Combinatorial Decision Making & Optimization

2024/2025

Second cycle degree/two year Master's in Artificial Intelligence

Dept of Computer Science and Engineering (DISI)

University of Bologna

Course Info

- **Organization**
  - Module I
    - Zeynep KIZILTAN
    - E-mail: zeynep.kiziltan@unibo.it
  - Module II
    - Roberto Amadini
    - E-mail: roberto.amadini@unibo.it
  - Appointment on Teams, upon request by e-mail.

Course Info

- **Timetable**
  - Available at the course website.
  - Tuesday 13:00 – 16:00 (Aula 0.6)
    Thursday 14:30 – 17:30 (Aula 0.6)
    - Arrive on time!
    - Not all hours will be used!
  - Module I: February 18 – April 3
  - Module II: April 8 – June 12

Course Info

- **Prerequisites**
  - Problem solving in artificial intelligence.
    - Covered by Module I of 91248 - Fundamentals of Artificial Intelligence and Knowledge Representation.
  - Basic notions of algorithms and programming, preferably in Python.
    - Covered by B5727 - Introduction to Languages for Artificial Intelligence (Modulo 1)
  - Logic for computer science.
    - Covered by B5727 - Introduction to Languages for Artificial Intelligence (Modulo 2)
  - Basic algebra and analysis.

Course Info

- **Learning outcome**
  - Popular methods in operations research and artificial intelligence for modeling and solving complex combinatorial optimization problems such as constraint programming, integer linear programming, SAT and SMT.

Artificial Intelligence

- Statistical / Sub-symbolic
  - ML, DL
  - Data-driven
  - Uses probabilistic learning and forecasting
  - Impressive and convincing
  - Lacks general intelligence
    - Recognizes patterns but doesn't understand context
    - No correctness guarantee
      - not fact-based
      - no access to knowledge base

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- Classical / Symbolic
  - Represents knowledge using (human readable) symbols and manipulates them using pre-defined rules
  - Uses logic-based inference and search
  - Deterministic methods that provide guaranteed correct results

Need for Symbolic AI

- From a cognitive perspective
  - Deeper real world reasoning (causality), abstraction, common sense reasoning
- From a technological perspective
  - Robustness, verifiability, explainability
- From a social perspective
  - Fairness, ethics

Advances of Symbolic AI

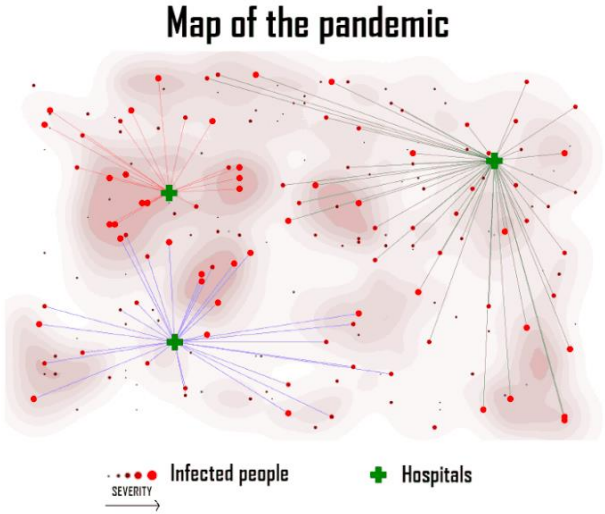
- Semantic systems (e.g. knowledge graphs when querying the web)
- Games (e.g. chess, poker)
- Automated theorem proving
- Solving mathematical problems (e.g. Pythagorean triples problem)
- Robotics & planning
- Verification (e.g. hardware and software)
- Argumentation (e.g. modelling human reasoning)
- Combinatorial optimization

Combinatorial Optimization

- Decision making within many combinations of possibilities subject to complex restrictions (constraints).
  - Any solution (that meets all constraints).
  - Optimal solution (best solution according to an objective).
- Can appear under different names, e.g.
  - combinatorial decision making and optimization,
  - constraint satisfaction/optimization.
- Frequently appear in daily lives, business, industry and science.

