Universitat Pompeu Fabra
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Metaheuristics for Combinatorial Optimization

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Outline

► Helena Ramalhinho Lourenço
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- Degree in Applied Mathematics
  * University of Lisbon, Portugal
- PhD in Operations Research
  * Cornell University, New York, USA
- Full Professor at Universitat Pompeu Fabra
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- Director of the Business Analytics Group

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Universitat Pompeu Fabra

► The newest university in Barcelona:

www.upf.edu

- In-city campus
  * Social sciences and Humanities
  * Health sciences
  * Technology and Communications
- International University
- Teaching in English
- Times Higher Education ranking (2018): 11th (under 50 years of age)

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BAR Group

► **B**usiness **A**nalytics **R**esearch Group
- The Business Analytics Research Group focuses on developing new insights and understanding of business performance based on broad set of analytical methodologies including Statistics and Operations Research Methods.
- The BAR Group at UPF draws faculty from different areas at UPF and other associated universities.

Website: http://www.upf.edu/barg/   **Blog**: http://blogbarg.upf.edu/   OR & Analytics   4

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Outline

► A gentle introduction to Operations Research & Business Analytics.
► Combinatorial Optimization Problems: Location, Routing and Scheduling.
► Metaheuristics Algorithms.
► Iterated Local Search.
► Briefly description of the extensions of Iterated Local Search (ILS): SimILS and MathILS.
► Application of Metaheuristics to problems arising in Supply Chain Management area. Description of real applications.

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Operations Research

► "In a nutshell, Operations Research (O.R.) is the discipline of applying advanced analytical methods to help make better decisions."
► "By using techniques such as mathematical modeling to analyze complex situations, operations research gives executives the power to make more effective decisions and build more productive systems based on:
  * More complete data
  * Consideration of all available options
  * Careful predictions of outcomes and estimates of risk
  * The latest decision tools and techniques"
- Source: http://www.scienceofbetter.org/what/index.htm

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Operations Research

► Operations Research (O.R.), or operational research in the U.K, is a discipline that deals with the application of advanced analytical methods to help make better decisions.

- The terms **Management Science** and **Analytics** are sometimes used as synonyms for operations research.
- Employing techniques from other Mathematical Sciences, such as mathematical modeling, statistical analysis, and mathematical optimization, operations research arrives at optimal or near-optimal solutions to complex decision-making problems.
- Source: https://www.informs.org/About-INFORMS/What-is-Operations-Research

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Introduction

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Business Analytics

► "Analytics is defined as the scientific process of transforming data into insight for making better decisions."

► Source: Informs Society
  * http://informs.org/About-INFORMS/What-is-Analytics
  * http://www.informs.org/Sites/Getting-Started-With-Analytics
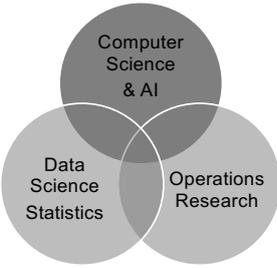
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Business Analytics

► Analytics is defined by three categories:

- **Descriptive analytics**
  * Prepares and analyzes *historical* data
  * Identifies patterns from samples for reporting of trends
- **Predictive analytics**
  * Predicts *future* probabilities and trends
  * Finds relationships in data that may not be readily apparent with descriptive analysis
- **Prescriptive analytics**
  * Evaluates and determines *new* ways to operate
  * Targets business objectives
  * Balances all constraints

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Business Analytics

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Business Analytics

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OR Methodology

Real Problem

Decision-maker

Data Analysis

Optimization Model

Set of Models

Solution Methods

Results & Interpretation

Simulation

Solution & Analysis

Scenarios

Make a decision

OR provides many methods and techniques to analyze the consequences of decisions before their introduction to reality.

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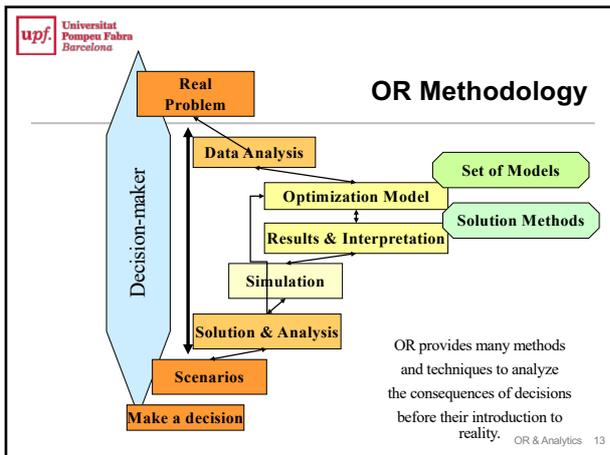
Modeling

▶ By modeling various alternatives for future systems design, Federal Express has, in effect, made its mistakes on paper. Computer modeling works; it allows us to examine many different alternatives and it forces the examination of the entire problem.

