LocalSolver: recent advances in solving hydro valley optimization problems

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www.localsolver.com

Who we are

Bouygues, one of the French largest corporation, €33 bn in revenues
http://www.bouygues.com

Operations Research subsidiary of Bouygues
15 years of practice and research
http://www.innovation24.fr

Mathematical optimization solver commercialized by Innovation 24
http://www.localsolver.com

LocalSolver 4.5

Quick tour

Combinatorial optimization

P-median: select a subset P among N points minimizing the sum of distances to each point from N to the nearest point in P.

```
function model() {
  x[1..N] <- bool() ; // decision : point i is in P iff x[i] = 1

  constraint sum[i in 1..N](x[i]) == P ;

  minDist[i in 1..N] <- min[j in 1..N](x[j] ? Dist[i][j] : InfiniteDist);

  minimize sum[i in 1..N]( minDist[i] ) ; // minimize sum of distances
}
```

Nothing else to write: “model & run” approach

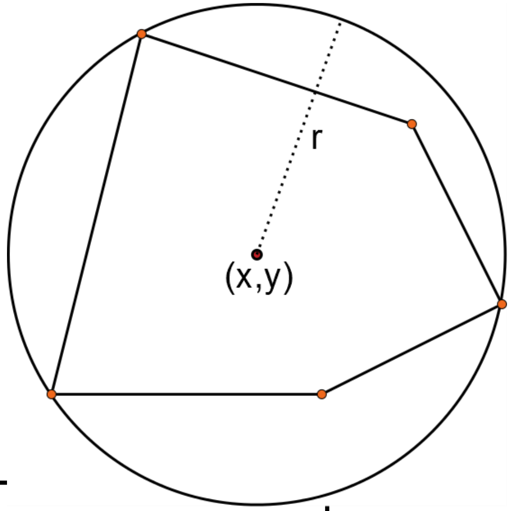
- Straightforward mathematical model
- Direct resolution: no tuning

Numerical optimization

Smallest circle: find a circle with minimal radius which contains a set of points in the plane.

Quantitative (continuous) decisions

Quadratic expression




```
x <- float(minX, maxX);
y <- float(minY, maxY);

r2 <- max[i in 1..n](pow(x-coordX[i],2) + pow(y-coordY[i],2));

minimize sqrt(r2);
```

Mathematical operators

Decisional	Arithmetic			Logical	Relational
bool	sum	sub	prod	not	==
float	min	max	abs	and	!=
int	div	mod	sqrt	or	<=
	log	exp	pow	xor	>=
	cos	sin	tan	if	<
	floor	ceil	round	array + at	>

What's inside?

Using local search as global search strategy

- Local search means "neighborhood search"
- To speed up the search with fast small-neighborhood explorations
- To scale by adapting the kind and size of neighborhoods explored
- To use different optimization techniques to explore neighborhoods at best

Ex: instead of embedding local search into tree search, we view tree search as a way to explore exponential-size neighborhoods

Separating solution search/optimization from lower bounding

- Under development…

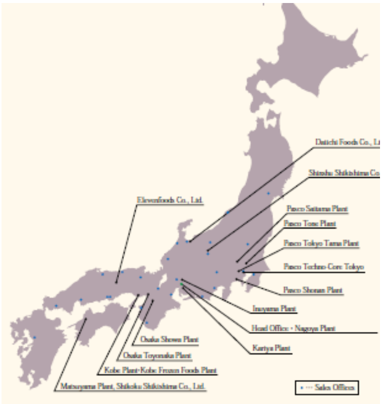
Supply chain optimization

Global supply chain optimization

- Both production and logistics optimization
- 10 factories, each with several production lines
- Large number of stores and distribution centers

A challenging context for LocalSolver

- 20,000,000 variables including 3 million binaries
- Rich model involving setup costs, delivery times, packaging, etc.
- Vain attempts to solve the problem with MIP solvers
- LocalSolver finds high-quality solutions in 5 minutes



Hydro valley optimization

Unit commitment

A classics in mathematical optimization

- Power plants to manage: thermal, hydro, nuclear
- Demands to meet over a number of time steps
- Plant management constraints: min/max power, min off, min on, ramps, etc.
- Piecewise linear or quadratic costs

→ Nonlinear, heterogeneous, ultra-large dynamic system with mixed-variable (on/off + quantitative) decisions and coupling constraints

Generally tackled through decomposition + approximation
Subproblems solved using DP or MILP/MIQP approaches

Hydro valley optimization

Management of hydro valleys

- Hydroelectric dams with pumps
- Forecasted/approximate energy prices over the horizon
  Or thermal power plants to manage for pricing
- From daily to yearly horizon

→ Nonlinear large-scale dynamic system with mixed-variable (on/off + quantitative) decisions and tight coupling constraints

