Statistical learning: some principles and applications

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Some vocabulary in statistical learning

1. Learning a decision rule
   - Prediction of an (labeled) outcome based on observed variables
   - Prediction of the outcome from new observations

2. Clustering
   - Creation of groups of similar individuals / objects / variables
   - Research of patterns

3. Learning a model from the data
   - Physical / biological models
   - Estimation of the parameters, shape of the model

4. Learning associations, statistical tests
   - Correlation between variables
   - Interactions in a network

5. Data visualization
   - Exploration of the data, outliers detection, errors
   - Reduction of the dimension

Challenges in statistical learning

- High dimension
  - A lot of variables per individual
  - **Aim: learn the effect of all these variables** even when the number of individuals / units remains small
- Repeated measures
  - Repeated trials
  - Longitudinal measurements: several measures in time
  - **Aim: learn the variability in the process and the evolution in time**
- Structured data
  - Connected objects: a function measured with high frequency
  - Functional data
  - **Aim: learn a function** (infinite dimension) and not only some parameters

Main approaches in statistical learning

Parametric versus Non Parametric

- **Non parametric**
  - No prior knowledge of a model, of a relationship between variables
  - Objectives: learn the model, the distribution of the variables, the network

- **Parametric**
  - Models with meaningful parameters: chemical interactions, physical laws, biological transformation
  - Prior models: linear regression, reliability
  - Objectives: numerical optimization of a criteria

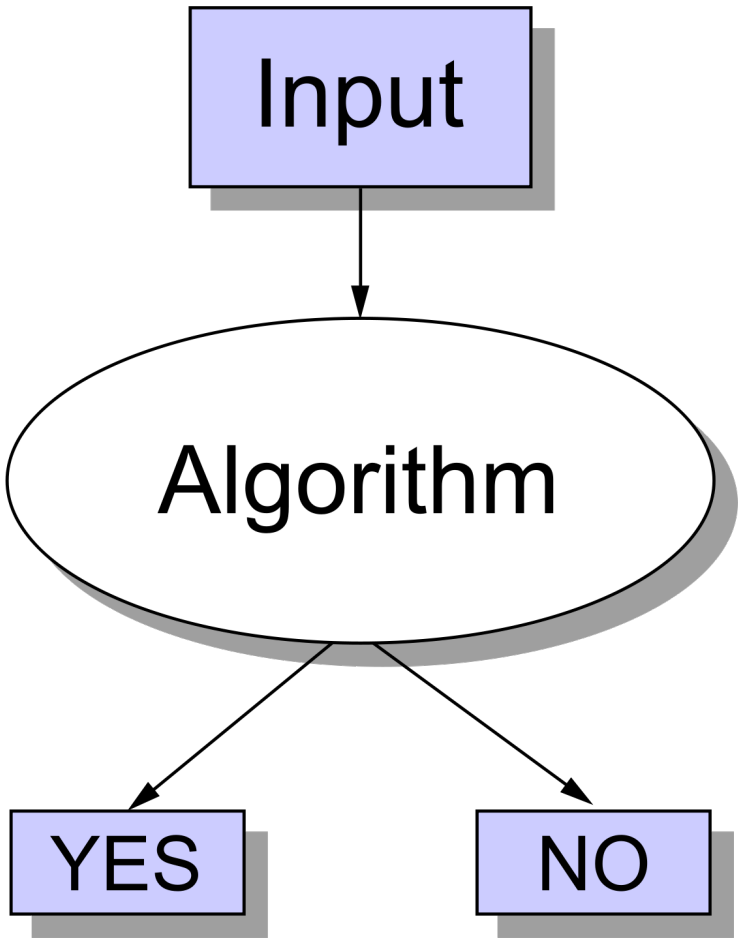
Challenges

- **Parsimony**: high dimension but maybe few significant signals
- **Optimization**: new technics to optimize complex criteria/space
- **Distributed calcul**: scalability of the solution

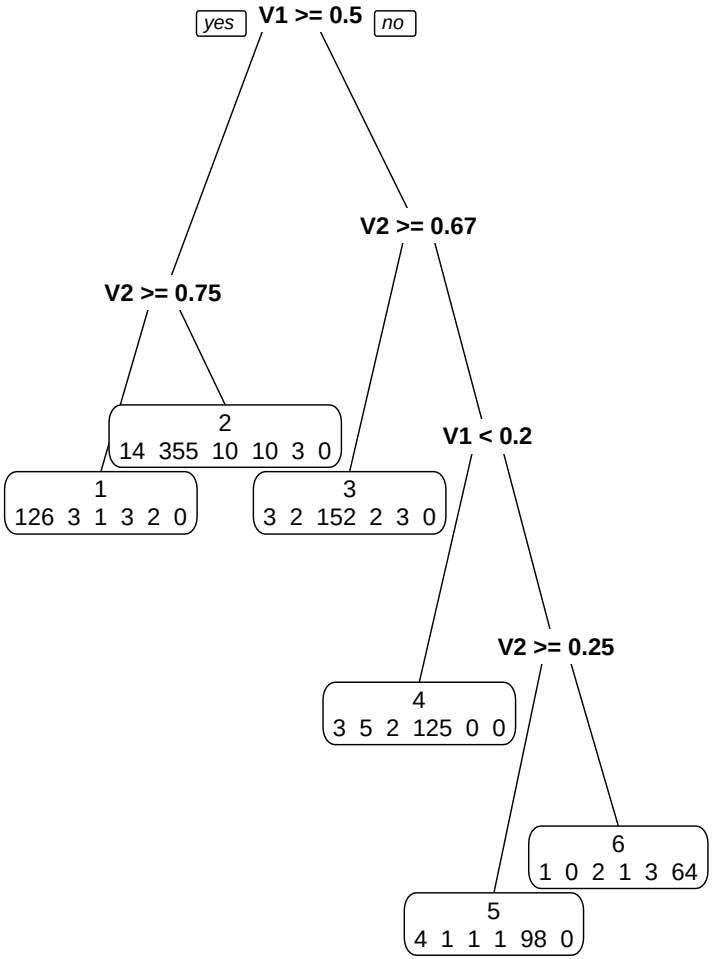
1. Decision rule, classification

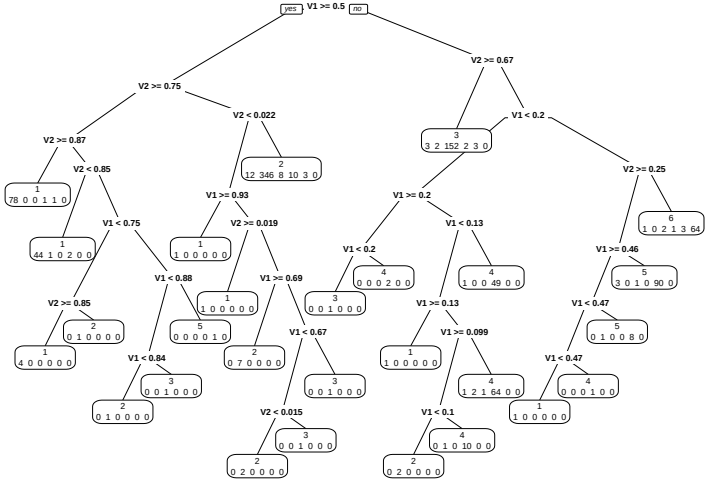
- Supervised learning: class labels are provided
- Aim: learn a classifier to predict class labels of novel data

