Configuring Advanced Evolutionary Algorithms for Multicriteria Building Spatial Design Optimisation

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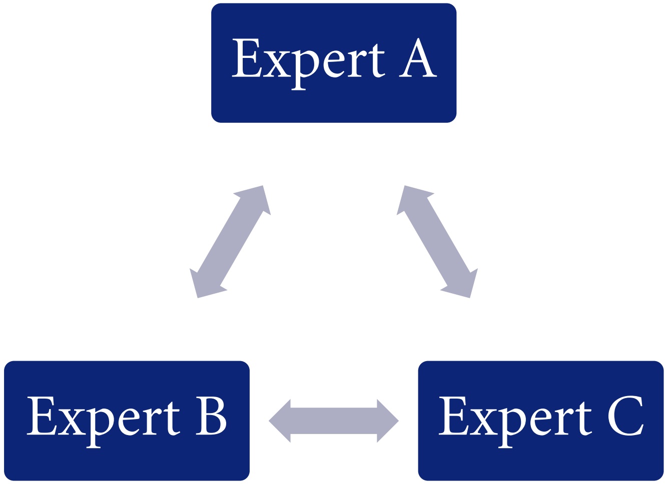
Enabling new technology

Traditional building design

- Many disciplines with different experts
  - E.g. Structural, plumbing, HVAC, etc.
- Issues
  - Sequential
  - Limited communication
- Solution: Automation

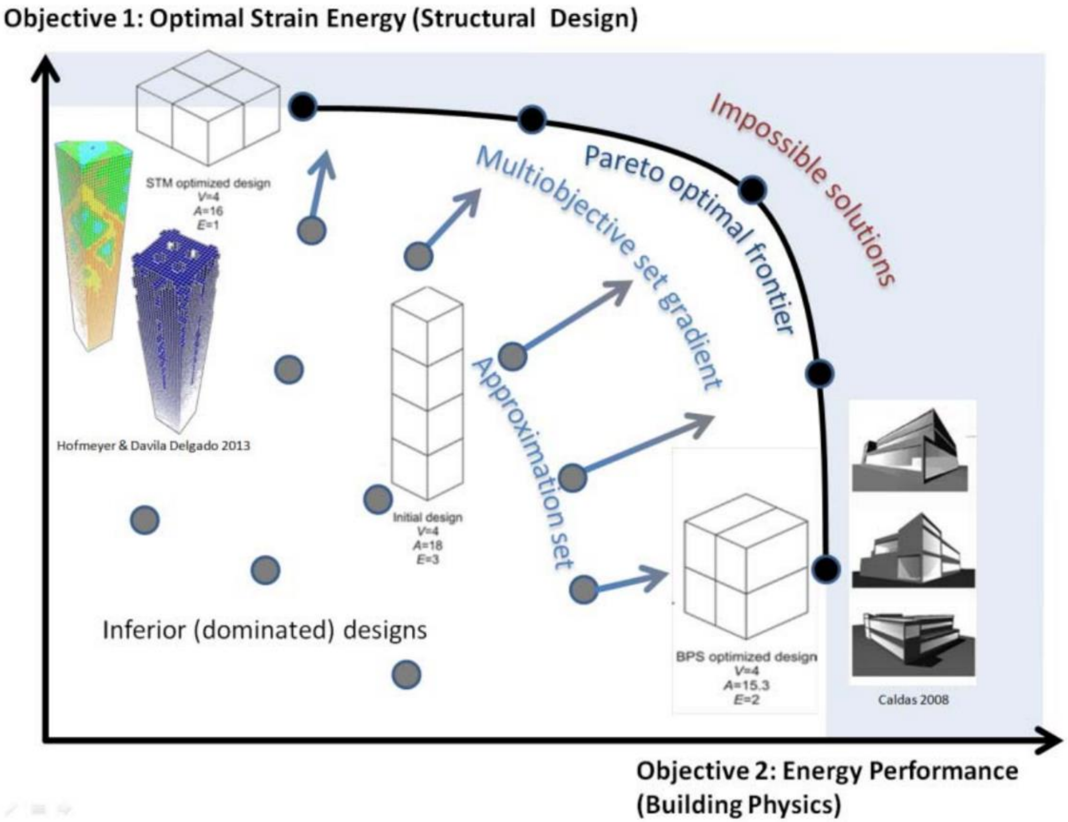

Expert A

Expert B

Expert C

Problem description

- Optimise building spatial design (i.e. the shape)
  - Structural performance (compliance)
  - Thermal performance (surface area)



Work so far

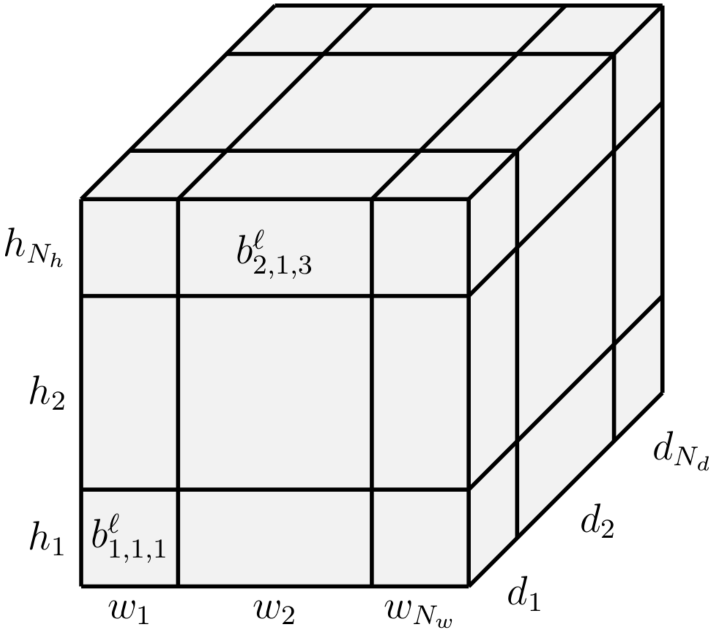
- Problem representation [1,2]
- Constraint functions [1,2]
- Tested with standard algorithms [2,3]
- Constraint satisfaction penalty functions [2]
- Constraint satisfaction by specialised initialisation and mutation operators [3]

