



FACULTY OF ECONOMICS  
AND BUSINESS ADMINISTRATION

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

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## Outline

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

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## 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

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## 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

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## 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

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## 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                           | ++         |

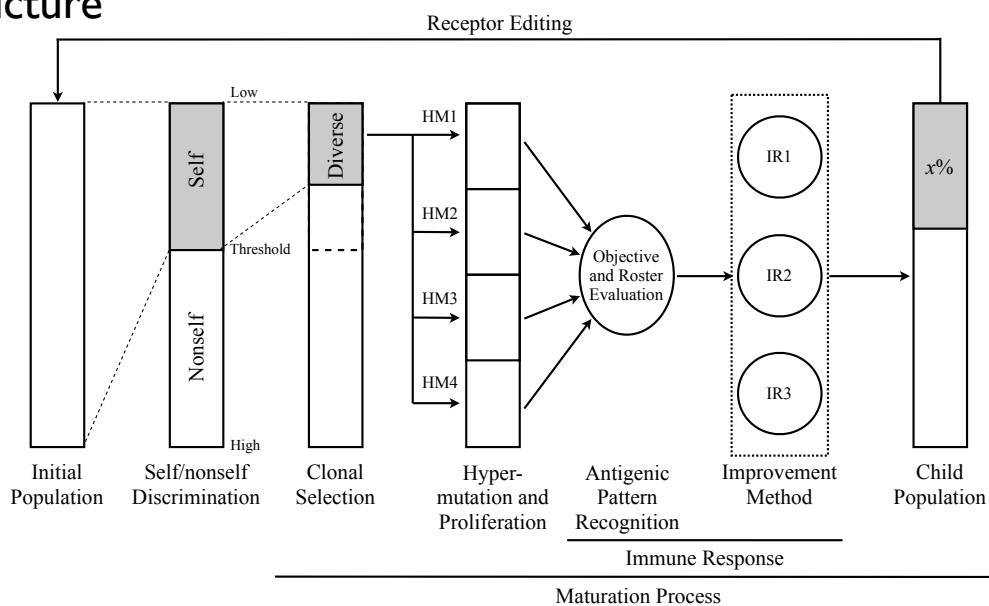
= Retain the original schedule as best as possible

## Outline

- Problem description
- An AIS for the Nurse Rostering Problem
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- Conclusions

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## Structure



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## Initial population

- Constructive heuristic
  - ◆ Start from empty schedule

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

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## Initial population

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

N	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														

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## Initial population

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

N	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

N	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															

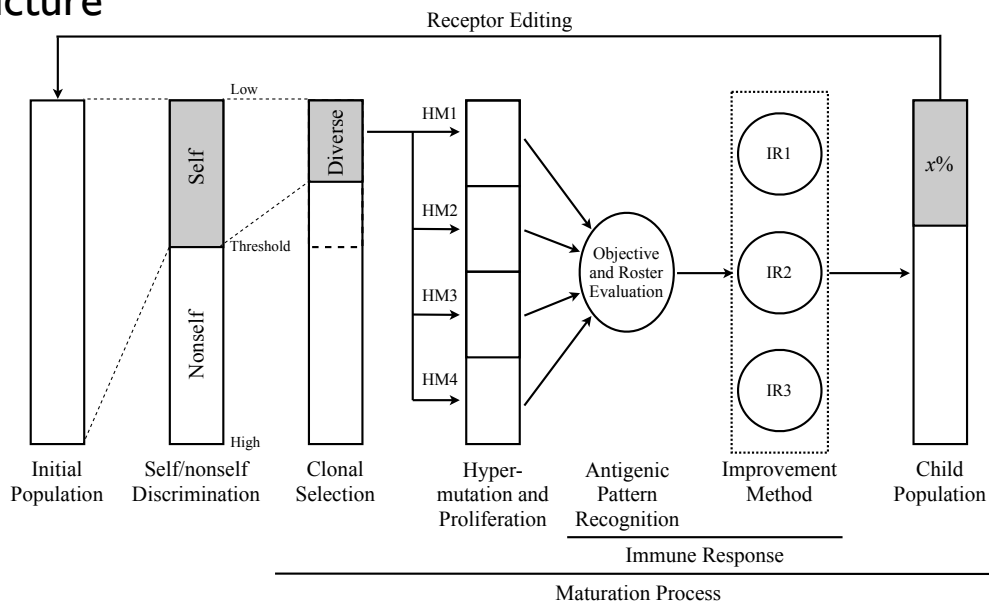
## Initial population

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

	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	E	E	L	F	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

