

FACULTY OF ECONOMICS
AND BUSINESS ADMINISTRATION

An Artificial Immune System Based Approach for Solving the Nurse Re-rostering Problem

Broos Maenhout[1] and Mario Vanhoucke[1,2,3]
[1]Faculty of Economics and Business Administration, Ghent University (Belgium)
[2]Vlerick Business School, Ghent (Belgium)
[3]University College London, London (UK)

EvoCOP 2013 - Vienna, Austria



Outline

- Problem description
- An AIS for the Nurse Rerostering Problem
- Computational Results
- Conclusions

Outline

- Problem description
- An AIS for the Nurse Rerostering Problem
- Computational Results
- Conclusions

Problem definition

- Starting point = NSP solution

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Nurse 1	E	E	F	F	E	N	F	F	L	N
Nurse 2	N	N	N	F	F	F	F	L	L	L
Nurse 3	E	E	L	L	F	F	L	N	F	F
Nurse 4	L	L	F	F	L	L	L	N	F	F
Nurse 5	F	F	E	E	L	L	F	F	E	L
Nurse 6	F	N	N	N	F	E	N	F	F	E
Nurse 7	F	F	F	E	N	N	N	F	N	N
Nurse 8	F	F	L	L	N	F	F	E	E	E
Nurse 9	N	F	E	N	F	F	E	L	N	F
Nurse 10	L	L	F	F	E	E	E	E	F	F
$\sum_i x'_{ijE}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijL}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijN}$	2	2	2	2	2	2	2	2	2	2

Problem definition

- Schedule disruptions disturb the original nurse roster

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Nurse 1	E	E	F	F	E	N	F	F	L	N
Nurse 2	N	N	N	F	F	F	F	L	L	L
Nurse 3	E	E	L	L	F	F	L	N	F	F
Nurse 4	L	L	F	F	L	L	L	N	F	F
Nurse 5	F	F	E	E	L	L	F	F	E	L
Nurse 6	F	N	N	N	F	E	N	F	F	E
Nurse 7	F	F	F	E	N	N	N	F	N	N
Nurse 8	F	F	L	L	N	F	F	E	E	E
Nurse 9	N	F	E	N	F	F	E	L	N	F
Nurse 10	L	L	F	F	E	E	E	E	F	F
$\sum_i x'_{ijE}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijL}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijN}$	2	2	2	2	2	2	2	2	2	2

Problem definition

- Restore feasibility by changing the original roster

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Nurse 1	E	E	F	F	N	N	F	F	L	N
Nurse 2	N	N	N	F	F	F	F	L	L	L
Nurse 3	E	E	F	L	L	F	L	N	F	F
Nurse 4	L	L	L	F	F	L	L	N	F	F
Nurse 5	F	F	F	E	L	L	N	F	E	L
Nurse 6	F	N	N	N	F	F	F	E	E	E
Nurse 7	F	F	E	E	E	E	F	F	N	N
Nurse 8	F	F	L	L	N	N	N	F	F	E
Nurse 9	N	F	E	N	F	F	E	L	N	F
Nurse 10	L	L	F	F	E	E	E	E	F	F
$\sum_i x'_{ijE}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijL}$	2	2	2	2	2	2	2	2	2	2
$\sum_i x'_{ijN}$	2	2	2	2	2	2	2	2	2	2

Adapted assignments

Broos Maenhout - April 5, 2013

Problem settings

- Constraints
  - Time-related constraints — HARD
    - cfr NSP
    - Different constraint types (e.g. number of working assignments, number of consecutive assignments)
  - Staffing requirements — SOFT
  - Disruption constraints — SOFT
    - Deterministic environment

