Optimal Design with FilMINT

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Summary

Many design applications involve both continuous and integer variables and lead to mixed-integer nonlinear programs. Applications of interest to DOE include the nuclear reactor core-reloading operation, the synthesis of FutureGen, the planned zero-emission power plant, and the design of a thermal insulation system for the Large Hadron Collider. We have developed an efficient solver for such problems. Our new solver outperforms existing solvers on a wide range of test problems. We have applied the solver in a case study to design a load-bearing thermal insulation system. Our solver reduced previous "optimal" solutions by 4%.

Enabling Computational Design. We have developed a new computational tool to solve the mixed-integer nonlinear programs (MINLPs) that arise in optimal design applications. The solver implements a linearization-based algorithm, illustrated in Figure 1. The new solver, FilMINT, combines the MINTO branch-and-cut framework for MILP with filterSQP used to solve the nonlinear programs that arise as subproblems in the algorithm. The MINTO framework allows us to easily extend cutting planes, primal heuristics, and other well-known MILP enhancements to MINLPs.

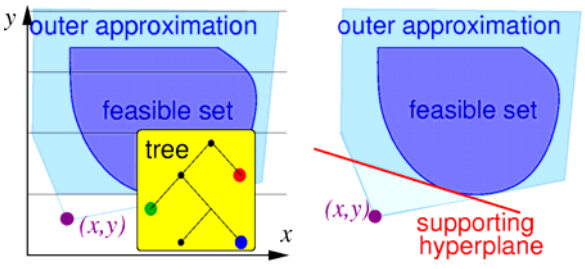

Fig. 1: Branch-and-cut approach.

Detailed computational experiments show the benefit of such advanced MILP techniques. Figure 2 shows a comparison to existing MINLP solvers and highlights the effectiveness of FilMINT. The figure shows a performance profile, the result of over 600 MINLP problems. Performance profiles estimate the probability that a solver's performance is within a factor *n* of the best solver. The blue line corresponding to FilMINT dominates the other solvers, which illustrating its superior performance.

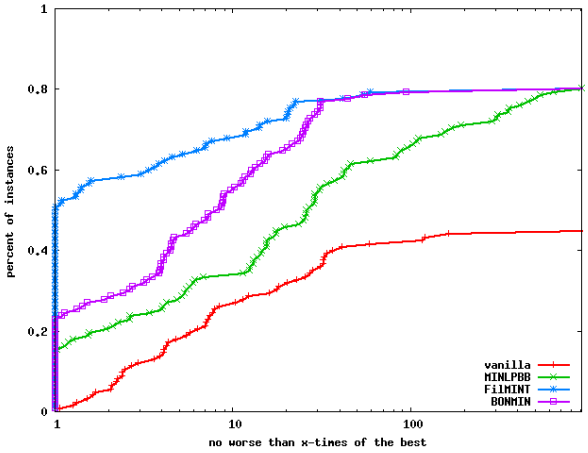

Fig. 2: Performance of FilMINT.

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Design of a Thermal Insulation System. We have applied our new solver to the design of a load-bearing thermal insulation system. This system uses a series of heat intercepts and insulators to minimize the power required to maintain the heat intercepts at certain temperatures so that the cold surface can be maintained at the required temperature. Figure 3 shows the conceptual design. The designer chooses the insulator material, the widths of the intercepts, and the number of intercepts. The heat flow between the intercepts, thermal expansion, and the stress constraint give rise to nonlinear equations.

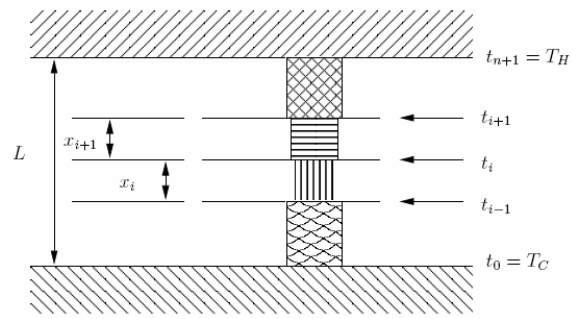

Fig. 3: Thermal insulation system.

Problems of this type arise in the design of superconducting magnetic energy storage systems, space borne magnets and have been used in the Large Hadron Collider project.

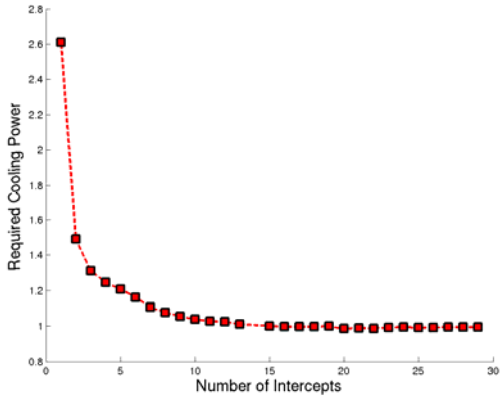

Fig. 4: Cooling power vs. intercept count.

Our solver reduced previous "optimal" solutions by 4%. This reduction is due largely to our ability to handle a greater number of intercepts than previously possible. Figure 4 shows the cooling power as a function of the number of intercepts. Previous designs had used up to 10 intercepts, a number that is clearly suboptimal.

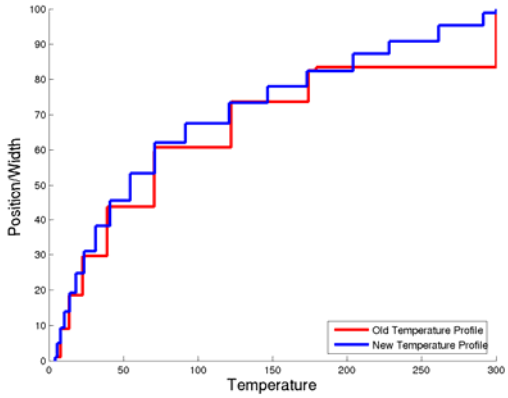

Fig. 5: Temperature profile (blue optimal).

The optimal temperature profile of the new design is shown as the blue curve in Figure 5, compared to the red curve for the previous suboptimal design. The area between the two profiles corresponds to the savings in cooling power.

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