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## Structure



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# Proliferation and Hypermutation

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

HM1: Mutation of single nurse schedules

N	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	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	F	E	N	N	F	F	
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F	
7	F	F	F	E	N	F	F	F	E	N	F	F	F	F	
8	F	L	L	F	E	N	F	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	L	N	F	F	F	F	F	F	
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L	

Randomize  
RCSP

HM2: Mutation of day rosters

N	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	F	E	N	N	F	F	
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F	
7	F	F	F	E	N	F	F	F	E	N	F	F	F	F	
8	F	L	L	F	E	N	F	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	L	N	F	F	F	F	F	F	
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L	

Randomize  
Assignment problem

HM3: Mutation of pairs of day rosters

N	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	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	E	L	F	F	E	N	F	F	F	F	
5	F	F	E	E	L	L	F	F	F	E	N	N	F	F	
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F	
7	F	F	F	E	N	F	F	F	E	N	F	F	F	F	
8	F	L	L	F	E	N	F	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	L	N	F	F	F	F	F	F	
10	N	F	F	F	E	L	F	E	N	F	E	E	L	L	

Randomize  
Swap

HM4: Mutation of single assignments

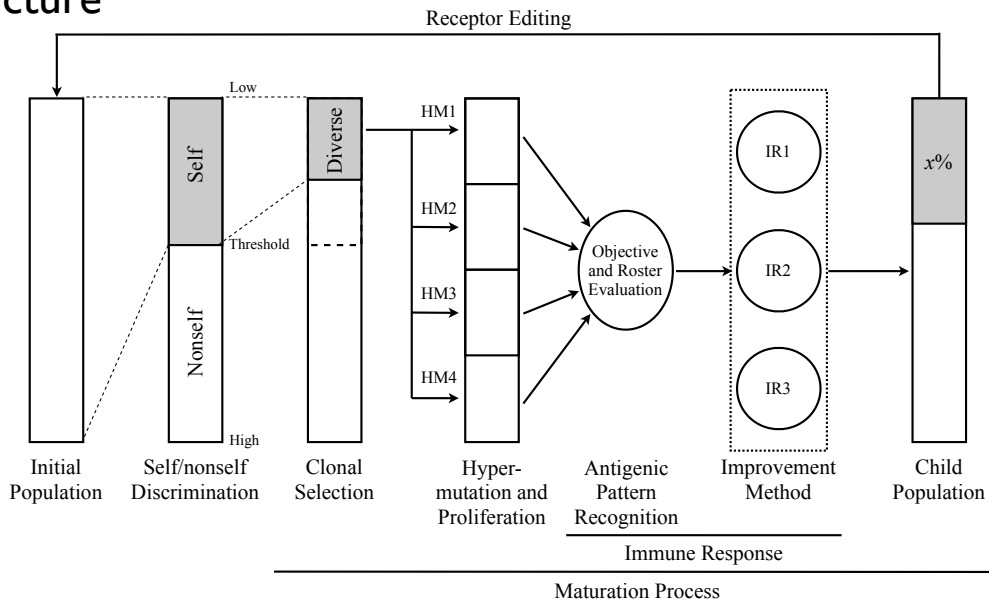
N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	E	E	N	F	E	N	F	F	L	N	N	F	F	F	
2	N	N	N	F	F	F	F	F	L	L	F	E	L	N	
3	F	E	L	F	F	L	L	N	N	F	F	F	F	F	
4	N	F	F	F	E	L	F	F	E	N	F	F	F	F	
5	F	F	E	E	L	L	F	F	F	E	N	N	F	F	
6	L	F	F	L	L	N	F	F	F	F	E	E	L	F	
7	F	F	F	E	N	F	F	F	E	N	F	F	F	F	
8	F	L	L	F	E	N	F	F	E	N	F	L	N	F	F
9	N	F	E	E	F	F	L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

Randomize  
L → E, L, N, F

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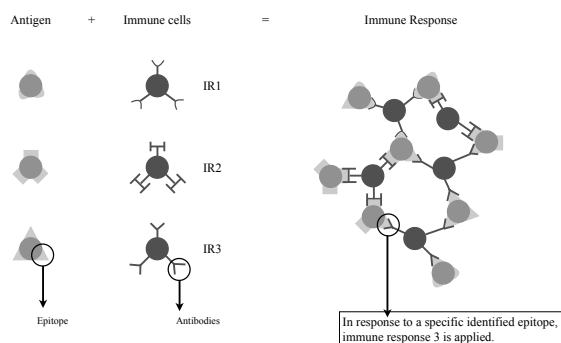
# Structure