- Statistical tools
  - Logistic regression (parametric)
  - K-nearest neighbors (non-parametric)
  - Decision tree (non-parametric)

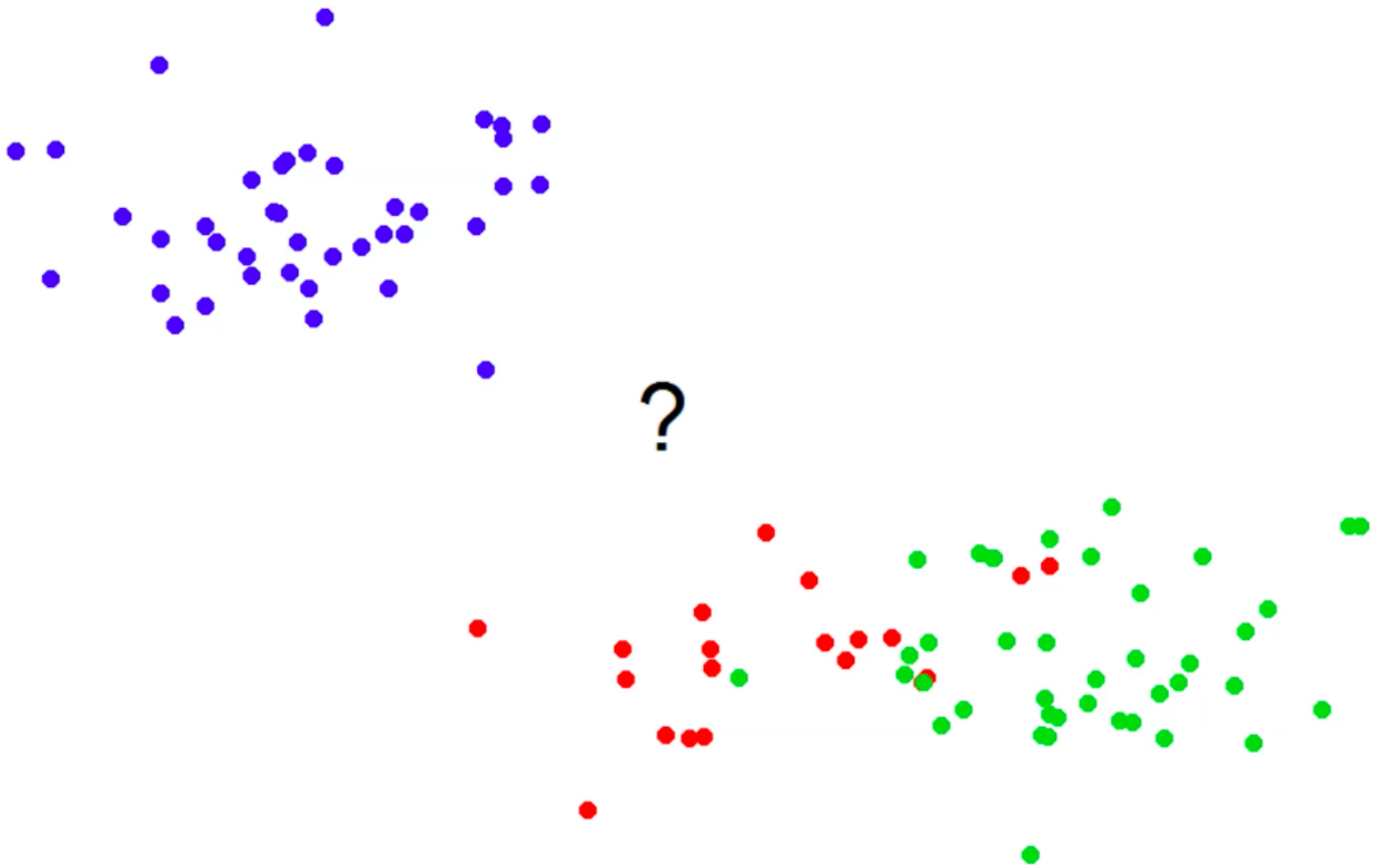


Decision tree



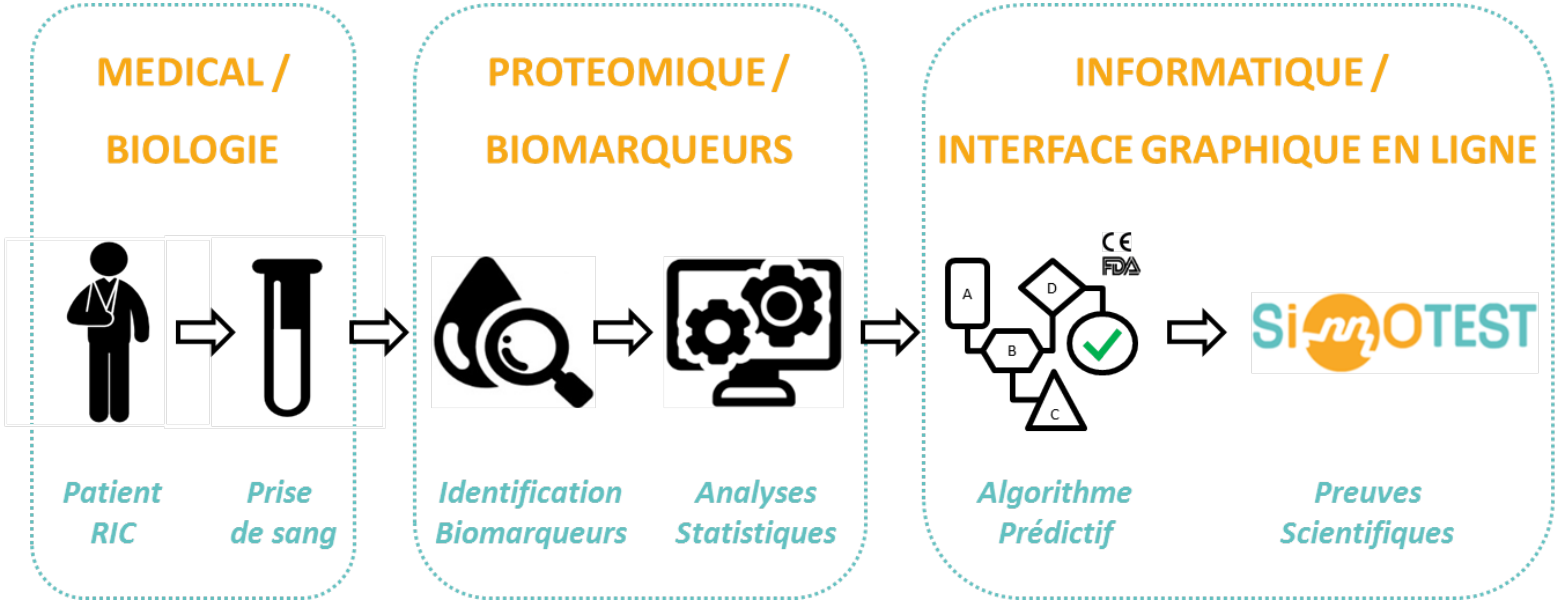


K-nearest neighbors



Examples

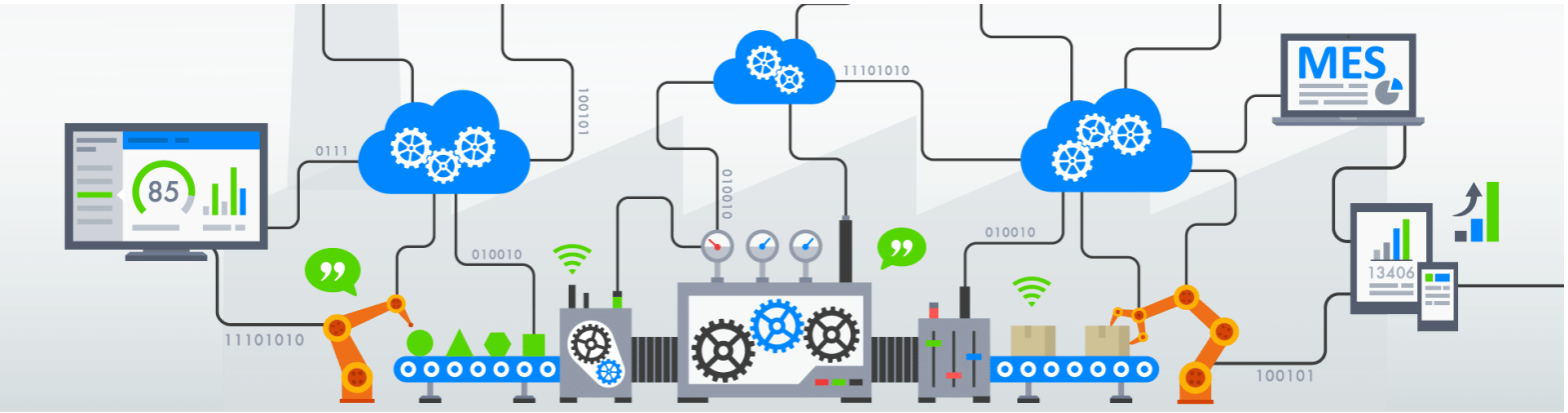
- **Advanced personalized medicine**



- Predict the best treatment from the knowledge of biomarkers measured at an initial clinical visit
