Algorithms for a Smarter and more Sustainable World

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Overview

- Part I: ICSO@IN3 - Barcelona
- Part II: R&D for a Smarter World
- Part III: Simheuristics & Learnheuristics
- Part IV: Case Studies
- Part V: Cooperation Opportunities
- Part VI: Conclusions & More
Part I:
ICS@IN3 - Barcelona
(2017 SGR 111 Consolidated RG)
Barcelona: City of Knowledge

6+ inter-connected universities promoting interdisciplinary and international research

Universitat de Barcelona
Introducing the IN3 @ Barcelona (1/2)
Introducing the IN3 @ Barcelona (2/2)

- Internet Interdisciplinary Institute
- Mediterranean Technology Park
Introducing ICSO @ IN3 (1/3)
Introducing ICSO @ IN3 (2/3)

Realizamos

Optimización
Sistemas y procesos más eficientes

Simulación
Análisis de escenarios (what if analysis)

Smart Algorithms
Toma de decisiones inteligente

Distributed Computing
Altas prestaciones computacionales

Data Analytics
Generación de información a partir de los datos

Áreas de aplicación

BRAs, Simheuristics, Learnheuristics

Transporte

Indoor Location

Logística

Collaborate Systems

Producción

Internet computing

http://dpcs.uoc.edu
Introducing ICSO @ IN3 (3/3)
ICSO@IN3 Training in MSc & PhD Programs

Universitat Oberta de Catalunya

MSc Computational Engineering & Maths

Universitat Rovira i Virgili

MSc Informatics & MSc Data Science

Euncet Business School

MSc Business Administration

Universitat Politècnica de Catalunya

PhD Network & ITs

Universitat Autònoma de Barcelona

MSc Logistics & SCM

MSc Aeronautical Management
Industrial Partners & Industrial Doctorates

http://dpcs.uoc.edu
Part II:
R&D for a Smarter World
The world around us is becoming increasingly complex: globalization, freight and people mobility, IoT, e-commerce, sustainability issues, ...
Can we work for a better and more sustainable world? (*wiser world*)
How can we support decision making in a complex world?

**Big Data Analytics**

if \( i \geq \text{maxval} \) then
\[ i \leftarrow 0 \]
else
  if \( i + k \leq \text{maxval} \) then
    \[ i \leftarrow i + k \]
  end if
end if

**Algorithms (Solving & Searching Methods)**
OR/Analytics solve Complex Problems for Business

**Problem**
Pack $m$ items into $n$ bins.

- **7 items into 4 bins**
  - $a=3$

**Model**
Formulate the problem as mathematical model
Use minimal number of bins

$$
\min \sum_{j=1}^{n} y_j
$$

Put each item in exactly one bin

$$\sum_{j=1}^{n} x_{i,j} = 1 \quad \forall i \in 1 \ldots m$$

Observe bin’s capacity

$$\sum_{i=1}^{m} a_i x_{i,j} \leq C y_j \quad \forall j \in 1 \ldots n$$

**Method**
Place each item after the other into the first free bin.

- $j = 1$
- $y_j = 1$
- $r_j = C$

for each item $i$

- flag = true
- for $k = 1$ to $j$

  - if $a_i \leq r_j$ then
    - $r_j = r_j - a_i$
    - $x_{i,j} = 1$
    - flag = false

if flag then

- $j = j + 1$
- $y_j = 1$
- $r_j = C - a_i$
- $x_{i,j} = 1$

**Solution**
3 bins are needed only to pack all 7 items.

$$
\begin{pmatrix}
1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
1 & 1 & 1 & 0
\end{pmatrix}
$$

- **Solution**
  - Bin 1: 8
  - Bin 2: 4
  - Bin 3: 3
  - Bin 4: 2
  - Bin 5: 5
  - Bin 6: 7
  - Bin 7: 1
Main applications areas

- Green Transportation
- Finance
- Internet Computing
- Telecomm. Systems
- Healthcare
- Sustainable Cities
- Logistics
- Production
- e-Commerce
Part III:
Simheuristics & Learnheuristics
Analytics: describe, predict, and prescribe

- **Descriptive Analytics (DA)** → processing **historical** data to describe the real context.