[1] S. Boonstra, K. van der Blom, H. Hofmeyer, R. Amor, and M. T. M. Emmerich, "Super-structure and super-structure free design search space representations for a building spatial design in multi-disciplinary building optimisation," in Electronic proceedings of the 23rd International Workshop of the European Group for Intelligent Computing in Engineering. Jagiellonian University ZPGK, 2016, pp. 1–10.
[2] Blom K. van der, Boonstra S., Hofmeyer H. & Emmerich M.T.M. (2016), A super-structure based optimisation approach for building spatial designs. In: Papadrakakis M., Papadopoulos V., Stefanou G., Plevris V. (Eds.) Proceedings of the VII European Congress on Computational Methods in Applied Sciences and Engineering.: National Technical University of Athens. 3409-3422.
[3] K. van der Blom, S. Boonstra, H. Hofmeyer, and M. T. M. Emmerich, "Multicriteria building spatial design with mixed integer evolutionary algorithms," in Parallel Problem Solving from Nature – PPSN XIV, ser. Lecture Notes in Computer Science, J. Handl, E. Hart, P. R. Lewis, M. López-Ibáñez, G. Ochoa, and B. Paechter, Eds., vol. 9921. Cham: Springer International Publishing, 2016, pp. 453–462.

Contributions

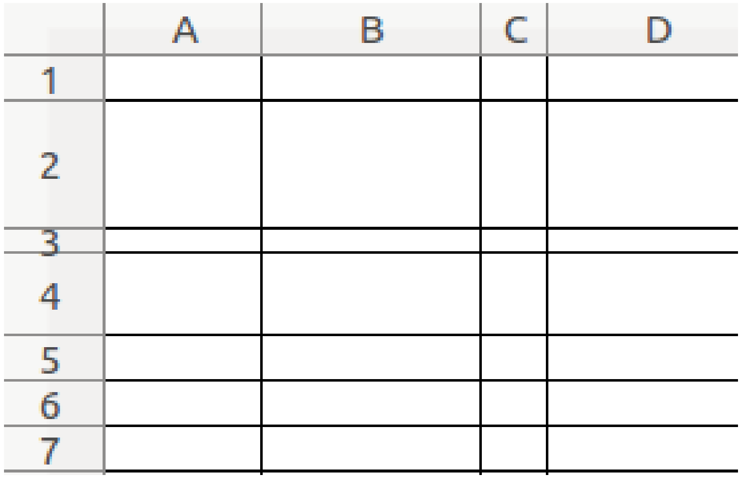
- New initialisation operator
  - Eliminates bias
- Extended mutation operator
  - Allows larger mutations
- Parameter tuning with expensive evaluations
  - irace and MIES
- Landscape analysis (not covered in the talk)

Problem representation

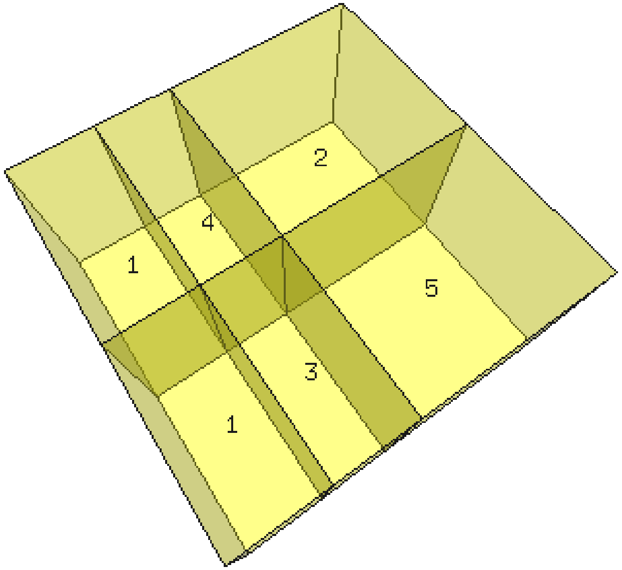


$$i \in \{1,2,\dots,N_w\} \qquad w_i \in \mathbb{R} \geq 0$$
$$j \in \{1,2,\dots,N_d\} \qquad d_j \in \mathbb{R} \geq 0$$
$$k \in \{1,2,\dots,N_h\} \qquad h_k \in \mathbb{R} \geq 0$$
$$\ell \in \{1,2,\dots,N_{spaces}\}$$

$$b^{\ell}_{i,j,k} = \begin{cases} 1 & \text{if cell } (i,j,k) \text{ belongs to space } \ell \\ 0 & \text{otherwise} \end{cases}$$