- Logistic regression and decision tree

Examples

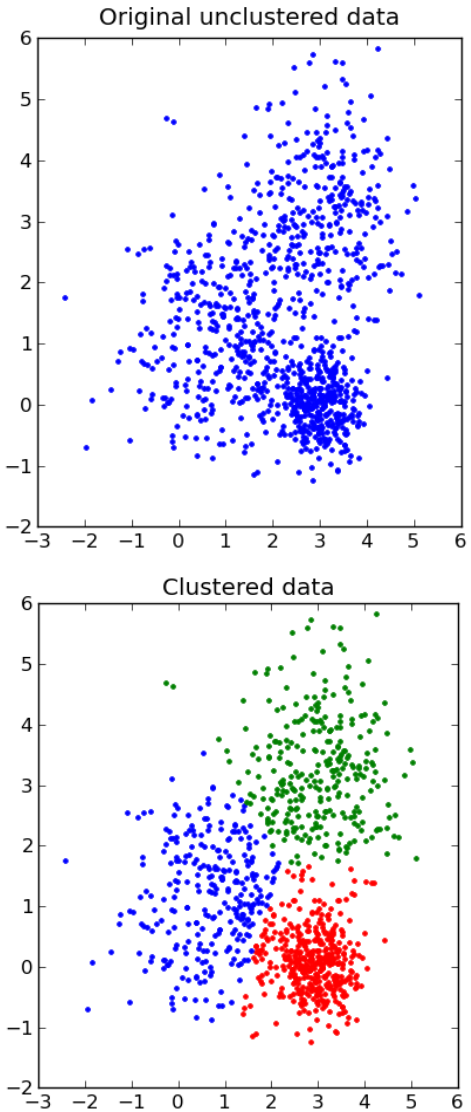
- **Manufacturing industry**
  - High production costs
  - Some non conformity at the end of the production process
  - Large number of sensors



  - Decision tree to predict early in the production process which piece is likely to be not conform
  - Reduce the proportion of non conformity