- **Predictive Analytics (PdA)** → forecast the future with time series analysis, regression models, and machine learning methods.

- **Prescriptive Analytics (PsA)** → complex decision-making (optimization-simulation algorithms)

- Anything else? Can’t we go smarter?
Different types of Optimization Algorithms

Exact Methods (lab problems?)

(Meta-) heuristics (real-life problems?)

Matheuristics (real-life problems?)
Yes, but... something is missing...

Real life is plenty of uncertainty!
What if we merge (Meta-) Heuristics with Simulation?

Simheuristics: a smart tool for a complex world

```plaintext
if i ≥ maxval then
  i ← 0
else
  if i + k ≤ maxval then
    i ← i + k
  end if
end if
```
Pros and cons of each solving approach

- **Exact methods**
  - High optimality
  - High scalability
  - High modeling
  - High computing time
  - Low uncertainty
- **Metaheuristics**
  - Moderate optimality
  - Moderate scalability
  - Moderate modeling
  - Moderate computing time
  - Moderate uncertainty
- **Simulation**
  - Low optimality
  - Low scalability
  - Low modeling
  - High computing time
  - Moderate uncertainty
- **Simheuristics**
  - Low optimality
  - Low scalability
  - Low modeling
  - Moderate computing time
  - Low uncertainty
How do simheuristics work?


Use efficient methods from the ‘deterministic world’ to generate promising solutions for the ‘stochastic world’. Then, use simulation feedback to: (a) ‘estimate costs of / validate’ these solutions; and (b) better guide the search process.

In SCOPs, the concept of ‘optimal solution’ has no sense (utility function of the decision maker?). Generate a set of ‘top’ solutions and use risk analysis.

Methodology assumption: in scenarios with moderate uncertainty (variance), high-quality solutions for the deterministic COP are likely to be high-quality solutions for the stochastic COP too.
Some technical details

Stage 1: Metaheuristic + Simulation

‘Short’ simulation of ‘promising’ sols.

Stage 2: Simulation

‘Long’ simulation of ‘elite’ sols.

Stage 3: Analytics

Risk / Reliability Analysis
Open Research Lines (1/2)

- A higher level of simulation-optimization integration (feedback)
- Additional objectives (e.g., variances, percentiles, and tail probabilities)
- Systems of increasing complexity (integrated Logistics & SCM)
- Use of more sophisticated simulation approaches (DES and ABS)
- Enhanced identification of promising solutions (proxy models)
- Statistically significant number of runs (CIs)

Open Research Lines (2/2)

- Extending the application fields (telecomm., finance, smart cities, ...)
- Heuristic-supported simulation (optimization of simulation parameters)
- Integration with machine learning (learnheuristics++)
- Multi-population simheuristics (GAs, PSO, etc.)
- Agent-based simheuristics (parallelized distributed simheuristics)

We are also working on a new concept...

Learn heuristics for dynamic problem settings
COPs with Dynamic Inputs

\[
\begin{align*}
\text{Min } & C(s, I_{OF}(s)) \quad \text{or, alternatively,} \\
\text{Max } & B(s, I_{OF}(s)) \\
\text{subject to: } & Q_j(s, I_C(s)) \leq r_j \quad \forall j \in J \\
& s \in S
\end{align*}
\]
What if we merge (Meta-) Heuristics with Machine Learning?

```
if i ≥ maxval then
  i ← 0
else
  if i + k ≤ maxval then
    i ← i + k
  end if
end if
```

Learnheuristics: a smart tool for a complex and dynamic world
Learnheuristics Basics

Machine learning techniques are integrated in the metaheuristic framework to predict the new inputs as the solution-construction process evolves.

Ex: MDVRP with Market Segmentation

What if customers’ willing to spend (input) is a function of the assigned facility?

A ‘learning’ mechanism must be used during the heuristic search in order to update the inputs at each step.

Part IV:
Case Studies
Data Analytics
Predictive Models: Auctions and Customers@Risk

Logistic Regression models that allow to estimate the probability of success in reverse auctions (e.g., tenders).

Survival Analysis (Reliability), Clustering, and Multiple-Regression models that allow to identify customers “at risk”.