Solved through MIP solvers by approximating/relaxing nonlinearities

Difficulties

Mixed, layered decisions

- Combinatorial on/off decisions
- Quantitative production decisions
- Two layers of decisions → structures

Hard coupling constraints

- Hard constraints on on/off decisions (ex: ramping constraints)
- Hard constraints on quantitative decisions (ex: flows with tight capacities)

Nonlinearities

- Piecewise-linear constraints and costs
- Quadratic (possibly non-convex) constraints and costs

→ Poor linear relaxation, hard for rounding & diving MIP heuristics

LocalSolver approach

Structure detection

Automatic detection of layered decisions

- Detection of the link between on/off and quantitative layers
- Allow to search on structured subspaces
- Allow to recover feasibility easier and faster at each iteration

Automatic detection of global constraints (= subproblems)

- Linear/convex knapsack subproblems
- Dynamic nonlinear systems: s(t) = s(t-1) + f(not depending on s)
- Allow to apply specific algorithms to solve these subproblems

→ Relying on structures to improve and speedup the search

Structured neighborhood search

Neighborhood search over combinatorial subspace

- Move on/off decisions locally
- Recover feasibility over combinatorial constraints using local or tree search

Neighborhood or greedy search over quantitative subspace

- Recover feasibility over continuous subspace
- Based on a continuous randomized local search approach
- Based on a randomized greedy approach: efficient on subproblems not so constrained, with ordered decisions (in particular, chronologically ordered)
- If the subproblem has a nice identified structure, specific exact or approximate algorithms could be employed to solve it (ex: knapsack)

→ Relying on the appropriate optimization techniques to explore efficiently the appropriate neighborhoods

Benchmarks

Unit commitment: hydro + thermal

Prototyped problem coming from KEPCO

- 1-year global optimization of all hydro + thermal power units
- 100-line model using LocalSolver modeling & scripting language (LSP)
- Mixed decisions: boolean (on/off) and continuous (power)

- Business scale:
  365 * 24 = 8760 time steps
  30 thermal power units
  4 dams and 18 hydro power units
- Mathematical scale:
  3 M expressions (= variables)
  1 M decisions whose 560,000 are binaries
  80,000 constraints

Unit commitment: hydro + thermal

Prototyped problem coming from KEPCO

- No solution after hours using MIP
- LocalSolver 5.0 beta:

1 sec	483,805,637
1 min	483,639,031
10 min	483,632,703

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Total cost without using dams: 483,805,637

Lower bound based on linear relaxation: 483,338,873

LocalSolver

Hydro valley optimization

Real-life problem coming from EDF

- Optimizing the hydro power yield for <u>one</u> valley
- 600-line model using LocalSolver modeling & scripting language (LSP)
- Model migrated from a MIP implementation
- Using LocalSolver modeling formalism, all variables are continuous
- Standard valley: 25,000 variables | Large valley: 200,000 variables

lsTimeLimit=60 sec				
Lower is better	Standard valley		Large valley	
	4.5	5.0 beta	4.5	5.0 beta
lsSeed=0	8,475	4,580	235,961	-15,978
lsSeed=1	21,881	4,894	230,777	63,834
lsSeed=2	X	4,852	369,711	1,805
lsSeed=3	7,954	4,876	199,679	17,562
lsSeed=4	X	5,193	300,101	-1,149
Average	12,770	4,879	267,246	13,215

Ongoing and future works

KEPCO hydro + thermal problem

- Enriched model with more operating constraints
- Feasibility becomes challenging

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EDF hydro problem

- Refined model coming from EDF R&D
- Mixing integer and continuous decisions
- Big valley -> big instance:
  1 million expressions
  900,000 continuous decisions representing hydro yields
  1000 integers representing 5-10 operating points of hydro units
- Also work to be ready to support more operating constraints

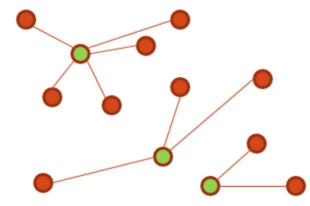
eDF

LocalSolver 5.0 – December 2014

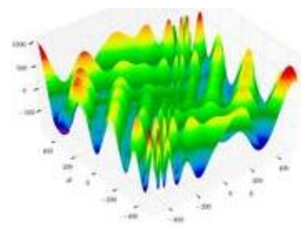
Hybrid math programming solver

LocalSolver
=
LS + CP/SAT + LP/MIP + NLP

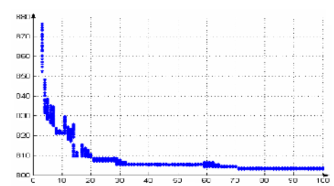
For combinatorial, numerical,
or mixed-variable optimization



Particularly suited for large-scale
non-convex optimization



High-quality solutions in seconds
without tuning



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