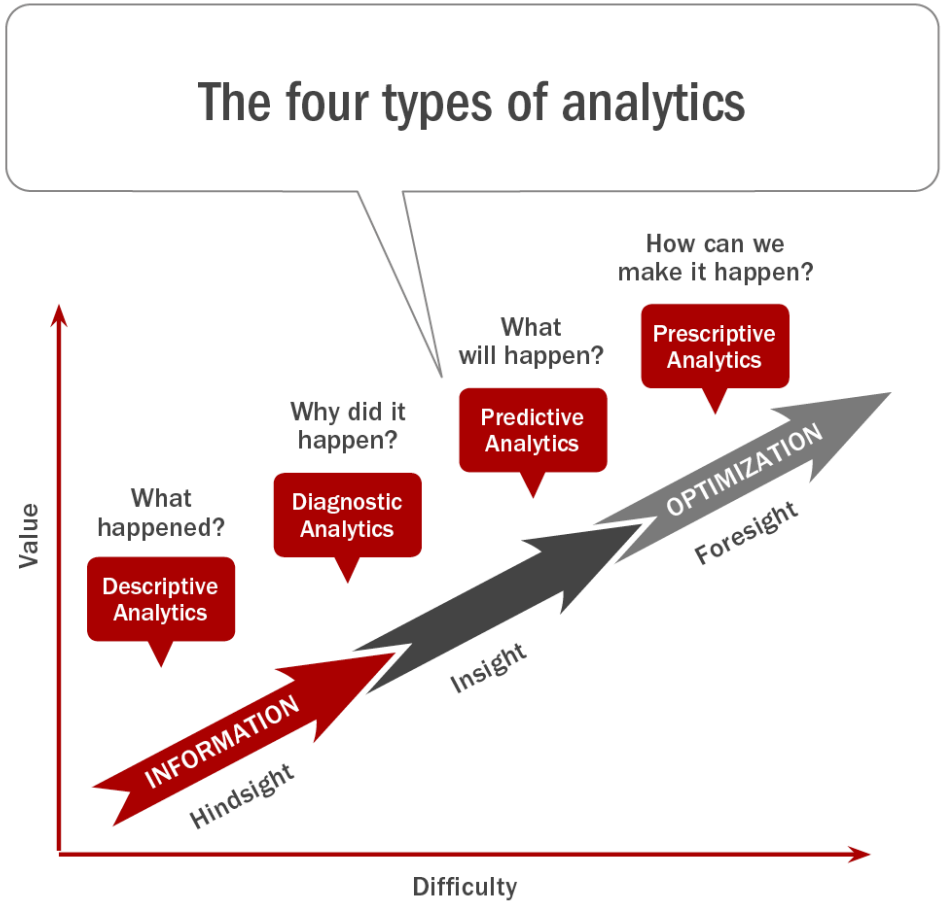
Hospitalization during the Pandemic

- Assign infected people to hospitals according to:
  - severity of illness,
  - patient age,
  - patient location,
  - hospital capacity,
  - hospital equipment, etc.



- An approach like neural networks is not suitable:
  - no historical data for training,
  - data cleaning and consolidation is time consuming,
  - a variety of architectures would need to be tested with lengthy training sessions.

