LAAS Days
Research & Technology

Combinatorial optimization methods for energy management

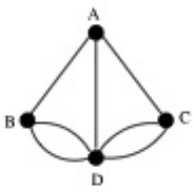
Sandra Ulrich Ngueveu

ngueveu@laas.fr

Combinatorial optimization

Operations research (maths + algorithmics + computer sc.) to solve decision pbs

Combinatorial explosion : $O(n!)$ solutions



20 nodes $\approx 1e^{17}$ solutions

> ”Brute-Force” Method

Nodes		
10		
15		
19		
27		
35		
40		
50		

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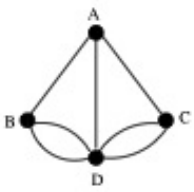

20 nodes $\approx 1e^{17}$ solutions

- ”Brute-Force” Method
- Proc. 3GHz : 3 op / nano second

Nodes	Proc. 3 GHz	
10	1/100s	
15	1 h	
19	1 an	
27	8× age univers	
35	?	
40	?	
50	?	

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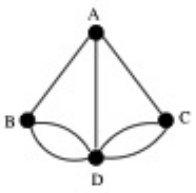

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- Proc. 3GHz : 3 op / nano second
- Proc. Planck : 1 op / Planck time (5.39×10^{-44})s

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35	?	5/1000s
40	?	12 ans
50	?	4000× age univers

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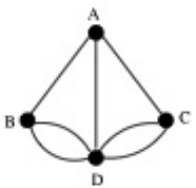

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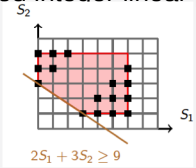
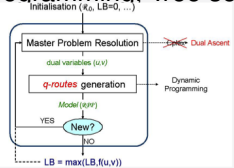
Theoretical analysis of classes of problems and generic solution methods

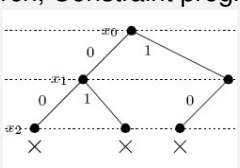
Solving combinatorial optimization problems

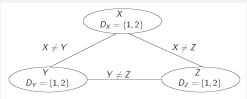
Powerful tools and methods

Mixed integer linear programming, Tree search, Constraint programming, etc.









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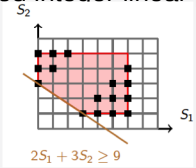
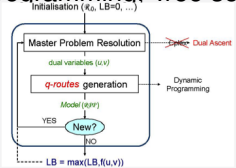
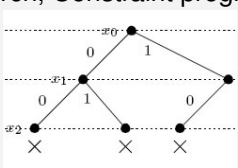
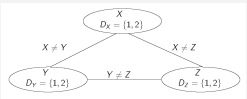
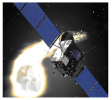


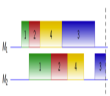




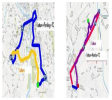


Various applications





	6		1	4		5		
		8	3		5	6		
2								1
8			4		7			6
		6				3		
7			9		1			4
5								2
		7	2		6	9		
4			5		8		7	

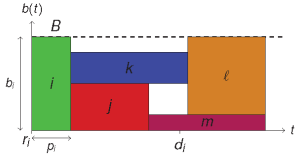


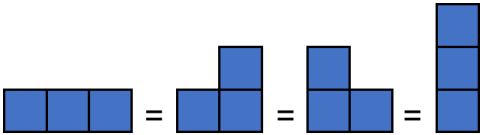
When tackling a practical problem, there are two elements to consider : the modeling phase and the solving phase (decomposition methods, ...)

LAAS research on energy and combinatorial problems

Before 2008-2010 :

- Energetic resources : equivalent to man-hours / materials / machines

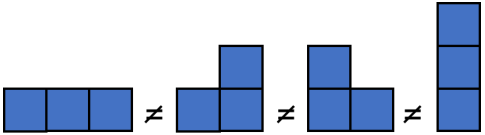




Energetic reasoning (P. Lopez 90s), RCPSP with energy resources (C. Artigues et al.), etc.

After 2010

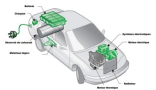
- Energy sources : energy transfer, energy losses, dynamics

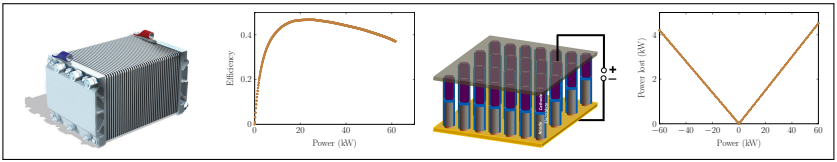


Combinatorial optimization with energy sources Nattaf et al, S.U. Nguevеu et al 90s,

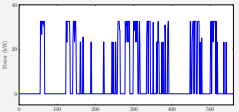
Energy optimization in hybrid electric vehicles

Energy sources characteristics : power limits (kW), efficiency (%), capacity (kWs) ...



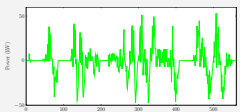


Find per instant the optimal power split between energy sources to minimize the total fuel consumption.