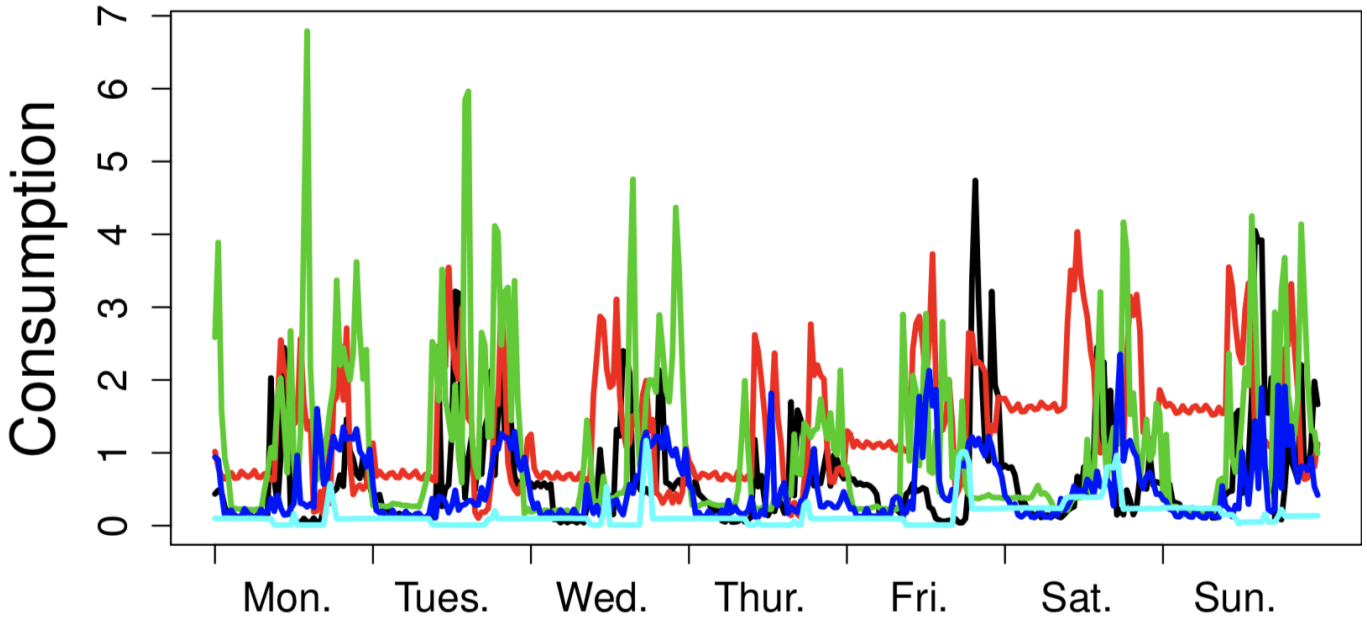
2. Clustering

- Unsupervised learning: no class label is given
- Aim
  - Creation of groups of similar individuals / objects / variables;
  - Understanding the structure underlying the data
- Statistical tools
  - K-means (non-parametric)
  - Mixture model (parametric)
  - Bi-clustering, Stochastic Block Model (parametric)



Examples

- **Consumption curves**
  - A curve per consumer
  - Prediction of the future consumption



  - Clustering and identification of profiles by mixture model of functional data
  - Prediction based on these clusters

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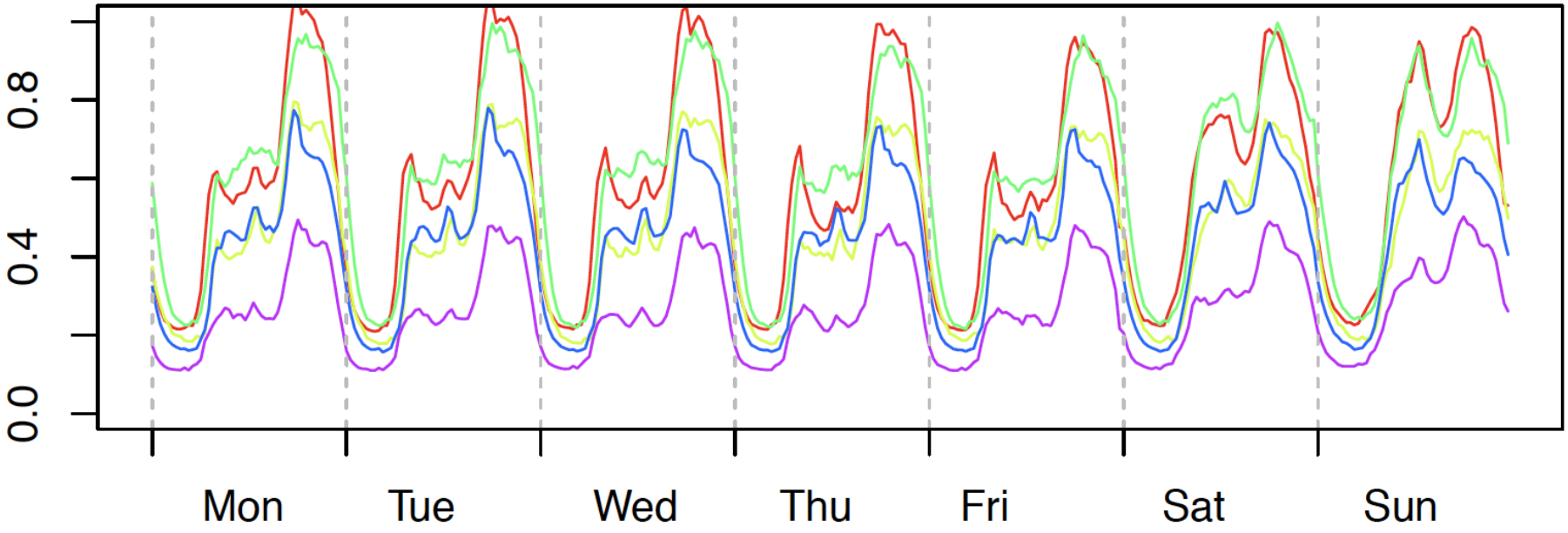