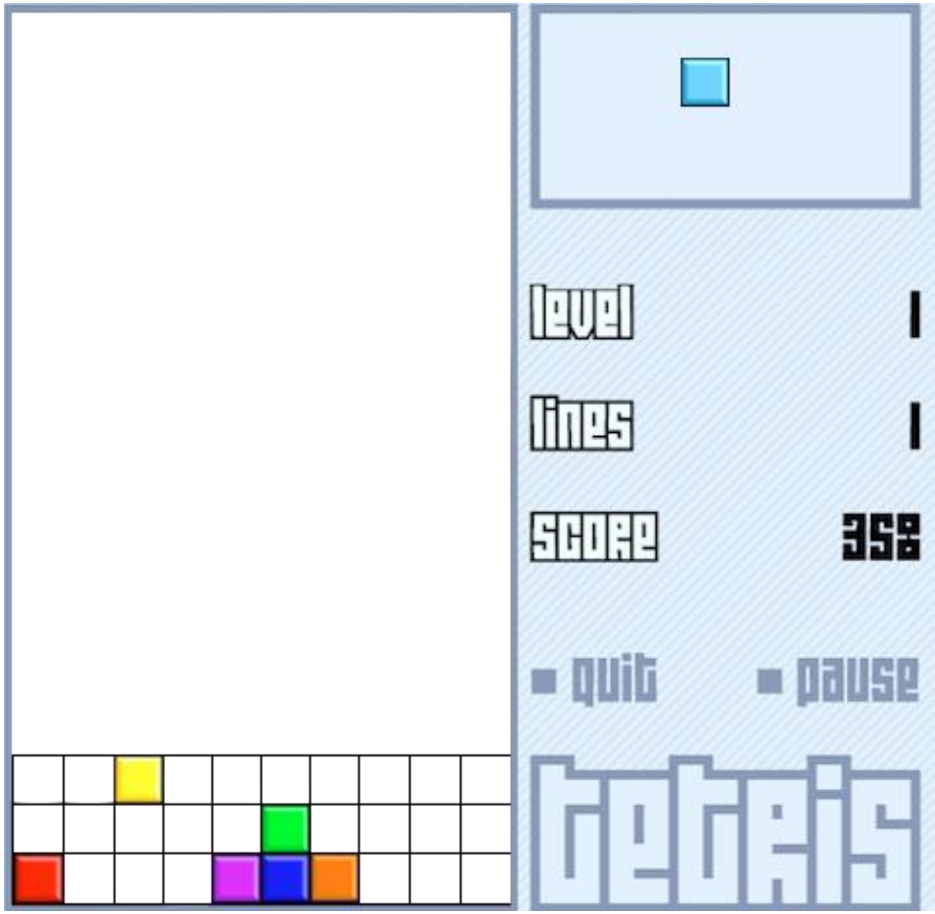
	A	B	C	D
1				
2				
3				
4				
5				
6				
7				