Problem settings

- Objectives

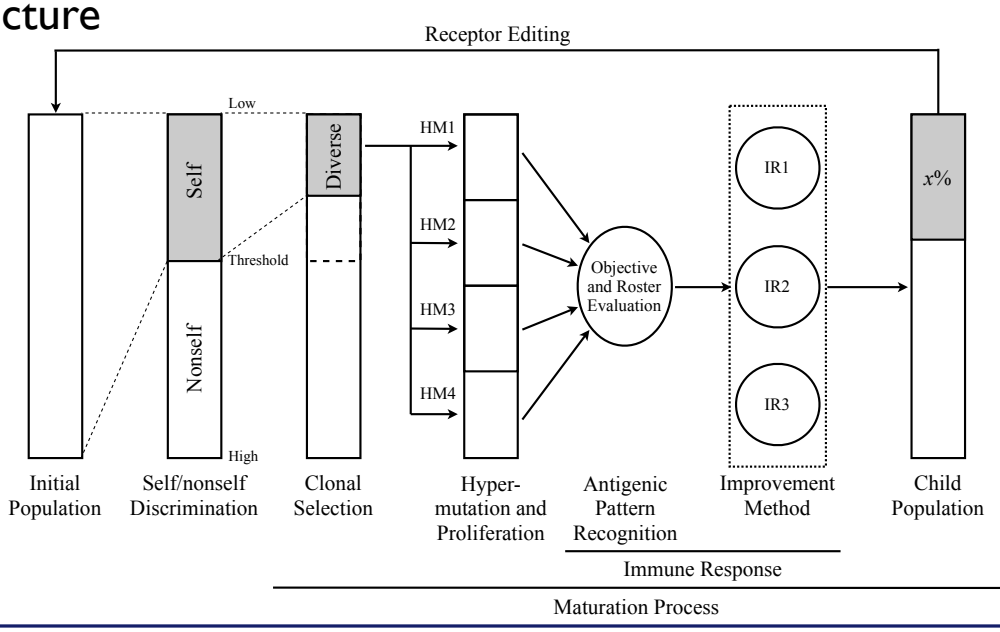
	Importance
Infeasibilities due to schedule disruptions	+++++
Service continuity	++++
Efficient staffing	+++
Fairness	+
Nurse preferences	++

= Retain the original schedule as best as possible

Outline

- Problem description
- An AIS for the Nurse Rerostering Problem
- Computational Results
- Conclusions

Structure



Initial population

- Constructive heuristic
  - ✦ Start from empty schedule

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

Initial population

- Constructive heuristic
  - ✦ Start from empty schedule
  - ✦ Schedule the nurses one by one in a random order

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5														
6														
7														
8														
9														
10														

Initial population

- Constructive heuristic
  - Start from empty schedule
  - Schedule the nurses one by one in a random order

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5														
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7														
8														
9														
10														

Initial population

- Constructive heuristic
  - Start from empty schedule
  - Schedule the nurses one by one in a random order

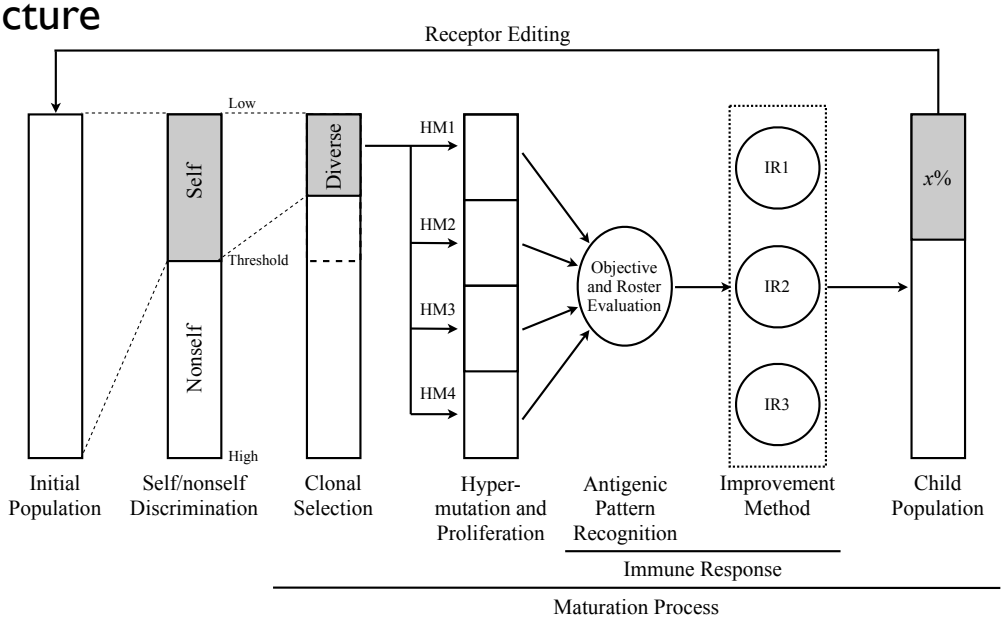
i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N
3														
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5														
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7														
8														
9														
10														