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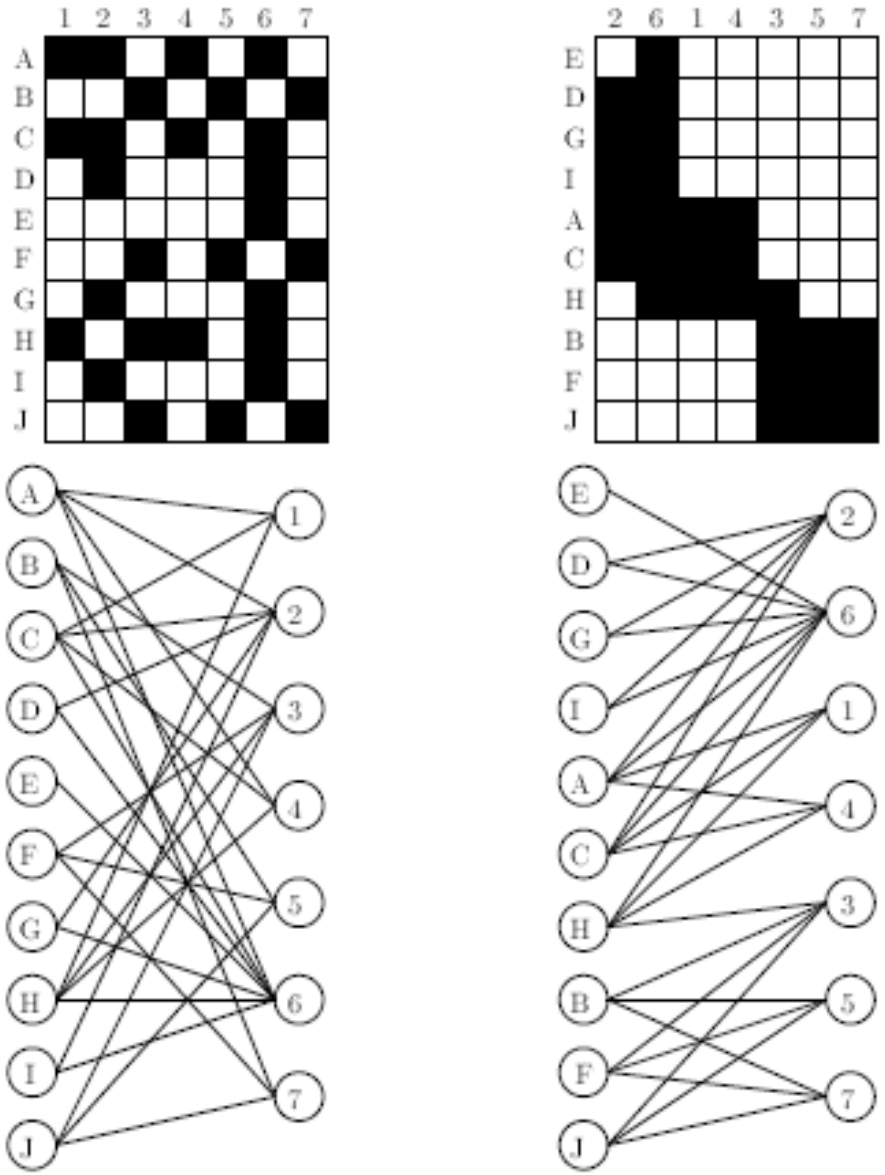
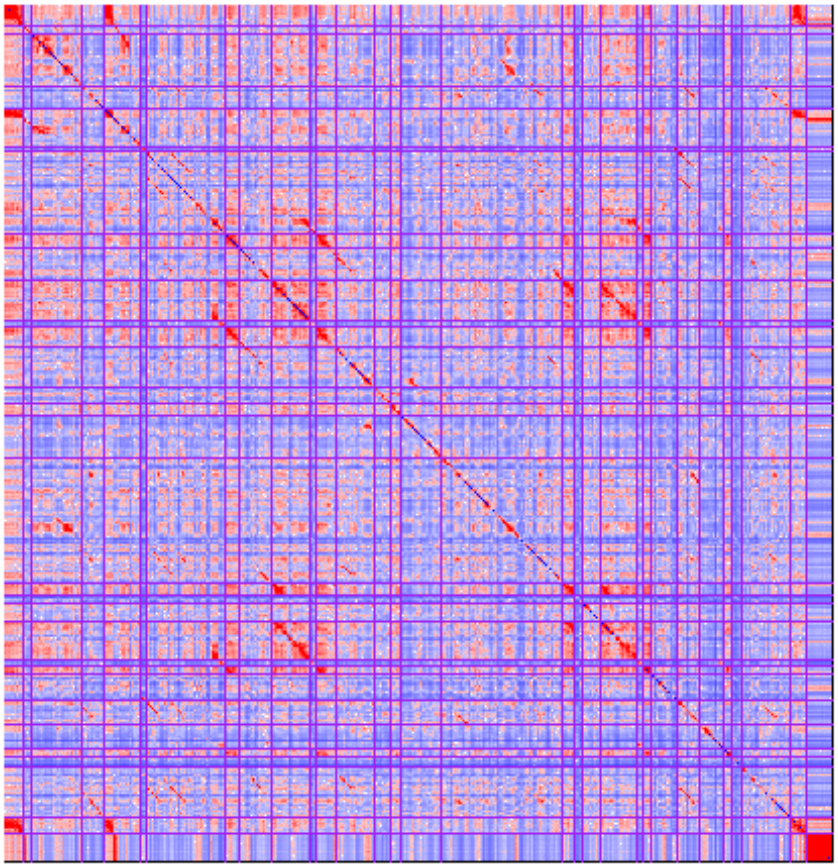
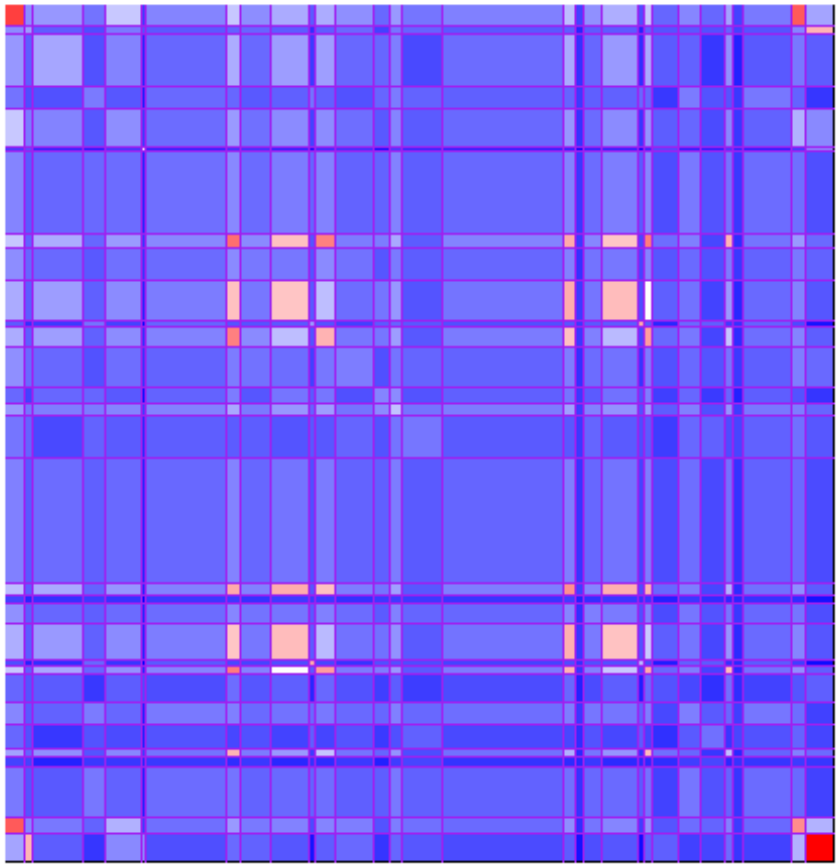
Bi-clustering