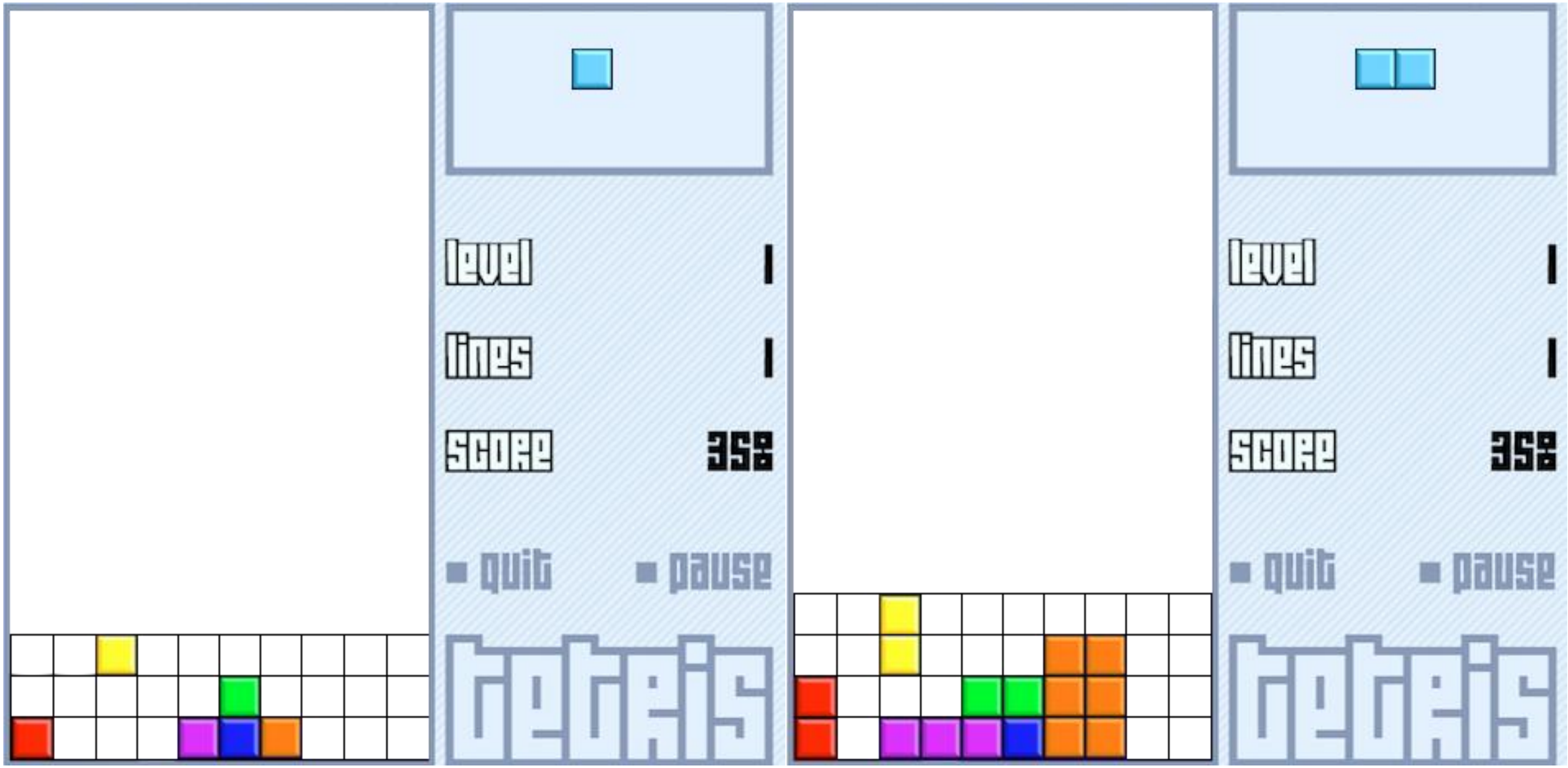
Problem representation – constraints

- Active – every room has at least one active cell
- No overlap – cell (x, y, z) is active for at most one room
- Cuboid shape – all cells active for a room together form a cuboid (3D rectangle)
- No floating cells – every cell has ground or another cell below it

Operators – initialisation



Operators – initialisation



Operators – initialisation

(**0**) Initialise heightmap $(N_w \times N_d)$ with zeros

(**1**) Find all possible shapes for the given supercube size $(N_w, N_d, N_h, N_{spaces})$

(**2**) Find all possible positions where each shape from (**1**) can fit

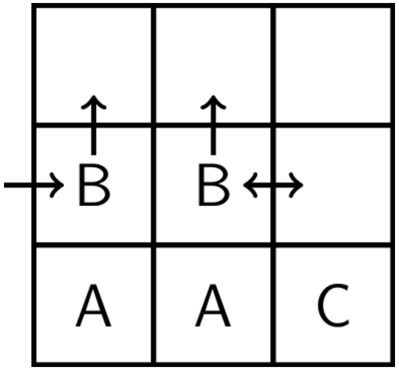
(**3**) Randomly select a combination of a shape and a position for that shape

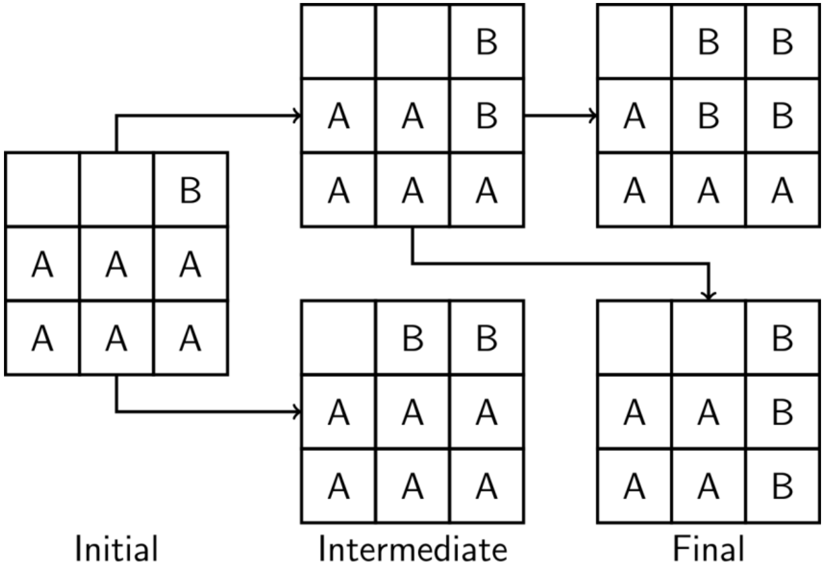
(**4**) Update heightmap, shapes and positions

(**5**) Spaces placed $< N_{spaces}$? Goto (**3**)

Operators - mutation

- Move from feasible state S_1 to feasible state S_n
- Intermediate states S_{n-x} may be infeasible if:
  - Supercube boundaries are not violated
  - All spaces are active
- If from all possible transitions from state S_{n-1} none lead to a feasible state, revert to state S_1