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## Immune response

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



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## Immune response

- 3 complementary improvement methods

IR1

$i \setminus j$	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	X	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	X	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	E	N	F	F	F	F
8	F	L	L	F	X	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

$i \setminus j$	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	X	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	X	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	X	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

$i \setminus j$	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	X	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	X	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	X	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

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# Immune response

**Service continuity**  
**Efficient staffing**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

Violations \_\_\_\_\_ **IR1**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

Violations \_\_\_\_\_ **IR2**

**Infeasibilities due to disruptions**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

The crossed cells are infeasible assignments due to the availability constraints **IR1**

**Nurse preferences**  
**= Minimize roster changes**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

Violations \_\_\_\_\_ **IR3**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

Violations \_\_\_\_\_ **IR1 and IR3**

**Fairness**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

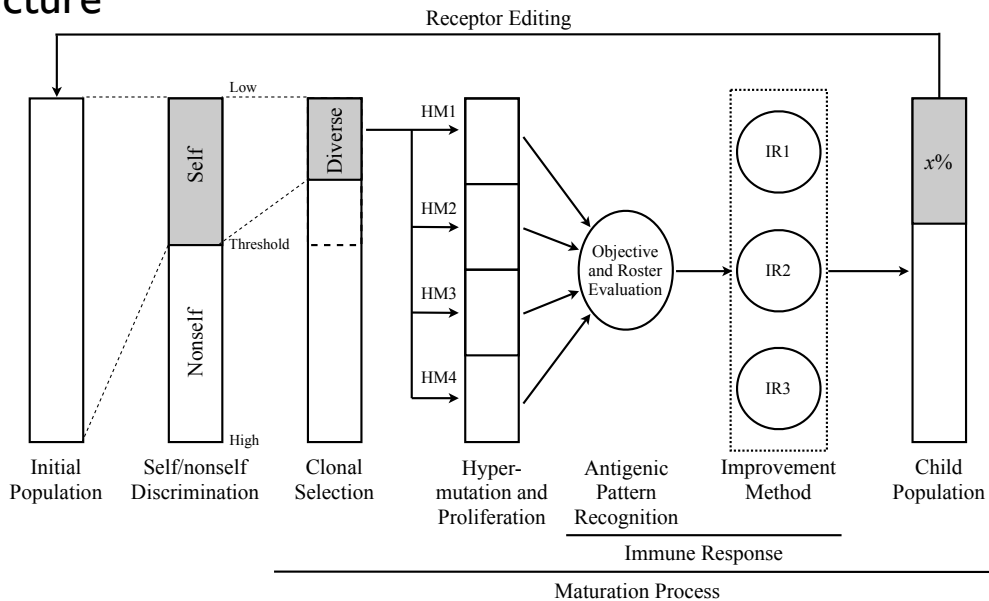
Violations \_\_\_\_\_ **IR2 and IR3**

N	1	2	3	4	5	6	7
1	E	E	N	F	E	N	F
2	N	N	N	F	F	F	F
3	F	E	L	F	F	L	L
4	N	F	F	F	F	E	L
5	F	F	E	E	L	L	F
6	L	F	F	L	L	N	F

Violations \_\_\_\_\_ **IR1**

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# Structure



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## 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

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28
Nurse 1	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F
Nurse 2	N	N	N	F	F	F	F	L	L	N	N	N	N	F	F	F	F	L	L	L	N	N	N	F	F	F	F	L
Nurse 3	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N
Nurse 4	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N
Nurse 5	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F	E	E	L	L	F	F	E	E	L	L
Nurse 6	F	N	N	N	F	E	N	F	F	E	F	N	N	N	F	E	N	F	F	E	F	F	N	N	N	F	E	N
Nurse 7	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F
Nurse 8	F	F	L	L	N	F	F	E	E	E	F	F	L	L	N	F	F	E	E	F	F	L	L	N	F	F	E	L
Nurse 9	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L
Nurse 10	L	L	F	F	E	E	E	E	F	F	L	L	F	F	L	E	E	E	E	F	F	L	L	F	F	E	E	E

TND = High

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28
Nurse 1	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F
Nurse 2	N	N	N	F	F	F	F	L	L	L	N	N	N	N	F	F	F	L	L	L	N	N	N	F	F	F	F	L
Nurse 3	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N
Nurse 4	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N
Nurse 5	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F
Nurse 6	F	N	N	N	F	E	N	F	F	E	F	N	N	N	F	E	N	F	F	E	L	F	N	N	N	F	E	N
Nurse 7	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F
Nurse 8	F	F	L	L	N	F	F	E	E	E	F	F	L	L	N	F	F	E	E	F	F	L	L	N	F	F	E	L
Nurse 9	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L
Nurse 10	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E