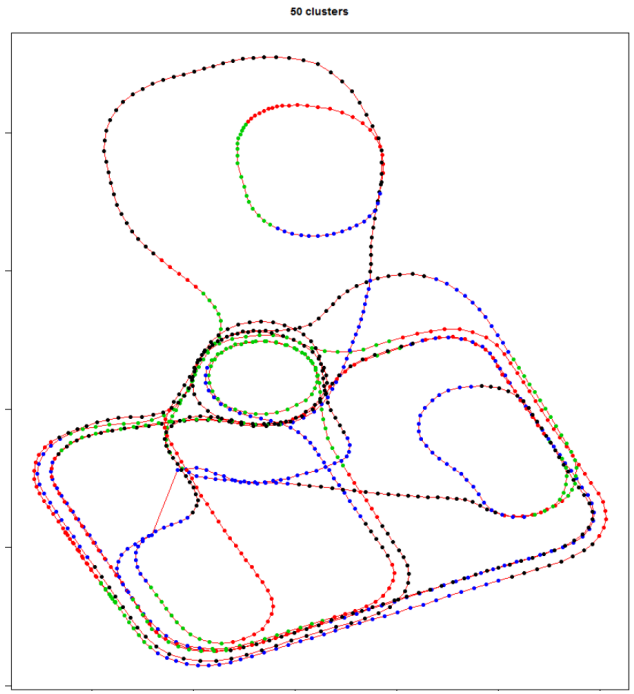
Stochastic block model





Examples

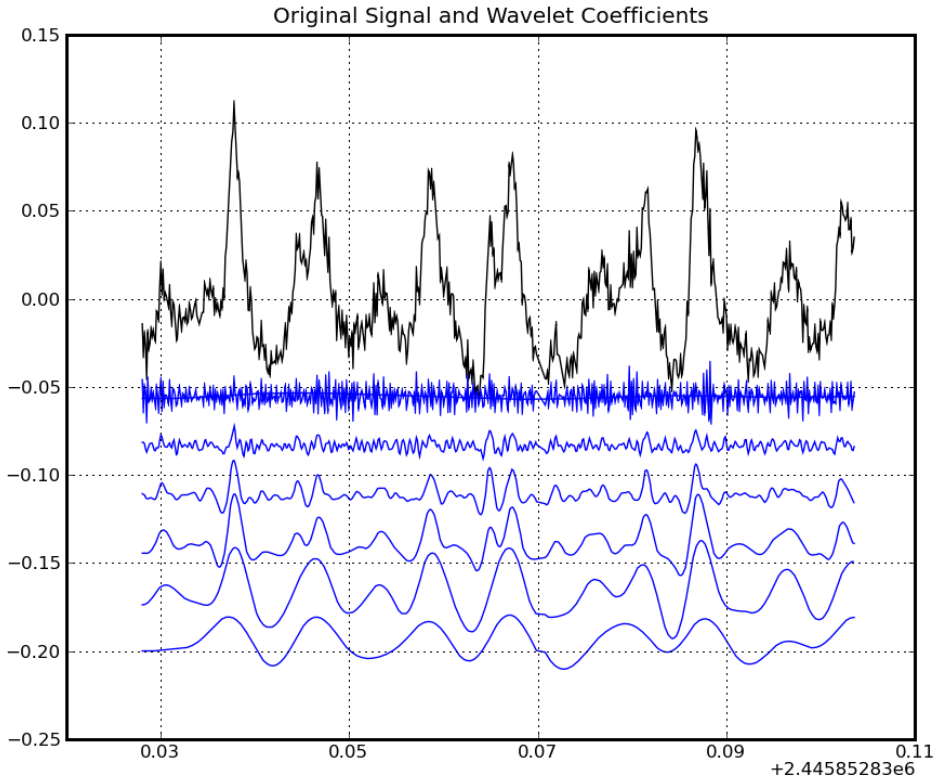
- **Autonomous Vehicle**
  - Precision of the position
  - Sequence of images



  - Segmentation of the images by Stochastic Block Model
  - Prediction of the position

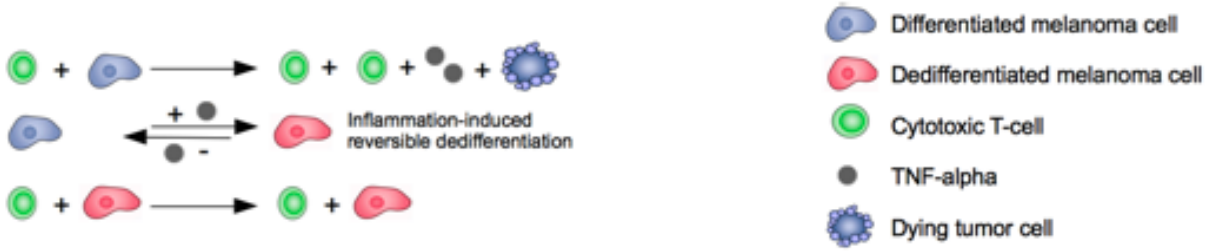
3. Learning a model

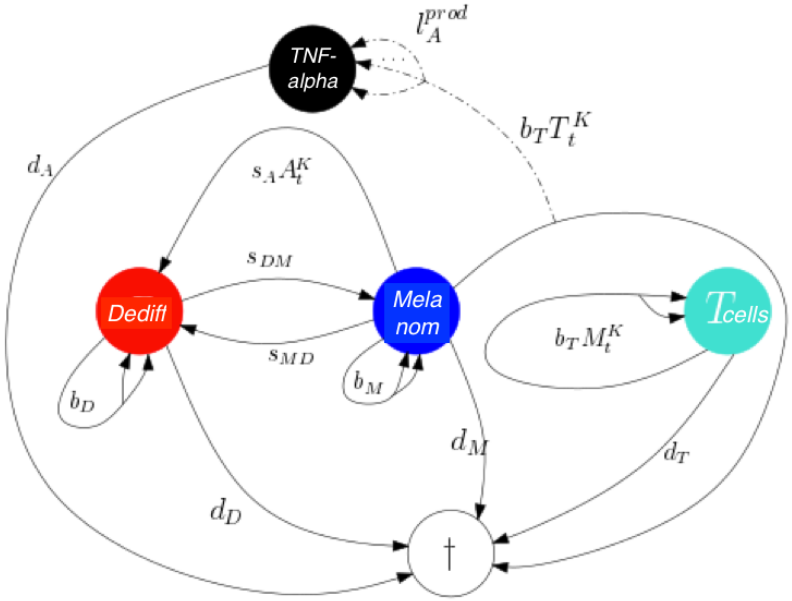
- Aim
  - Fit the data with a model
  - Regression model
- Statistical tools
  - Differential equations
  - Point process
  - Estimation of the parameters (parametric)
    - Maximum likelihood
    - Bayesian
    - Penalization with high dimension
  - Estimation of the model (non-parametric)
    - Splines, Wavelets, Fourier