Parameter tuning

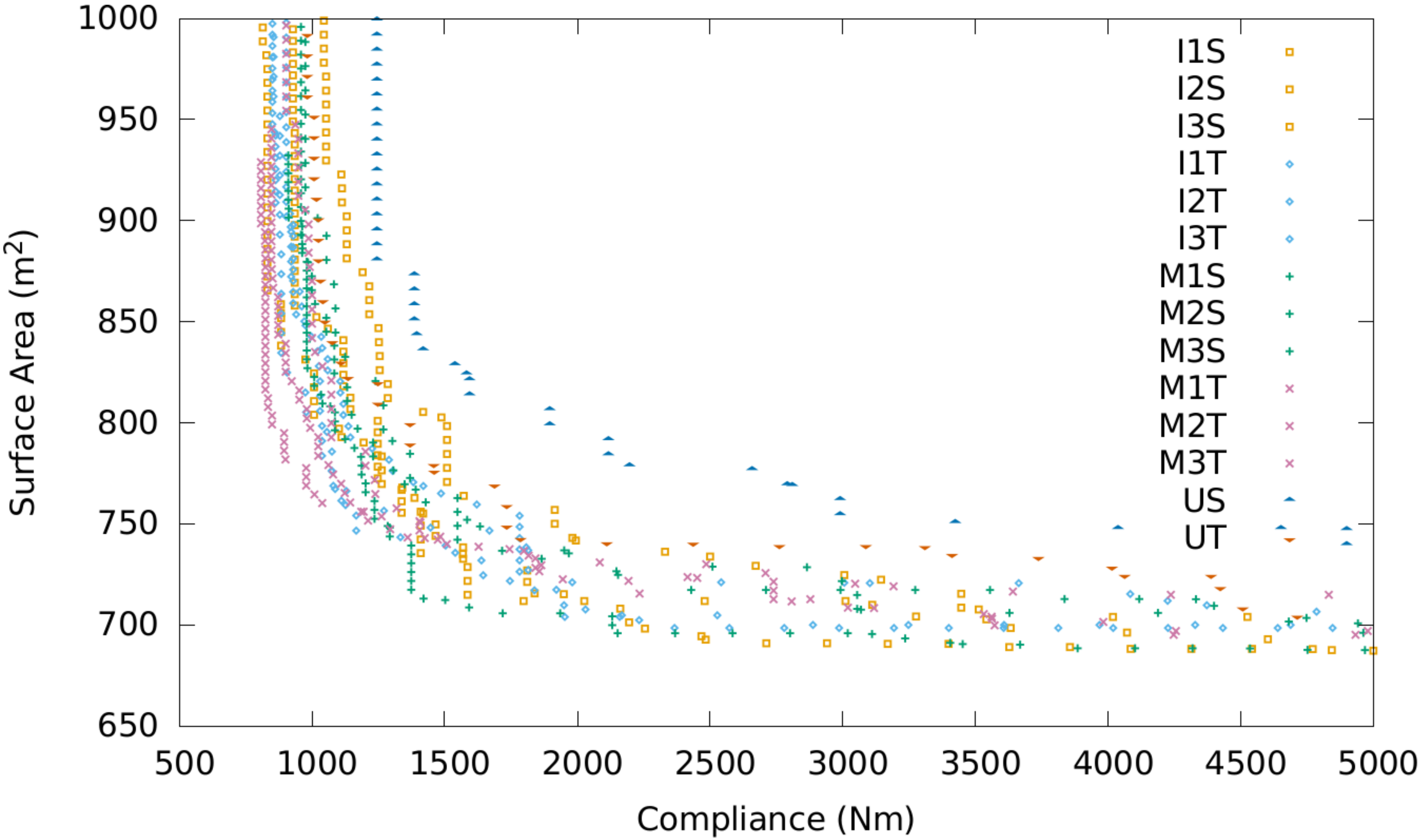
- Algorithms, using 300 function evaluations
  - Standard SMS-EMOA (**S**)
  - Tailored SMS-EMOA (**T**), problem specific operators
- Problem instance
  - Supercube size 3 × 3 × 3 with three rooms
- Parameters
  - **S**: Three; one integer, two continuous
  - **T**: Seven; two categorical, three integer, two continuous

Parameter tuning

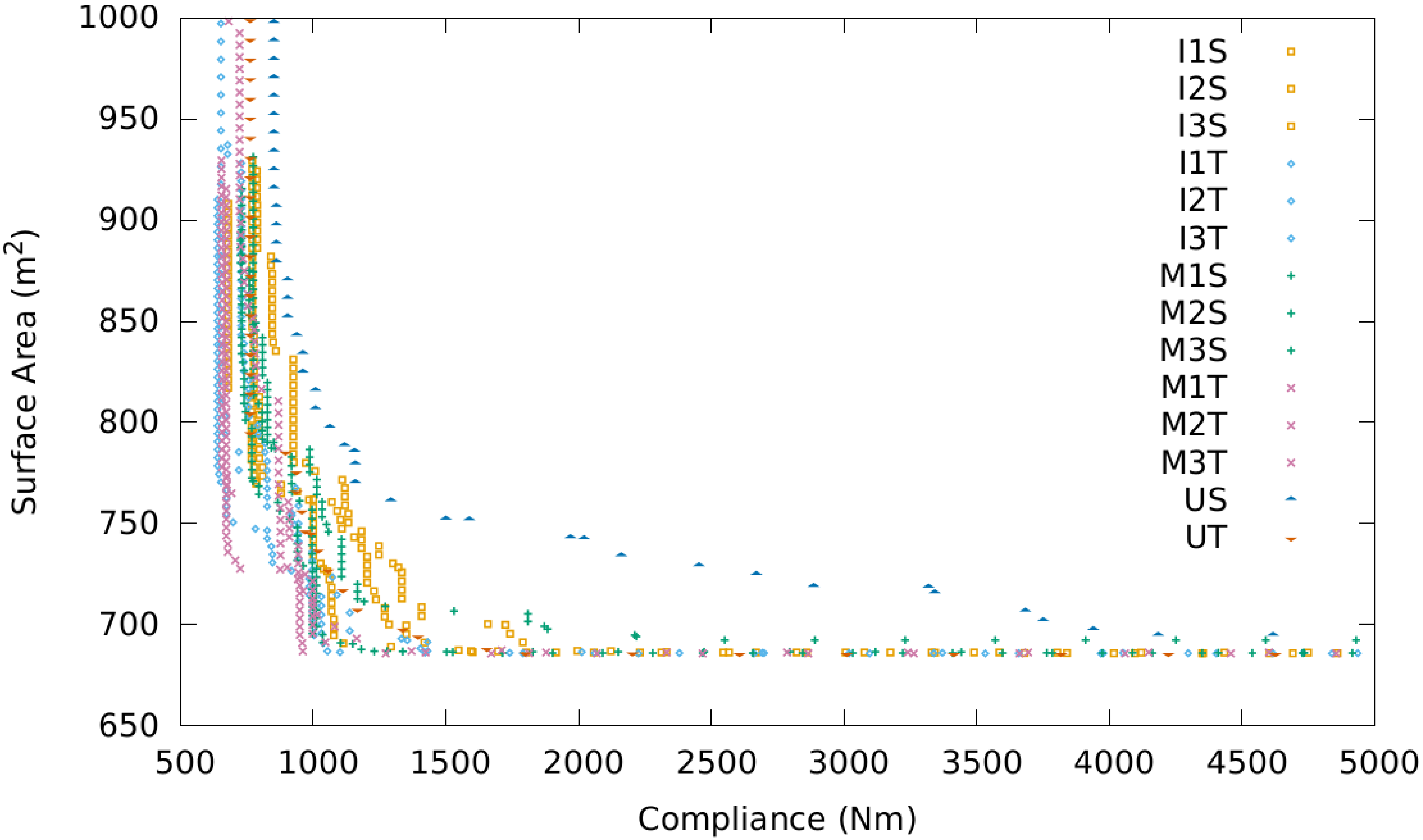
- Budget: 180 algorithm executions
- Maximise hypervolume, reference point (100000,1500)
- Iterated Racing for Automatic Algorithm Configuration (irace) [1]
    - Multiple executions per solution
- Mixed Integer Evolution Strategy (MIES) [2]
    - Single execution per solution