Frederick W. Smith
Chairman and CEO of Federal Express Corporation

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Modeling

▶ A Model is an abstract representation of a real world system
  ▪ A model always simplifies reality.
▶ Modeling is the process of creating a simplified representation of reality and working with this representation in order to understand or control some aspects of the world.
▶ Why study modeling?
  ▪ To make better decisions…
  ▪ Improves the thinking skills…

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Modeling

▶ Advantages of Using Models
  ▪ Less expensive and disruptive than experimenting with the real world system
  ▪ Allow operations managers to ask "What if" types of questions
  ▪ They are built for management problems and encourage management input
  ▪ They force a consistent and systematic approach to the analysis of problems
  ▪ They require managers to be specific about constraints and goals relating to a problem
  ▪ They can help reduce the time needed in decision making

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Modeling

▶ Limitations of Models
  ▪ They may be expensive and time-consuming to develop and test
    * Extensive and accurate data
  ▪ They are often misused and misunderstood (and feared) because of their mathematical complexity
  ▪ They tend to downplay the role and value of non-quantifiable information
  ▪ They often have assumptions that oversimplify the variables of the real world
  ▪ Specialized knowledge

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Modeling

▶ Types of models
  ▪ Physical model
    * urban planners build models
  ▪ Analog model
    * highway road map
  ▪ Symbolic model
    * decision models
      – managerial situation
      – decision variables
      – performance measures

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Modeling

- ▶ Building models
  - Study the environment of the managerial/engineering/… real situation.
  - Formulate a selective representation of the situation.
    - * Technical know-how
    - * Sector and problem know-how
    - * Realism
    - * Experience
    - * Models knowledge
  - Construct and analyze the quantitative model.
  - A model is valuable if you made better decisions when you use it than when you do not.

Modeling

- ▶ **After a model is formulated… Solve it!**
  - Apply a method to find answers from the models created previously
    - * Develop a procedure (usually a computer-based procedure) for deriving solutions to the problem from this model.
  - **Algorithms**
  - **Simulation**
  - ...
- ▶ And after?
  - Interpretation and validation
  - Sensitivity analysis

Algorithms

- ▶ Algorithms characteristics
  - **Efficient** vs Effective
  - Optimal vs **Heuristic**
  - Construction vs **Improvement**
  - **Optimization** vs **Simulation**
- ▶ Types of algorithms:
  - Spreadsheet, Simulation, Exact methods, Heuristics, AI algorithms,…
- ▶ P vs NP
  - "Easy" vs "Difficult" problems

Algorithms

- ▶ Approaches to NP-hard (difficult and complex) problems
  - Exact non-polynomial algorithms
    - * branch-and-bound
    - * branch-and-cut
    - * dynamic programming
      - – Commercial Software
      - – Specific application (for each problem)
  - Heuristics & Metaheuristics
    - * Several available techniques…
    - * Local search, Tabu Search, Genetic Algorithms…
      - – Specific application (for each problem)
      - – Some commercial applications…

Algorithms

- ▶ Heuristics
  - Any approximate method build up on the basis of the structural properties or on the characteristics of the problem solution, with reduced complexity with respect to exact methods and providing, in general, good feasible quality solutions, without a forma guarantee of solution quality.
  - Cost vs. Time

Algorithms

- ▶ Metaheuristics
  - The process of finding a good solution (eventually the optimum) consists in applying at each step (guiding) a subordinate heuristic which has to be design for each particular problem.
    - * C. Ribeiro [1996]

Algorithms

► Metaheuristics

- **local optimization**
- multi-start, GRASP
- iterated local optimization
- tabu-search
- simulated annealing
- variable neighborhood search
- genetic algorithms
- ant colony optimization
- …

Algorithms

► Metaheuristics...

- Have been designed to attack complex optimization problem where classical heuristics and optimization have failed (so far) to be effective and efficient.
- When implementing a metaheuristic, begin with a simple method and then turn, if necessary, to a more complicated one or refine the first implementation.
- Very successful method when applied to large-scale complex optimization problems.