Scatterplot of P(Success) vs Temperature x
Electric Vehicle Routing Problems with Driving Range Limitations
Towards “greener” fleets

Optimizing waste collection in urban areas
Stochastic Waste Collection Problems

Waste collection is a complex optimization problem with various constraints and extensions including time-dependency, closed roads, etc.

Results: Optimized waste collection routes in terms of costs and social impact in the city of Sabadell


Barcelona pondrá sensores en contenedores de basura para avisar cuando estén llenos

El proyecto está desarrollado por investigadores de la Universitat Oberta de Catalunya.

Barcelona. (EFE).- Barcelona instalará sensores electrónicos en los contenedores de basura que indicarán cuándo están llenos o vacíos y que servirán para reducir la circulación de los camiones de recogida y evitar viajes innecesarios, con lo que disminuirá la contaminación generada por este tipo de transporte. Ésta es una de las medidas que desarrolla el proyecto Smartlogistics@ib, una red de investigación creada...
Inventory Routing Problems
Stochastic Inventory Routing Problems


Goal: To analyze how Vendor Management Inventories strategies and policies can impact on the total supply chain costs.

Results: a methodology to determine the refill policy that should be applied to optimize the overall efficiency of the SC.
Optimizing location of charging stations and hubs
Facility Location Decisions


Results: a fast method to obtain near-optimal solutions for the stochastic UFLP.

Observation: In stochastic problems, indicators other than expected cost must be considered.

In this work, the simulation feedback is also used to ‘drive’ the metaheuristic behavior (stochastic driven base selection in an ILS/VNS framework)


Physical Internet & Global Networks

Improving efficiency of global distribution systems by imitating how the Internet works.

Simulation based on product distribution flow to two top retailers in France, from their 100 top suppliers

- Current flows
- Physical Internet flows
- Physical Internet traffic
2L Vehicle Routing Problems


Team Orienteering Problem (UAVs)
Team Orienteering Problem (UAVs)

Exploring new paradigms on the use of teams of aerial drones with limited batteries.

Reliability issues need to be considered, too.

Price Discount for Flexibility

Analyzing scenarios with price-discount for flexibility in the delivery day.

Inventories Reallocation

Re-allocation of valuable inventories (e.g., fresh fruit) among supermarkets in the same city.

Trade Credit Risk Analysis

Rich Portfolio Optimization


\[ \min f(X) = \sum_{i=1}^{n} \sum_{j=1}^{n} \sigma_{ij} x_i x_j \]

Subject to:

\[ \sum_{i=1}^{n} r_i x_i \geq R \]
\[ \sum_{i=1}^{n} x_i = 1 \]
\[ k_{\min} \leq \sum_{i=1}^{n} z_i \leq k_{\max} \]

\[ 0 \leq x_i \leq 1, \quad \forall i \in \{1, 2, \ldots, n\} \]
\[ a_i z_i \leq x_i \leq b_i z_i, \quad \forall i \in \{1, 2, \ldots, n\} \]
\[ x_i \leq z_i \leq p_i, \quad \forall i \in \{1, 2, \ldots, n\} \]
\[ z_i \in \{0, 1\}, \quad \forall i \in \{1, 2, \ldots, n\} \]

In real-life, assets’ returns are random variables → probabilistic constraint (simheuristics)

Cardinality constraint

NP-hard

Unconstrained Efficient Frontier (UEF)
Stochastic Project Portfolio Optimization

Realistic POPs (NP-hard in nature) + Uncertainty => Simheuristic algorithms are needed

Results: using the optimal solution for the deterministic and simplified POP will yield suboptimal results