[1] M. López-Ibáñez, J. Dubois-Lacoste, L. Pérez Cáceres, M. Birattari, and T. Stützle, "The irace package: Iterated racing for automatic algorithm configuration," Operations Research Perspectives, vol. 3, pp. 43–58, 2016.
[2] R. Li, M.T.M. Emmerich, J. Eggermont, T. Bäck, M. Schütz, J. Dijkstra, and J.H.C. Reiber, "Mixed integer evolution strategies for parameter optimization," Evolutionary computation, vol. 21, no. 1, pp. 29–64, 2013.

Results – attainment curves 300



Results – attainment curves 1000



Conclusion

- Optimising buildings spatial design performance
  - Structural
  - Thermal
- New unbiased initialisation operator
- Improved mutation operator
  - Can escape disconnected feasible regions
  - Larger mutations possible
- Tuning (irace/MIES) improves attained Pareto Front
  - Tailored SMS-EMOA improves over standard SMS-EMOA
  - irace and MIES perform very similarly
  - Feasible for small problem instances
  - Very time consuming for larger instances

Future work

- Scaling to larger problem instances; five, ten, twenty rooms…
- Extend comparison of tuning with approaches using meta-models (e.g. SMAC, SPOT)
- Replace thermal measure: heating and cooling simulations instead of surface area
    - What does that mean for problem complexity?
- Problem specific crossover operator

Questions?

Acknowledgements
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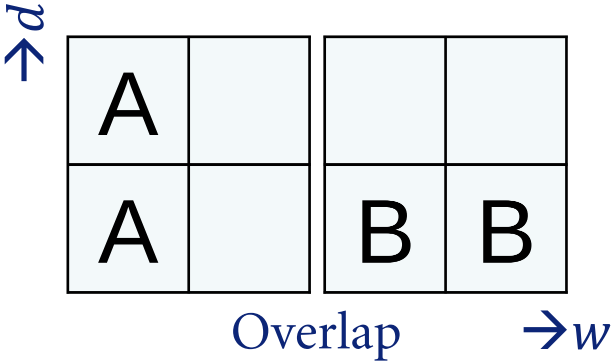
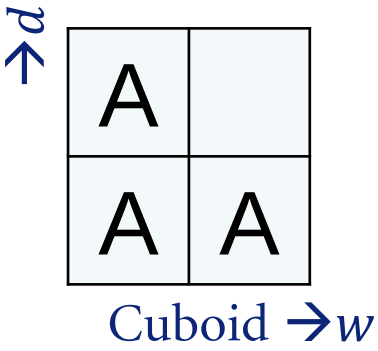
Excellent Buildings via Forefront MDO, Lowest Energy Use, Optimal Spatial and Structural Performance

Problem representation – constraints

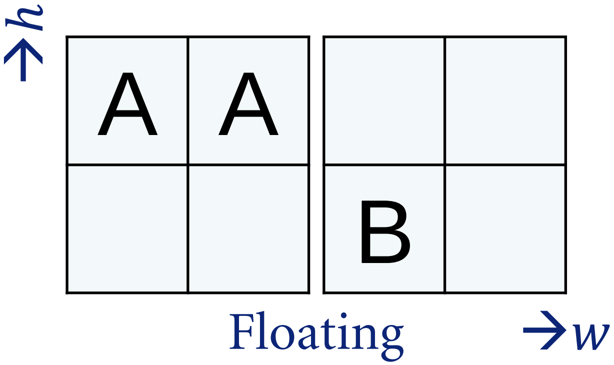
- On the continuous variables
  - Fixed volume – rescale continuous variables
- On the binary variables
  - Active – for every space at least one cell is active
  - No overlap – cell (x, y, z) is active for at most one space
  - Cuboid shape – all cells active for a space together form a cuboid (3D rectangle)
  - No floating cells – always ground or another cell (of any space) below each cell