Initial population

- Constructive heuristic
  - Start from empty schedule
  - Schedule the nurses one by one in a random order

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E	E	N	F	E	N	F	F	L	N	N	F	F	F
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N
3	F	E	L	F	F	L	L	N	N	F	F	F	F	F
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5	F	F	E	E	L	L	F	F	E	N	N	F	F	F
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7	F	F	F	E	N	N	F	F	F	E	N	F	F	F
8	F	L	L	F	E	N	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	F	L	N	F	F	F	F	F
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L

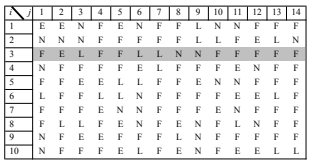
Structure



Proliferation and Hypermutation

- Proliferation: Reproduction of existing rosters (no crossover)
- Hypermutation: Change parts of rosters randomly

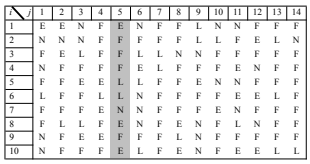
HM1: Mutation of single nurse schedules



Randomize

RCSP

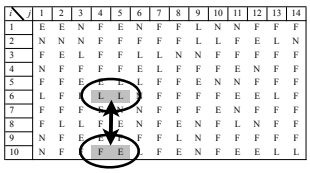
HM2: Mutation of day rosters



Randomize

Assignment problem

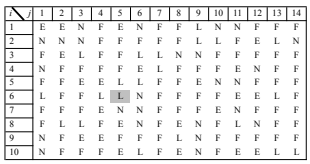
HM3: Mutation of pairs of day rosters



Randomize

Swap

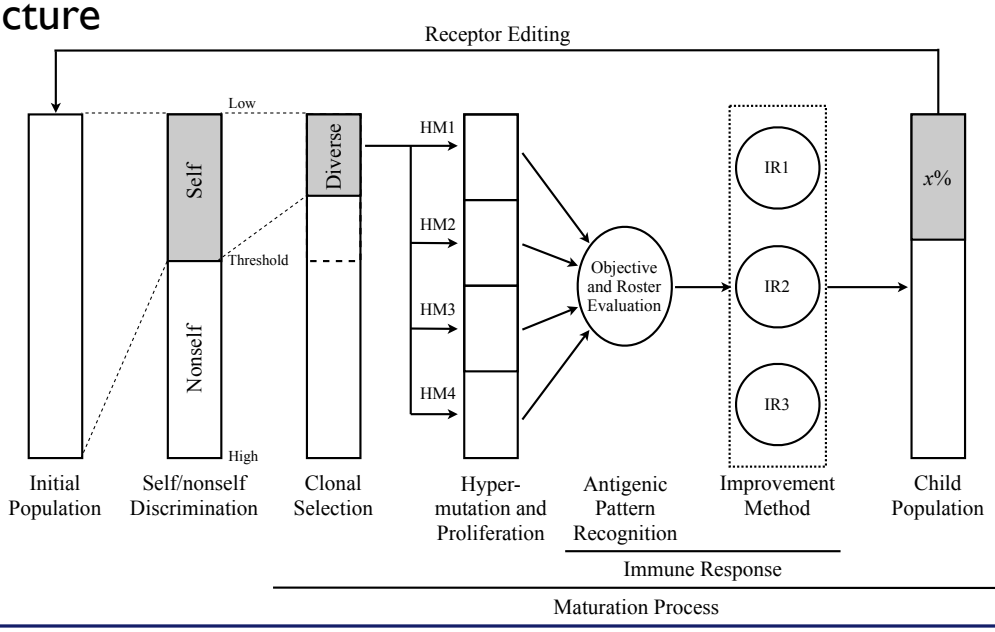
HM4: Mutation of single assignments



Randomize

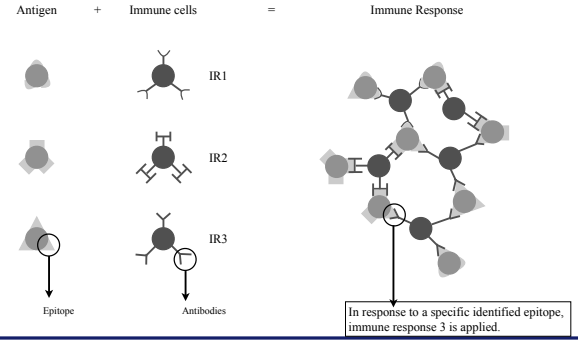
L →E, L, N, F