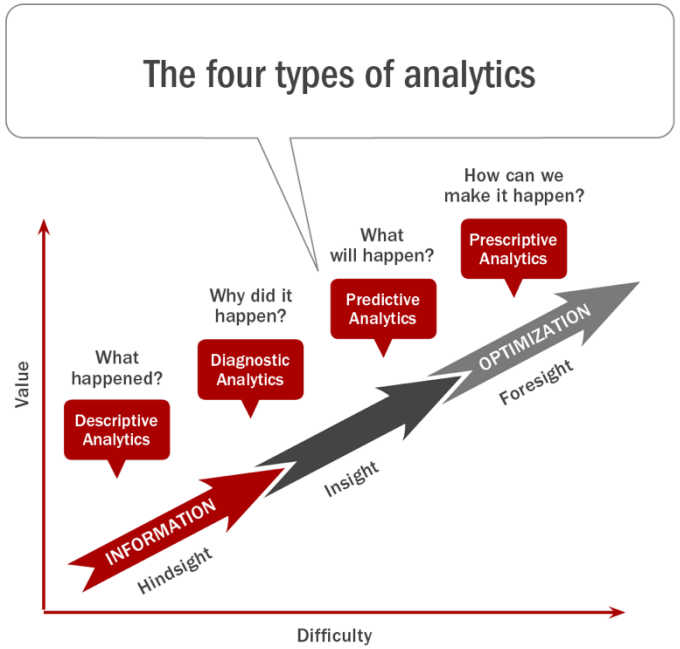
Data Analytics



Source: Gartner © June 2016 The Financial Brand

Data Analytics

- AI is not just for machine learning, but also for decision support. E.g.,
  - London bike hiring scheme developed by Serco and Decision Brain using IBM decision optimization tools.
  - ML to forecast and predict the movements of bikes, customer demand, customer behavior, maintenance time of bikes, …
  - Optimization to decide how to move bikes to the stations in the best possible way and how many bikes to leave in each station for best QoS.



Combinatorial Decision Making

- Properties
  - Computationally difficult (NP-hard in general).
  - Can only be solved by intelligent search.
  - Experimental in nature.
  - Finding good/optimal solutions can save time, $ and reduce environmental impact.
- Many solution techniques
  - Heuristic search (local search, metaheuristics, etc) → FAIKR
  - Complete search methods
    - Constraint Programming (CP) → Mod. I
    - Boolean SATisfiability (SAT) → Mod. I
    - Satisfiability Modulo Theories (SMT) → Mod. II
    - Linear Programming (LP) and Integer LP (ILP) → Mod. II

Course Info

- **Lectures**
  - Theoretical foundations.
  - Practical exercises using personal laptops.
  - Invited lectures by experts in the field.
- **References**
  - Course material and resources: course Virtuale page.
  - A list of reading: course website.

Course Info

- **Tools for exercises**
  - Module I
    - MiniZinc
      - A modeling language with interfaces to several CP (and other) solvers (https://www.minizinc.org/).
    - Z3
      - A SAT/SMT solver (https://github.com/Z3Prover/z3/)
      - Via input in SMT-LIB2 syntax or APIs for Python, C, C++, Java.
    - Download & start getting familiar with them.
  - Module II
    - Z3, CVC5, Python and Gurobi.

Course Info

- **Assessment**
  - One single project for the entire course.
    - Modelling and solving a combinatorial optimization problem in CP, SAT/SMT and ILP.
      - Project work instructions are on Virtuale (start reading it!).
      - Actual problem will be announced during the second module.
      - First learn the theoretical foundations, the tools (MiniZinc, Z3, etc) and practice with small exercises.
    - Unique discussion, with submission and on-line discussion in July'25, Sep'25, Dec'25, Feb'26.
  - Oral exam on the entire course topics during the project discussion.
  - A single mark between 18 and 30L.

Course Info

- **Course engagement**
  - Lectures are important for the oral exam but…
  - Lectures are very important to apply the optimization technology and use the tools successfully.
    - Essential for the project, past students confirm that!
  - Lectures will be recorded.
    - ⚠ ⚠ do not substitute them with attendance ⚠ ⚠
  - Follow the material on the Virtuale page.
    - Use the forum for discussions and exchange of knowledge.
  - Ask questions, don’t be shy ☺
  - Answer questions, don’t be humble ☺

Course Info

- **Important rules**
  - Follow your unibo e-mail regularly for announcements (even after the end of the course for project discussions).
  - DO NOT send us e-mail unless strictly necessary.
    - Read well the provided information.
    - Check the announcements archieve in the Virtuale page.
    - Use the discussion forum in Virtuale to ask everybody.
  - Raise your hand for questions.
    - We will pause regularly for raised hands.

Final Words

- In the meantime…
  - I am responsible for internationalization in master's in AI.
  - As you are notified to be accepted for a study mobility programme 2025/2026 (Erasmus+ study, Overseas, etc), contact me with info on your exchange.
    - I will organize a meeting in April to give information on preparing a Learning Agreement (LA).