Overlap



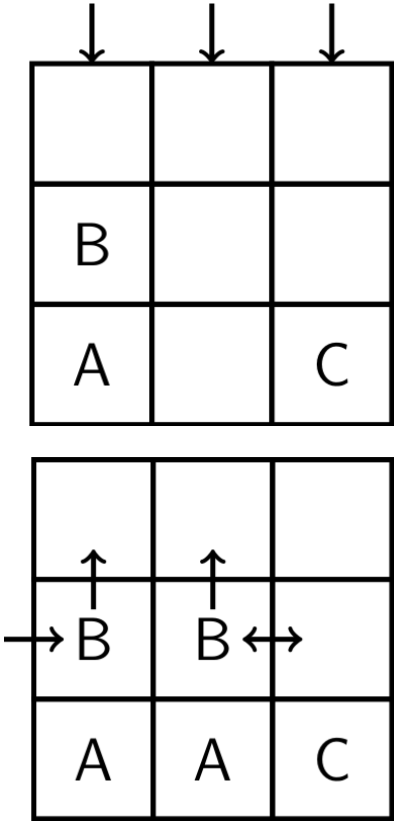
Cuboid



Floating

Operators

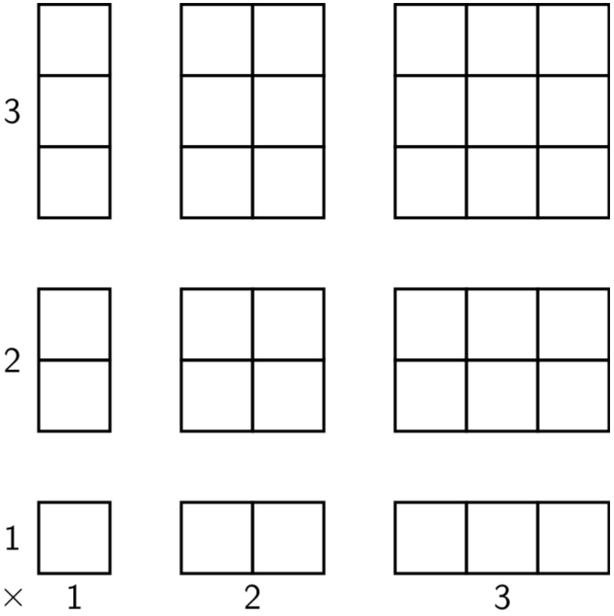
- Previously [1]
  - Initialisation: single cell per room, mutate x times to improve diversity
  - Mutation: single step only
- Goal
  - Eliminate bias
  - Allow multistep mutations
    - Larger changes possible
    - Escape disconnected feasible regions



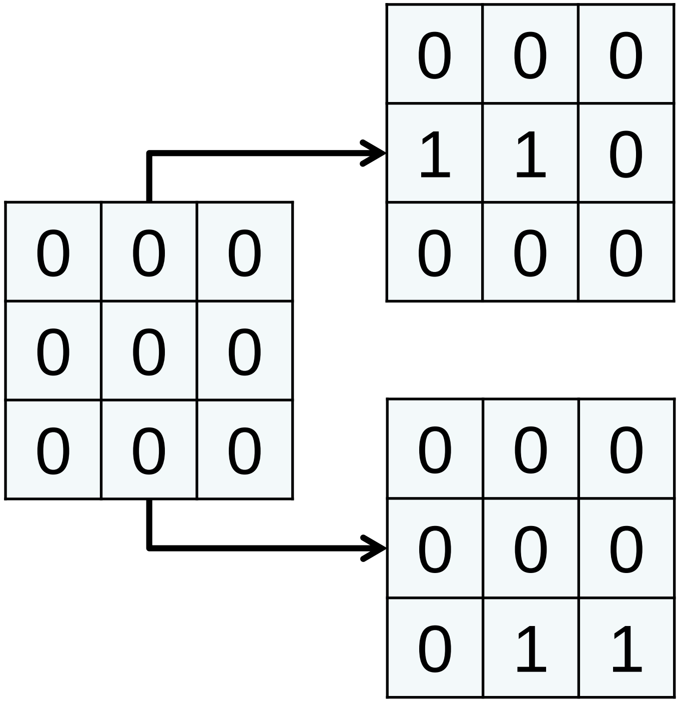
[1] K. van der Blom, S. Boonstra, H. Hofmeyer, and M. T. M. Emmerich, "Multicriteria building spatial design with mixed integer evolutionary algorithms," in Parallel Problem Solving from Nature – PPSN XIV, ser. Lecture Notes in Computer Science, J. Handl, E. Hart, P. R. Lewis, M. López-Ibáñez, G. Ochoa, and B. Paechter, Eds., vol. 9921. Cham: Springer International Publishing, 2016, pp. 453–462.

Operators – initialisation

Shapes



Heightmap



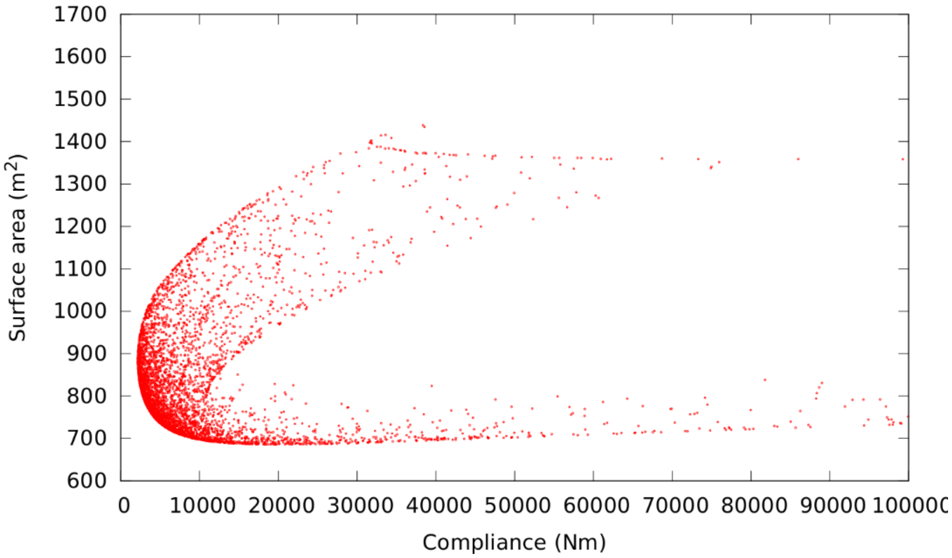
0	0	0
0	0	0
0	0	0

0	0	0
1	1	0
0	0	0

0	0	0
0	0	0
0	1	1

Landscape analysis

- What does objective space look like?
- 5000 points initialised with the new approach