Structure



Immune response

- Match immune response and roster based on antigenic pattern recognition
  - ✦ Evaluation of objective function components
  - ✦ Evaluation of roster characteristics



Immune response

- 3 complementary improvement methods

IR1

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E	E	N	F	E	N	F	F	L	N	N	F	F	F
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N
3	F	E	L	F	F	L	L	N	N	F	F	F	F	F
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5	F	F	E	E	L	L	F	F	E	N	N	F	F	F
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7	F	F	F	E	N	N	F	F	F	E	N	F	F	F
8	F	L	L	F	E	N	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	F	L	N	F	F	F	F	F
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L

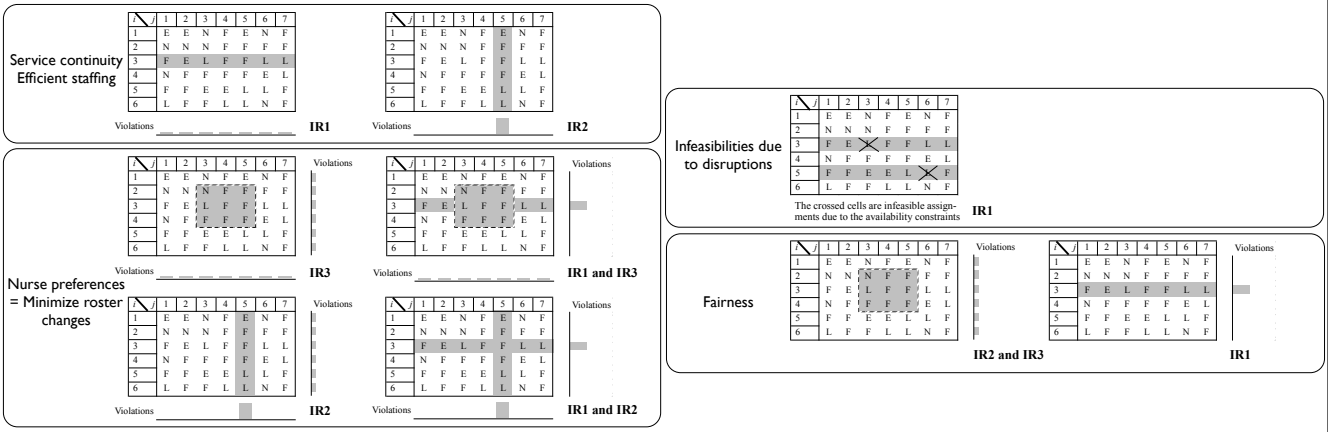
IR2

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E	E	N	F	E	N	F	F	L	N	N	F	F	F
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N
3	F	E	L	F	F	L	L	N	N	F	F	F	F	F
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5	F	F	E	E	L	L	F	F	E	N	N	F	F	F
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7	F	F	F	E	N	N	F	F	F	E	N	F	F	F
8	F	L	L	F	E	N	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	F	L	N	F	F	F	F	F
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L

