An Advanced Answer Set Programming Encoding for Nurse Scheduling

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Nurse Scheduling Problem (NSP)

NSP amounts to the totalization of partial schedules assigning nurses to working and rest days over a predetermined period of time.
Admissible schedules must satisfy the following set of requirements:

- **Hospital requirements.** For every working day, nurses can be assigned to exactly one of the following shifts: *morning* (7 A.M. – 2 P.M.), *afternoon* (2 P.M. – 9 P.M.), *night* (9 P.M. – 7 A.M.). In order to ensure the best assistance program for patients, the number of nurses in every shift $x \in \{morning, afternoon, night\}$ must range from x_{min}^{nurse} to x_{max}^{nurse}.
- **Nurses requirements.** In order to guarantee a fair workload, each nurse must work a number of hours ranging from $work_{min}$ to $work_{max}$. Additional requirements are also imposed to ensure an adequate rest period to each nurse:
  (a) nurses are legally guaranteed 30 days of paid vacation;
  (b) the starting time of a shift must be at least 24 hours later than the starting time of the previous shift;
  (c) each nurse has at least two ordinary rest days for every window of fourteen days; and
  (d) nurses working on two consecutive nights deserve one special rest day in addition to the ordinary rest days.
- **Balance requirements.** The number of morning, afternoon and night shifts assigned to every nurse should range over a set of acceptable values, that is, from x_{min}^{day} to x_{max}^{day} for each $x \in \{morning, afternoon, night\}$.
- **Optimal balance requirements (NSP^o).** The number of morning, afternoon and night shifts assigned to every nurse should be *preferably* fixed to some desired values, that is, x^{day} for each $x \in \{morning, afternoon, night\}$.

Existing ASP Solution

NSP has been modeled by means of an Answer Set Programming (ASP) encoding presented in [1].

Pros:

- Natural and intuitive encoding, in the sense that it was designed by applying the standard modeling methodology.
- Reasonable performance on solving the analyzed instances.

Cons:

- Shows some limitations and intrinsic weaknesses, mainly due to *aggregates*, since it presents some aggregates with a quite large number of literals and few different weights, resulting to be counterproductive for the performance of modern ASP solvers, since they decrease their propagation power.

Contributions

The main contributions of the paper are the following:

- We formalize the variant of NSP considered in this paper and in [1].
- We propose a new ASP-based solution to NSP overcoming some limitations of the encoding presented in [1].
- We present an experimental analysis comparing the ASP solution proposed in this paper with the previous one as well as with SAT and ILP based solutions. Results show a significant improvement of the performance of ASP solvers and, specifically, CLINGO performs better than all other alternatives.

Real Data Evaluation

- One year schedule using requirements provided by an Italian hospital.
- Considered 41 nurses working at the Italian hospital.
- Holidays selected according to nurse preferences of 2015.
- Tested approaches NSP^d: ASP (solvers CLINGO and WASP), SAT (solvers GLUCOSE and LINGELING), ILP (solver GUROBI)
- Tested approaches NSP^o: ASP (solvers CLINGO and WASP), MaxSAT (solvers MSCG and MAXINO), ILP (solver GUROBI)

NSP^d		NSP^o	
Solver	**Time (s)**	**Solver**	**Time (s)**
CLINGO (ORIG ENC)	1352	CLINGO (ORIG ENC)	431
CLINGO (ADV ENC)	43	CLINGO (ADV ENC)	70
WASP (ORIG ENC)	-	WASP (ORIG ENC)	-
WASP (ADV ENC)	-	WASP (ADV ENC)	-
GLUCOSE (SAT ENC)	-	MSCG (MAXSAT ENC)	-
LINGELING (SAT ENC)	-	MAXINO (MAXSAT ENC)	-
CLASP (SAT ENC)	-	CLASP (MAXSAT ENC)	-
GUROBI (ILP ENC)	1018	GUROBI (ILP ENC)	1073

Scalability

- One year schedule using requirements provided by an Italian hospital.
- Scalability of the approach considering different number of nurses.
- Holidays selected randomly.

	Solver	**Nurses**				
		10	**20**	**41**	**82**	**164**
NSP^d	CLINGO (ORIG ENC)	155	117	738	1486	2987
	CLINGO (ADV ENC)	4	9	70	351	1291
	WASP (ORIG ENC)	-	-	-	-	-
	WASP (ADV ENC)	5	20	-	-	-
	GLUCOSE (SAT ENC)	-	-	-	-	-
	LINGELING (SAT ENC)	-	-	-	-	-
	CLASP (SAT ENC)	-	-	-	-	-
	GUROBI (ILP ENC)	62	172	1018	-	-
NSP^o	CLINGO (ORIG ENC)	37	94	339	798	1689
	CLINGO (ADV ENC)	4	13	72	482	1590
	WASP (ORIG ENC)	-	-	-	-	-
	WASP (ADV ENC)	4	-	-	-	-
	MSCG (MAXSAT ENC)	-	-	-	-	-
	MAXINO (MAXSAT ENC)	-	-	-	-	-
	CLASP (MAXSAT ENC)	-	-	-	-	-
	GUROBI (ILP ENC)	113	411	2004	-	-

References

[1] C. Dodaro and M. Maratea.
Nurse scheduling via answer set programming.
In *LPNMR*, volume 10377 of *LNCS*, pages 301–307. Springer, 2017.