TND = Low

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# Test design

- Spread

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28
Nurse 1	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F
Nurse 2	N	N	N	F	F	F	F	L	L	L	N	N	N	N	F	F	F	L	L	L	N	N	N	F	F	F	F	L
Nurse 3	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N
Nurse 4	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N
Nurse 5	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F
Nurse 6	F	N	N	N	F	E	N	F	F	E	F	N	N	N	F	E	N	F	F	E	F	N	N	N	F	E	N	F
Nurse 7	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F
Nurse 8	F	F	L	L	N	F	F	E	E	E	F	F	L	L	N	F	F	E	E	F	F	L	L	N	F	F	E	L
Nurse 9	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L
Nurse 10	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E

Spread = High

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22	Day 23	Day 24	Day 25	Day 26	Day 27	Day 28
Nurse 1	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F	L	N	E	E	F	F	E	N	F	F
Nurse 2	N	N	N	F	F	F	F	L	L	L	N	N	N	N	F	F	F	L	L	L	N	N	N	F	F	F	F	L
Nurse 3	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N	F	F	E	E	L	L	F	F	L	N
Nurse 4	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N	F	F	L	L	F	F	L	L	L	N
Nurse 5	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F	E	L	F	F	E	E	L	L	F	F
Nurse 6	F	N	N	N	F	E	N	F	F	E	F	N	N	N	F	E	N	F	F	F	E	F	N	N	N	F	E	N
Nurse 7	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F	N	N	F	F	F	E	N	N	N	F
Nurse 8	F	F	L	L	N	F	F	E	E	E	F	F	L	L	N	F	F	E	E	F	F	L	L	N	F	F	E	L
Nurse 9	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L	N	F	N	F	E	N	F	F	E	L
Nurse 10	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E	F	F	L	L	F	F	E	E	E	E

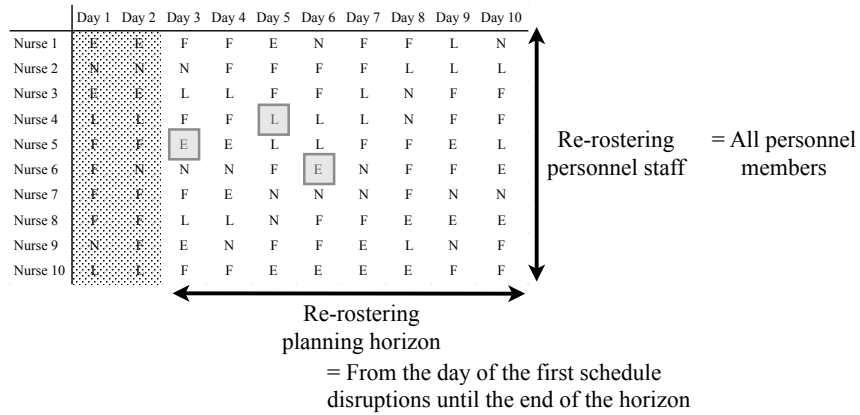
Spread = Low

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## Test design

- Re-rostering size parameters



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

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## Algorithmic performance

Strategy		Overall	%Dev	CPU
Hypermuation	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

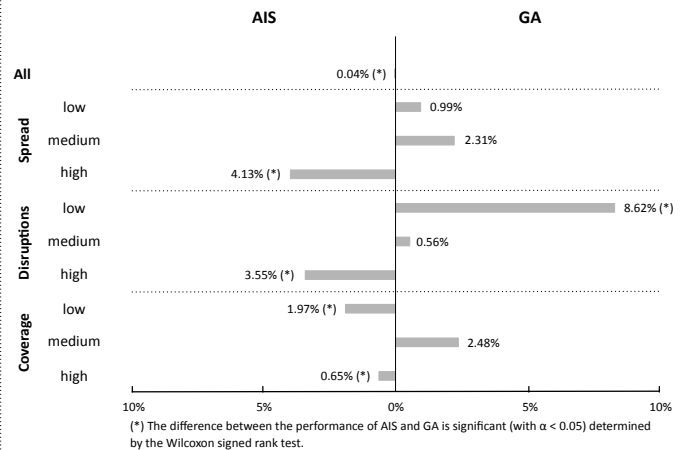
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## Comparison

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



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## Outline

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

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## Conclusions

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

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Questions?



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