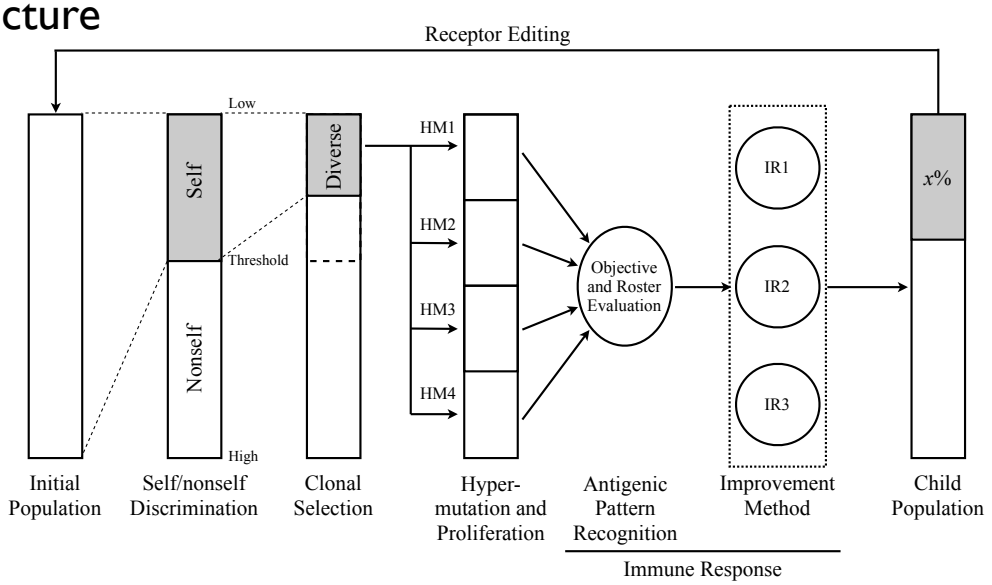
IR3

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E	E	N	F	E	N	F	F	L	N	N	F	F	F
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N
3	F	E	L	F	F	L	L	N	N	F	F	F	F	F
4	N	F	F	F	F	E	L	F	F	F	E	N	F	F
5	F	F	E	E	L	L	F	F	E	N	N	F	F	F
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F
7	F	F	F	E	N	N	F	F	F	E	N	F	F	F
8	F	L	L	F	E	N	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	F	L	N	F	F	F	F	F
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L

Immune response



Structure



Outline

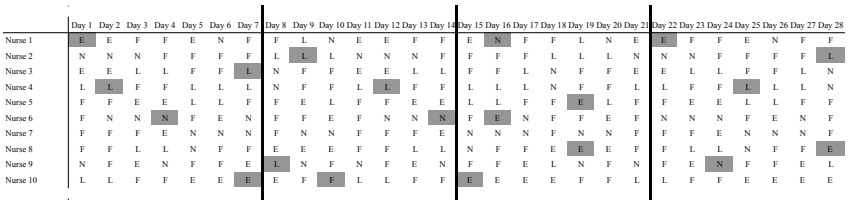
- Problem description
- An AIS for the Nurse Rerostering Problem
- Computational Results
- Conclusions

Test design

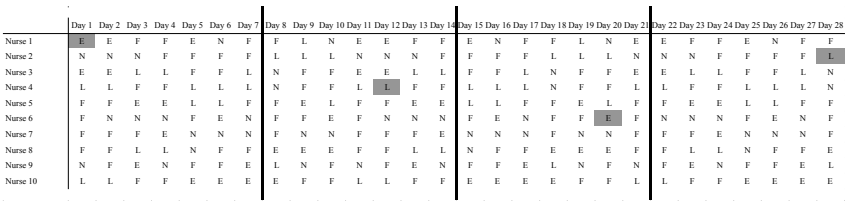
- Original rosters: NSPLib
- Schedule disruptions are controlled
  - Total number of disruptions (between 0 and 1)
  - Spread of disruptions (between 0 and 1)
- Full factorial design: 864 problem instances
- Constraint set and objective weights