Decision Support System

► The use of data, models and analysis to give insights that aid decision.

► Basic components

- Input Data (Data Analytics)
- Analytical Tools (Algorithms)
- Presentation Tools (Visualization)

► An information system is a system that collects, stores, retrieves, processes, and display information.

Decision Support System

► Analytical Tools

- Adds knowledge
- Tools
  * Operations Research (Modeling and Optimization)
  * Artificial Intelligence
  * Simulation
  * Flow Analysis
- The most complex component.

Decision Support System

► Presentation Tools

- Data visualization techniques
- Tables
- Lists
- Geographic information systems (GIS)
- Charts
- Animation

Decision Support System

Modeling, Algorithms and DSS

Models have no value.

Metaphysivcal faith in mathematical models.

Heuristics have no value, you should obtain the optimal solution.

Heuristics are the crystal ball for decision making.

The Modeling Process should be used as one of a number of tools for decision making.

Modeling ⟶ Algorithms ⟶ DSS

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Focus on the Applications of Combinatorial Optimization

► Applications in many different industries and sectors:
- Retailing
- Logistics
- Manufacturing
- Transportation
- Marketing
- Telecommunications
- Health
- Energy
- Computer Science
- Etc.

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Combinatorial Optimization

► Combinatorial Optimization problem
- Given a set of elements $E = \{1, 2, ..., n\}$
- Set of feasible solutions F
  * Each element of F is a subset of E.
- Objective function $f(x): F \rightarrow R$.
- In the minimization version the problem consists in
  * Finding $x^* \in F$, such that $f(x^*) \leq f(x) \ \forall x \in F$.
    – Discrete Optimization
    – Graph models

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Combinatorial Optimization Problems

► Traveling Salesman Problem (TSP)
► Routing problems
- Vehicle Routing Problem (VRP)
- Heterogeneous Vehicle Routing Problem (HVRP)
► Location problems
► Scheduling problems
- Job-shop scheduling problem
- Parallel machines
► Other …
- Clique problems

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Retailing

► Planning distribution routes – VRP
► Optimizing picking routes in a warehouse
► Last mile routes for ecommerce
► Store, warehouse location decisions
► Inventory & location decisions
► Inventory & routing decisions
► …

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Health Care

► Home health care planning
- Home Care (HC) is defined as "medical and paramedical services delivered to patients at home"
► Location of medical resources
- Hospitals, ambulances, etc.
► Planning emergency health care services
► Optimization of the location of preventive health care services providers
► Optimization in Kidney Exchange Programmes
► …

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Transportation

- ► Horizontal cooperation in transportation
- ► Sustainable transportation
- ► Air Transportation problems (airplanes and personnel)
- ► Location of transportation hubs
- ► Optimization in maritime transportation
- ► Optimization for electrical vehicles
- ► Optimization of the location of charge station
- ► …

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Logistics and Supply Chain

- ► Supply Chain Design
  - ▪ Optimization of the location and connections in a supply chain
- ► Optimization of City Logistics
- ► Optimization in Smart Logistics
- ► Humanitarian Logistics
- ► Optimization in Reverse Logistics
  - ▪ Design of reverse logistics networks
  - ▪ Garbage collection
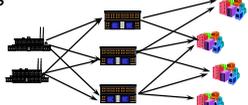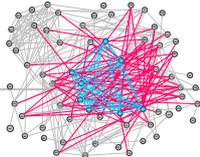
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Manufacturing

- ► Production Scheduling
- ► Inventory management
- ► Lotsizing problems
- ► Cutting and packing Problems
- ► …

Inputs

Goods
Services

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Marketing

- ► Market Basket Analysis
  - ▪ The main objective is to analyze large dataset of store transactions.
  - ▪ Obtain relevant insights to do a better planning of the Marketing strategies and operations
- ► Optimization of target offers in marketing campaigns
- ► Segmentation and site location analysis

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Many more applications…

- ► Human resources problems
- ► Energy
- ► Timetabling
- ► Sports applications
- ► Humanitarian Logistics
- ► Public sector

- ► Crew Scheduling
- ► Resource Allocation Problems in Telecommunications
- ► Water resources
- ► Revenue Management
- ► Finances

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Conclusions

- ► Prescriptive Analytics … the next step on Analytics!
- ► Many problems in real life are Combinatorial Optimization Problems.
- ► It is still "hard" to solve large-scale Combinatorial Optimization Problems in a short running time.

Get **Value** and **Insights** out
of **Data** to make better
Decisions

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