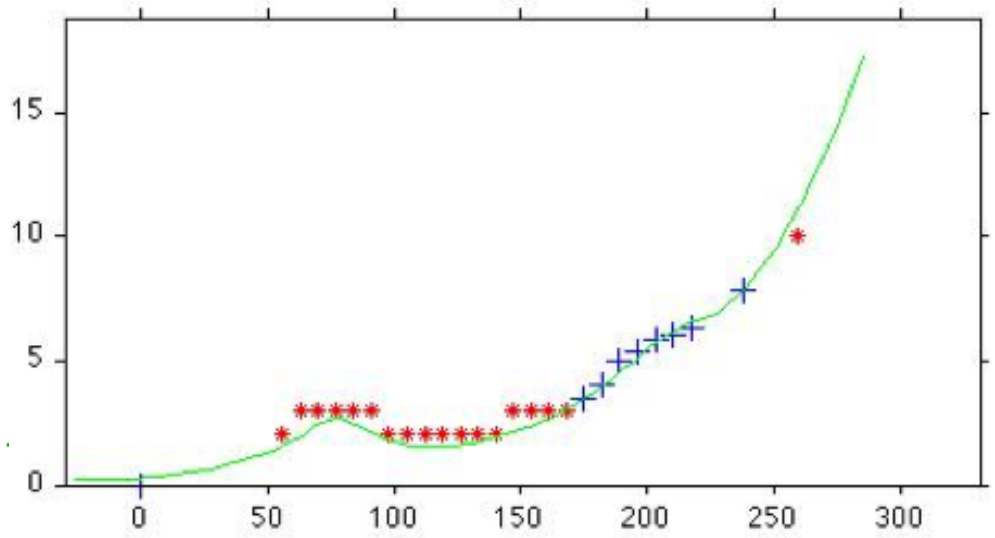


Examples

- **Immunotherapy**







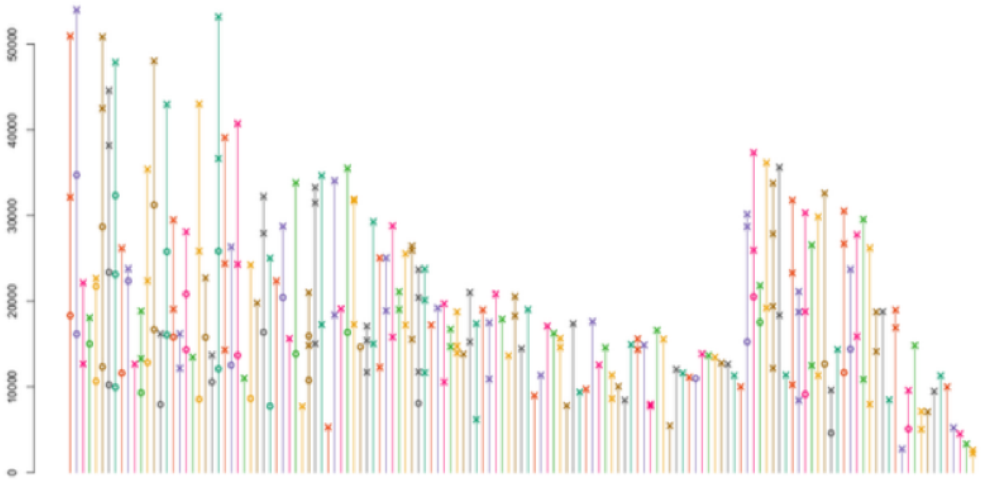
- Efficacy of the treatment
- Optimization of the treatment, in terms of dose and time to treatment

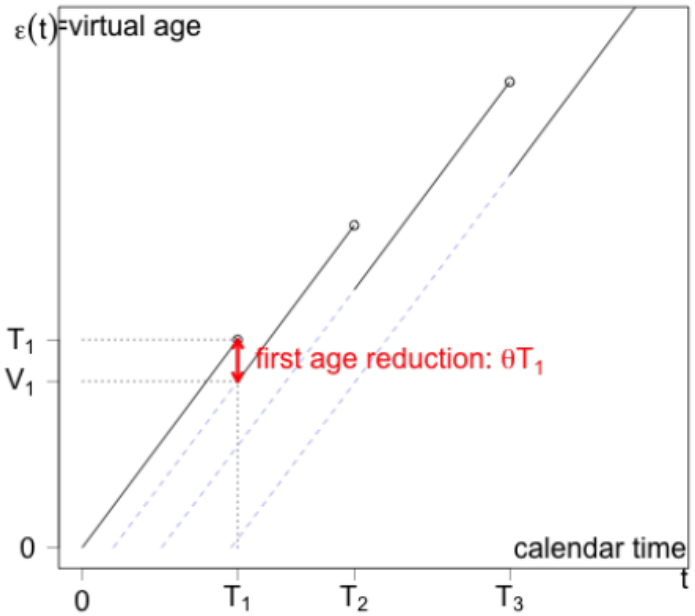
Examples

- **Maintenance, reliability**
  - Maintenance optimization
  - Imperfect maintenance

141 iid engines:

- 208 Corrective Maintenances MC (x);
- 52 Preventive Maintenances PM (o):

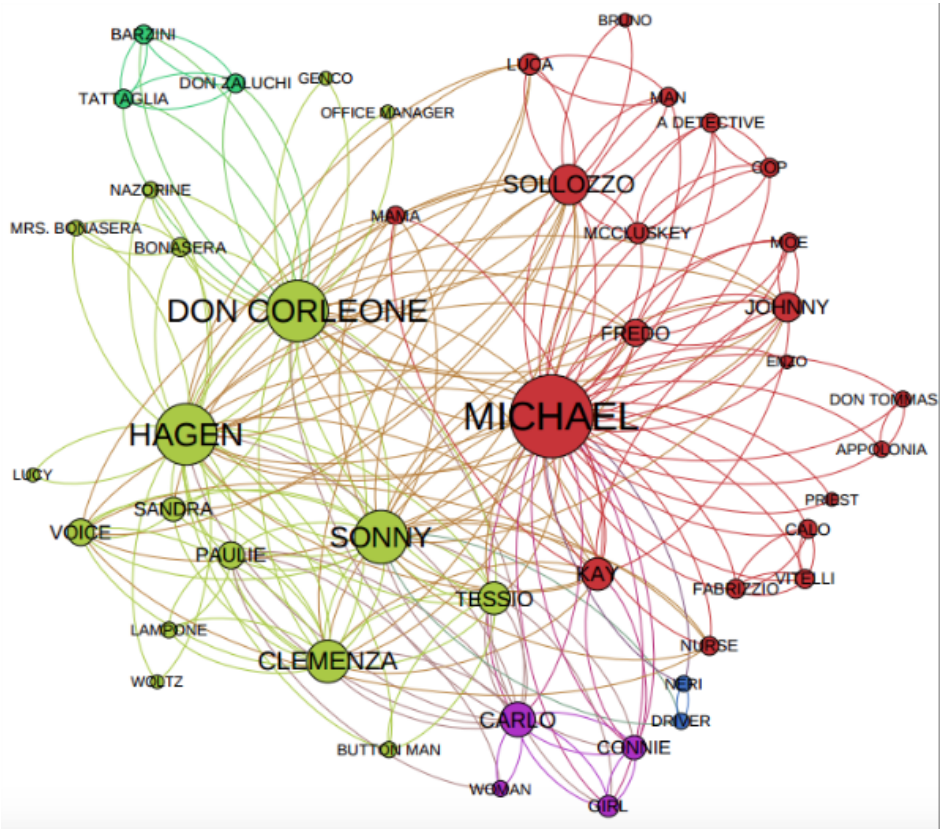




  - Virtual age modeling, point processes
  - Optimization of the next preventive maintenance