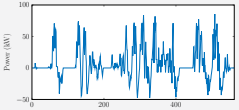
Power from FC

+



Power from/to SE

=

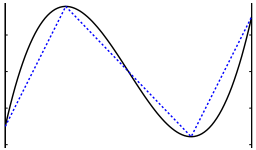


Total power provided

Difficulties when considering real energy sources

Modeling phase

- Intrinsic non linearities : non linear conversion/consumption functions
  - approximate with piecewise linear functions



  - MINLP solution methods

Solving phase

Difficulties when considering real energy sources

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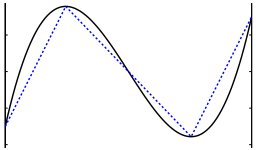

+ (more) tractable problems
- try and error approach : No guarantees on the solution quality, undefined number of iterations
- global optimality cannot be guaranteed

  - MINLP solution methods

Solving phase

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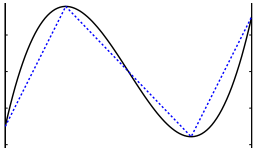

+ (more) tractable problems
- try and error approach : No guarantees on the solution quality, undefined number of iterations
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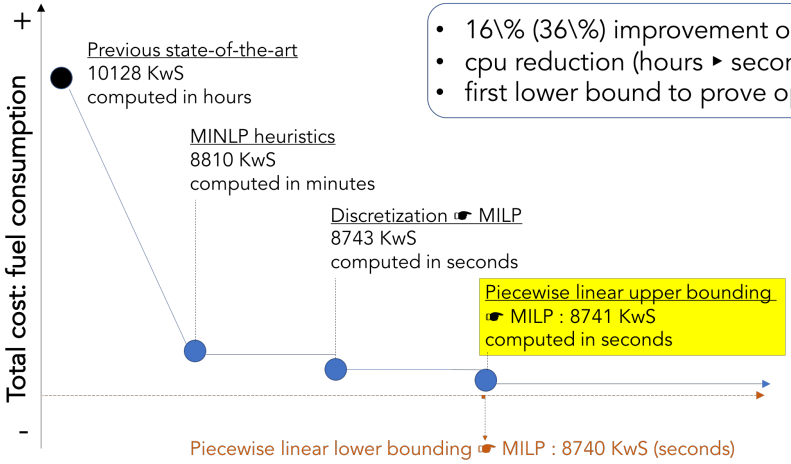
  - MINLP solution methods

+ global optimality guaranteed if carried out to completion
- only for small/medium instances

Solving phase

Results obtained for hybrid electric vehicules

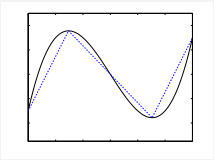


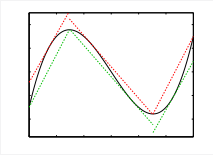
- 16\% (36\%) improvement over state-of-the-art
- cpu reduction (hours ▸ seconds)
- first lower bound to prove optimality gap 0.01\%

How it works, Why it works

New two-step solution scheme : (Ngueveu et al., 2014, 2016, 2018)

Step 1 : Piecewise linear bounding of the nonlinear energy transfer/efficiency functions





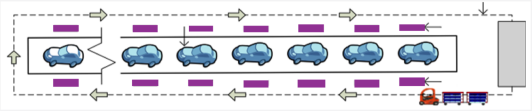
Step 2 : Reformulation of the problem into two mixed integer problems (MILP)

- solve with a black box MILP solver
- or design a dedicated solution method (only one needed)

3rd Robert Faure ROADEF prize 2018 (https ://www.laas.fr/public/fr/node/1741)

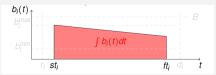
What happens if the problem is not easy to solve ?

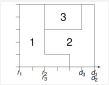
Energy aware-feeding system (production line)



minimize Energy consumption and Work-in Process

Energetic resources w non linear conversion functions

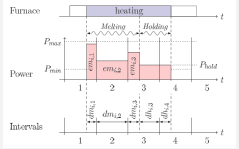


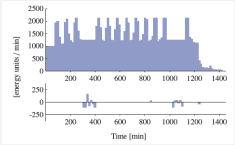


constraint propagation algorithms : “Energy reasoning”

C. Artigues, C .Briand, E. Hébrard, N. Jozefowiez, P. Lopez, S. U. Ngueveu + A. Haït (ass. res.).
4 phD : M. Guemri (2013), Y. Gaoua (2014), M. Nattaf (2016), Y. He (2017). 1 postdoc : G. Simonin (2012–2014) Several interships

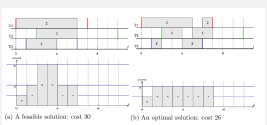
Production scheduling with energy costs, case study : foundry (Min energy cost) / steel plant (load tracking)