## Predictive Models for Cat Bonds


<table>
<thead>
<tr>
<th>Technique</th>
<th>Error</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Time (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearest Neighbours classifier</td>
<td>0.18%</td>
<td>99.84%</td>
<td><strong>94.44%</strong></td>
<td>7.22</td>
</tr>
<tr>
<td>Naïve Bayes classifier</td>
<td>0.77%</td>
<td>99.58%</td>
<td>4.35%</td>
<td>1.62</td>
</tr>
<tr>
<td>Linear Discriminant Analysis</td>
<td>0.64%</td>
<td>99.57%</td>
<td>0.00%</td>
<td>0.28</td>
</tr>
<tr>
<td>Quadratic Discriminant Analysis</td>
<td>0.42%</td>
<td>99.63%</td>
<td>57.14%</td>
<td><strong>0.12</strong></td>
</tr>
<tr>
<td>Classification Trees</td>
<td>0.24%</td>
<td>99.79%</td>
<td>87.50%</td>
<td>2.62</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>0.45%</td>
<td>99.58%</td>
<td>33.33%</td>
<td>0.87</td>
</tr>
<tr>
<td>Cluster-wise Logistic Regression</td>
<td>0.43%</td>
<td>99.57%</td>
<td>undefined</td>
<td>5.7</td>
</tr>
<tr>
<td>Neural Networks</td>
<td><strong>0.14%</strong></td>
<td><strong>99.94%</strong></td>
<td>82.14%</td>
<td>190.86</td>
</tr>
<tr>
<td>Support Vector Machines</td>
<td>0.27%</td>
<td>99.78%</td>
<td>81.25%</td>
<td>161.25</td>
</tr>
<tr>
<td>Evolutionary Algorithm (Franco, 2010)</td>
<td>0.34%</td>
<td>99.86%</td>
<td>55.56%</td>
<td>hours</td>
</tr>
</tbody>
</table>

![Image of earthquake impact areas](image-url)
Volunteer Computing over the Internet


A Discrete-Event Simulation is combined with a metaheuristic framework to design efficient network configurations with probabilistic availability.
Optimizing production systems under uncertainty
Stochastic Flow Shop Problem

Jobs are processed by machines

Result: optimize expected makespan and find more reliable solutions.


Stochastic Distributed Scheduling

Which are the right starting times for each of the lines in a distributed project with stochastic processing times?


Results: an extension of the previous algorithm for distributed scheduling.
Optimizing airline crew scheduling
Social Responsible Crew Rostering

Part V: Cooperation Opportunities
ICSO@IN3 Cooperation with Industrial Partners

- Contracted R&D Projects (OSRT)
- Industrial Doctorates (SGR)
- H2020 and Spanish R&D Calls
- MSc and PhD Sponsored Grants
- Chairs and Altruistic Donations
- Students’ Internships

http://dpcs.uoc.edu
The Industrial Doctorate Programme @ ICSO (SGR)

INDUSTRIAL DOCTORATE PROJECT

COMPANY: Strategic research project

UNIVERSITY: RESEARCH INSTITUTIONS

DOCTORAND

Innovation and competitiveness

Technology and Knowledge transfer

Doctoral thesis

Private companies with a workplace in Catalonia (regardless of the location of their headquarters)
**H2020 Calls @ ICSO for 2018/2019**

**Intelligent, Sustainable, and Resilient Transport & Smart City Logistics**

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**CALL: MARIE SKŁODOWSKA-CURIE INNOVATIVE TRAINING NETWORKS**

Call identifier: H2020-MSCA-ITN-2019  
Publication date: 27 October 2017

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**TOPIC:** Logistics solutions that deal with requirements of the 'on demand economy' and for shared-connected and low-emission logistics operations

- **Topic identifier:** LC-MG-1-10-2019  
- **Publication date:** 27 October 2017  
- **Focus area:** Building a low-carbon, climate resilient future (LC)
Part VI: Conclusions & More
Conclusions...

- Real-life systems are increasingly complex (e.g., smart cities, SCMs, financial and telecom. systems)

- Being ‘smart’ is not enough, sustainability issues need to be considered as well.

- Simheuristics & Learnheuristics combine metaheuristics with simulation and machine learning to deal with uncertainty and dynamism.

- ‘Unlimited’ applications to L&T, SCM, smart cities, computational finance, IoT, telecommunication systems, etc.

- More than ever, enterprises and research centers must establish alliances to develop smart and sustainable strategies in a global and evolving market.
Call for applications for postdoctoral research stays at the UOC

SmartTransLog@EU: Erasmus+ Consortium

UOC - Doctoral School grants programme

01/02/2018

Smart Transportation & Logistics in EU

https://smarttranslog.wordpress.com
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thanks!