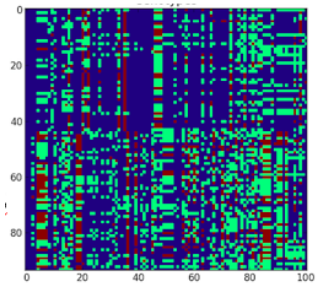
4. Learning associations, statistical tests

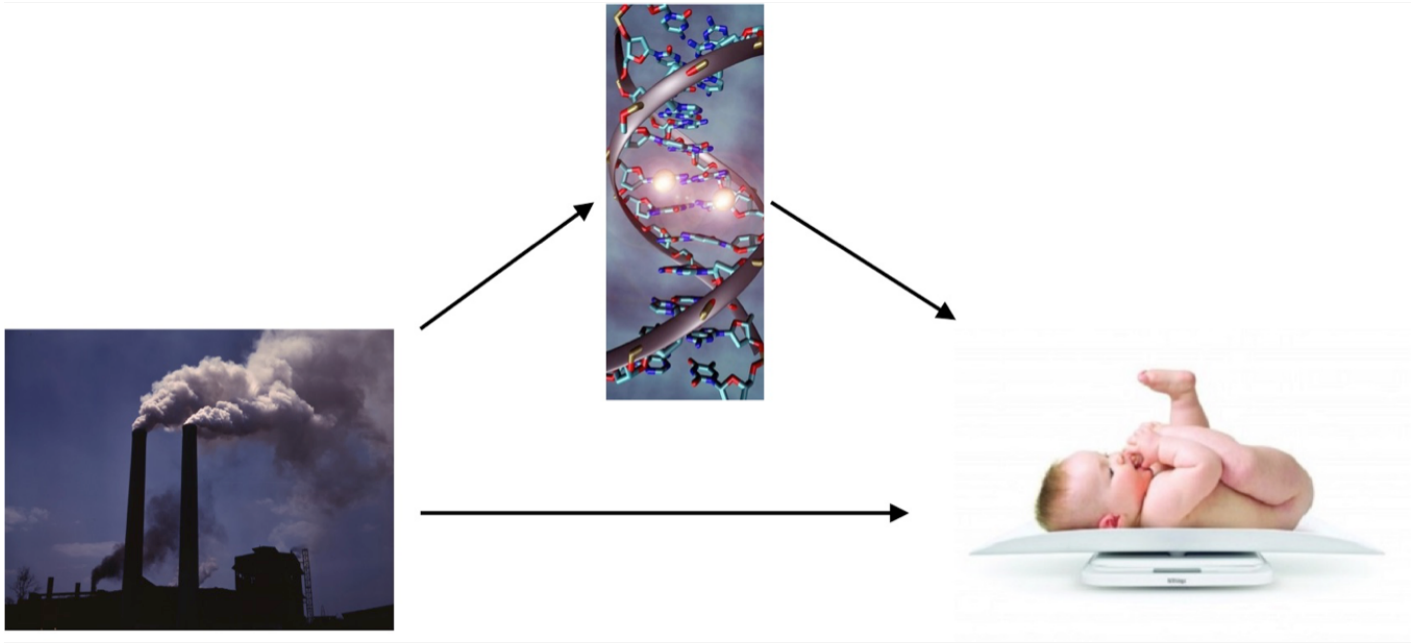
- Aim
  - Correlation between variables,
  - Learning communities and networks
- Statistical tools
  - Correlation tests, multiple tests
  - Graphical models



Examples

- Genomics
  - Effect of the pollution on epigenetics and baby growth

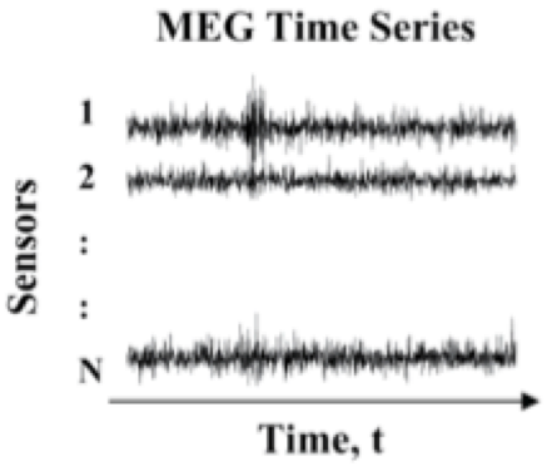


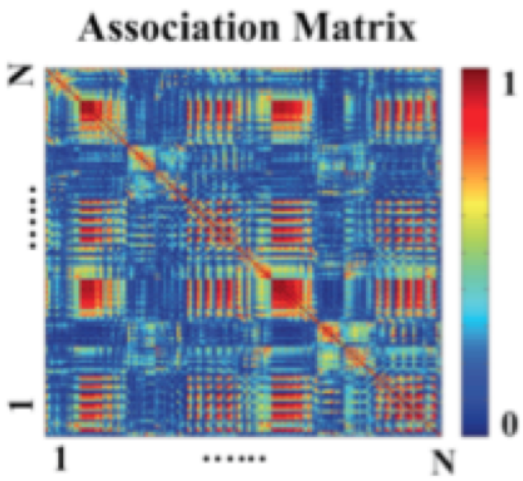


  - Associations tests and multiple testing
  - Mediation to infer causality

Examples

- Neurosciences
  - Understanding the connexions in the brain
  - Longitudinal, functional data through EEG, MEG data





Statistical learning frameworks

Open source development frameworks available

Possible to use in industry

Take-Home message

- Core-idea of statistical learning
  - Variety of (industrial) problems
  - Variety of statistical questions
  - Variety of learning approaches
  - Machine learning: decision rule, clustering
  - Statistical learning: model learning, association/correlation
- A strategy that is effective across different disciplines
  - Health
  - Environment
  - Energy
  - Marketing
  - Manufacturing industry

Some directions of ongoing research

- Structured data, connected objects
- Social networks, interaction graph
- High dimension
- Optimization with constraints
- Distributed computation