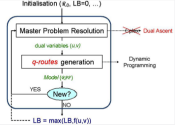




hybrid MILP/CP method, mixed continuous/discrete models

Scheduling at minimal energy consumption cost

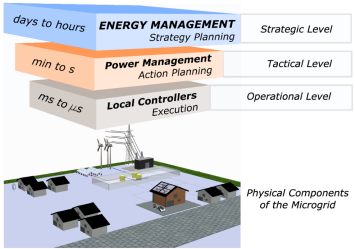


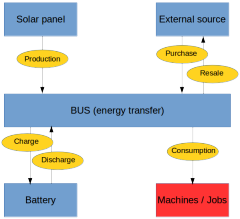


Dantzig-Wolfe decomposition, column generation method

Focus on LAAS Project OPA

Our interest : Long term / short term planning / link with control





Poster and demonstrations tomorrow during your visit of the platform ☺

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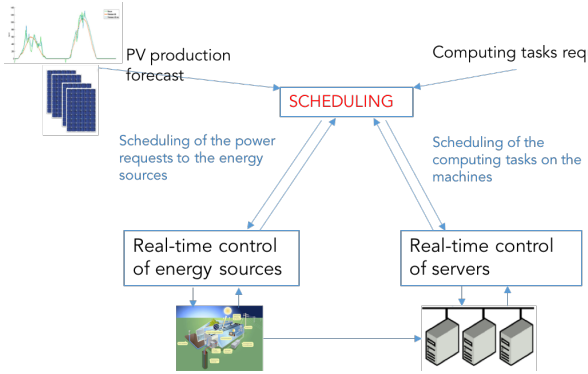
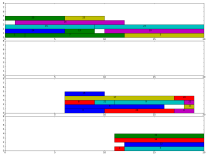
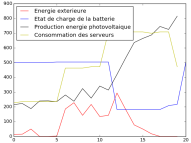
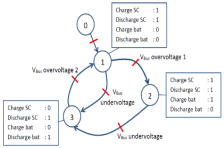
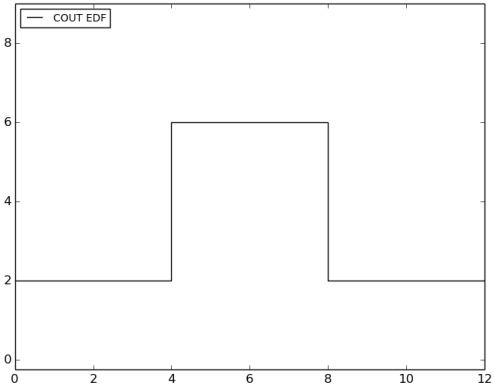








Illustrative example



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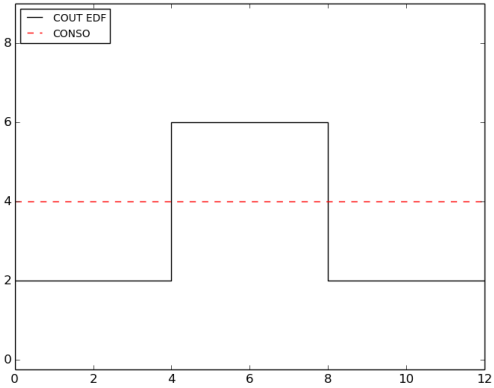

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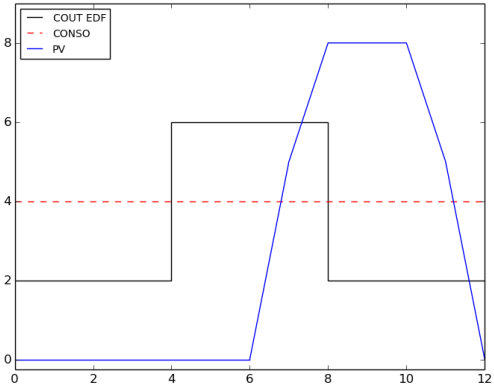

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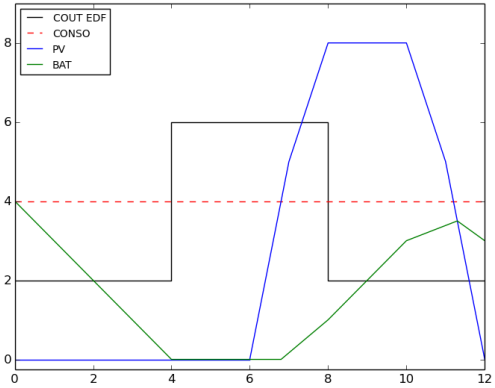

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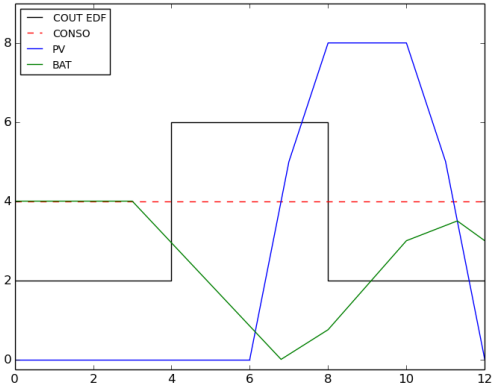

Thank you for your attention.