell: *Machine Learning*. McGraw Hill, 1997.
- G. Piatetsky-Shapiro and W. Frawley: *Knowledge Discovery in Databases*. AAAI/MIT Press, 1991.
- P.-N. Tan, M. Steinbach and V. Kumar: *Introduction to Data Mining*. Wiley, 2005.
- S. M. Weiss and N. Indurkhya: *Predictive Data Mining*. Morgan Kaufmann, 1998.
- I. H. Witten, E. Frank and M. A. Hall: *Data Mining: Practical Machine Learning Tools and Techniques*. Morgan Kaufmann, 3rd ed. 2011.
- C. Shearer: *The CRISP-DM Model: The New Blueprint for Data Mining*. Journal of Data Warehousing, vol. 5, no. 4, pp. 13-22.
- T. Xie, S. Thummalapenta, D. Lo and C. Liu: *Data Mining for Software Engineering*. IEEE Computer, August 2009, pp. 55-62.
- R. Hyndman and G. Athanasopoulos: *Forecasting: Principles and Practice*. 2nd ed. Monash University, Australia, April 2018.

Thank you for your attention.
Any questions about the first chapter?

Ask them now, or again, drop me a line:
luciano.melodia@fau.de.