Test design

- Total number of disruptions = # Disruptions / # Duties



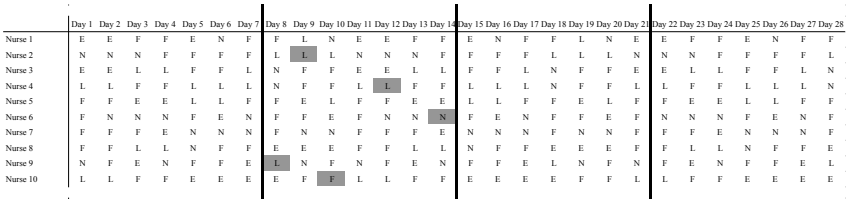
TND = High



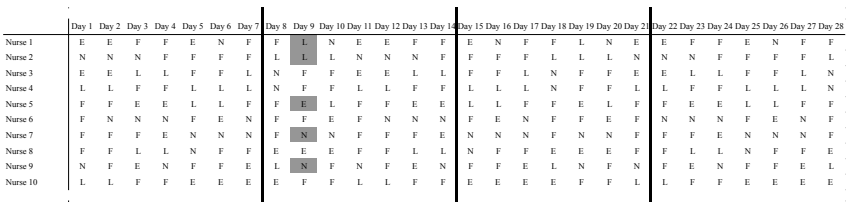
TND = Low

Test design

- Spread



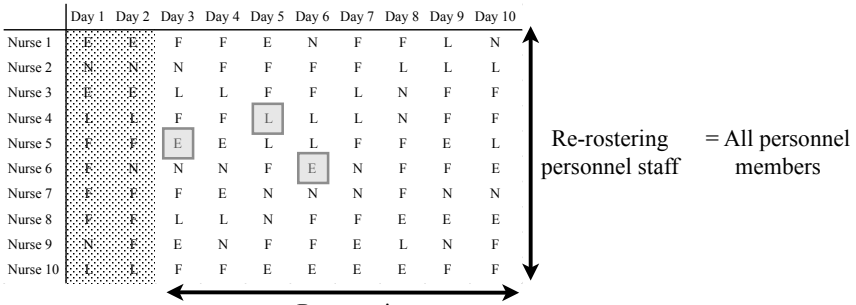
Spread = High



Spread = Low

Test design

- Re-rostering size parameters



cfr. Maenhout, B., and Vanhoucke, M., 2013, "Reconstructing nurse schedules: Computational insights in the problem size parameters", Omega

Algorithmic performance

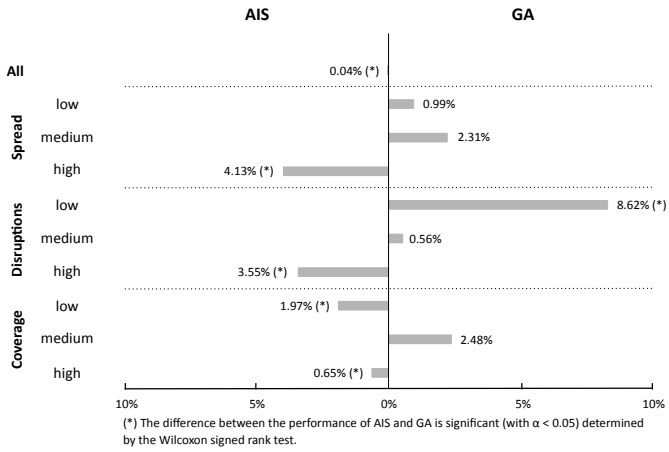
Strategy		Overall	%Dev	CPU
Hypermutation	This procedure	27,631	0.00%	16.4
	HM1	36,354	31.57%	17.0
	HM2	30,593	10.72%	15.2
	HM3	31,518	14.07%	15.8
	HM4	37,260	34.85%	13.6
Immune response	This procedure	27,631	0.00%	16.4
	AIS_LS_Fixed	28,281	2.35%	19.8

Comparison

AIS vs literature

Procedure	Overall	CPU
Pato and Moz (2008) (GA)	91,478	22.2
Maenhout and Vanhoucke (2011) (GA)	27,640	16.0
Multi-start heuristic	35,882	20.9
This procedure (AIS)	27,631	16.4

AIS vs GA



(*) The difference between the performance of AIS and GA is significant (with $\alpha < 0.05$) determined by the Wilcoxon signed rank test.

Outline

- Problem description
- An AIS for the Nurse Rerostering Problem
- Computational Results
- Conclusions

Conclusions

- Heuristic nurse re-rostering tool
  - AIS is competitive/outperforms traditional optimization methods
  - Roster-specifc improvement procedure
- Future research
  - New optimisation techniques and hybridisation
  - Robust personnel scheduling

Questions?