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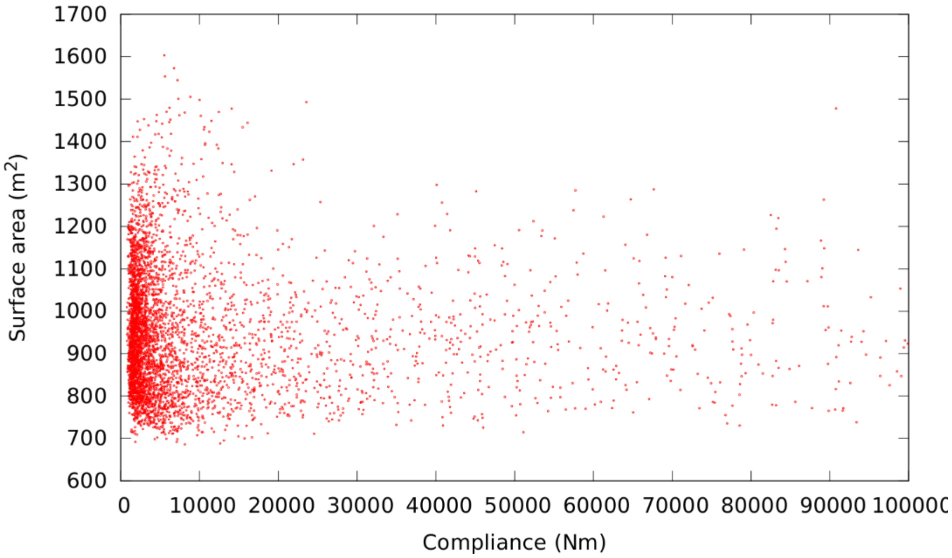

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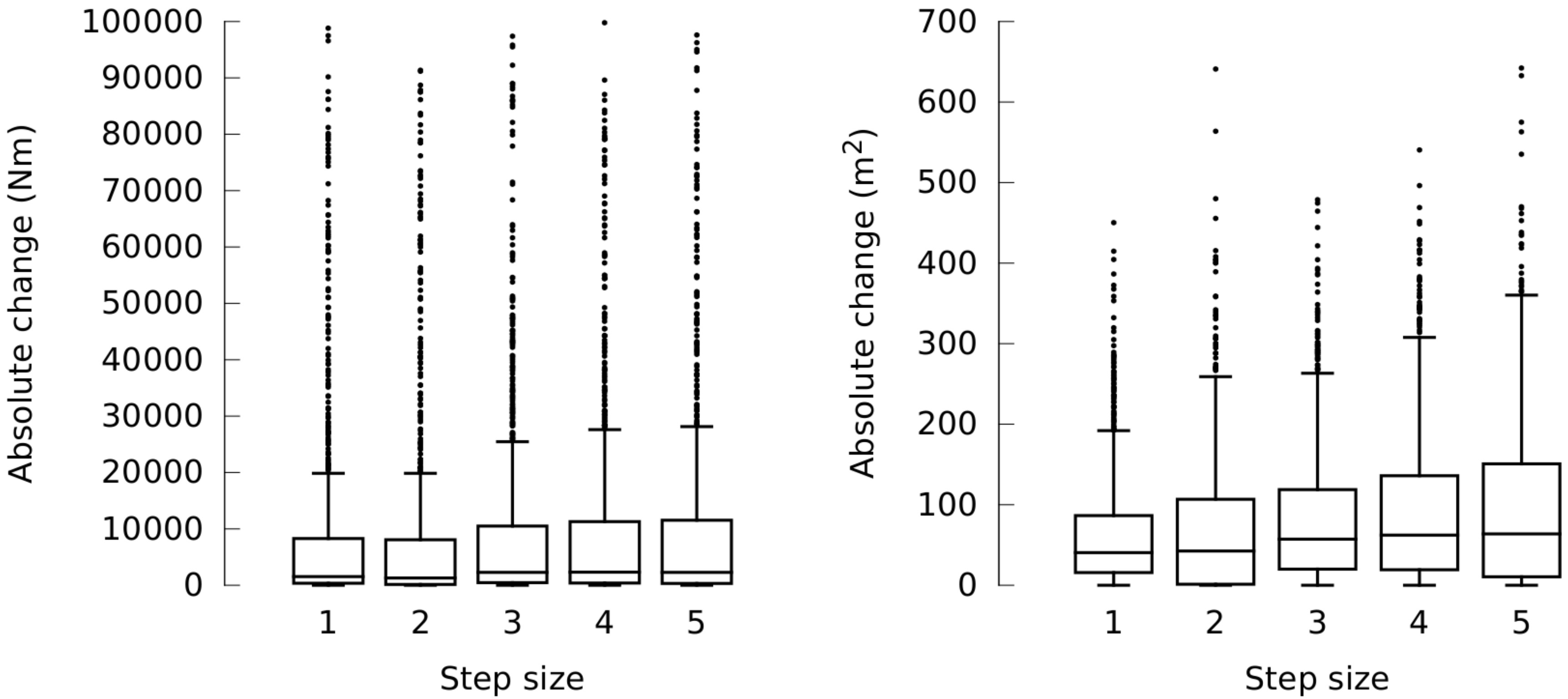
Landscape analysis

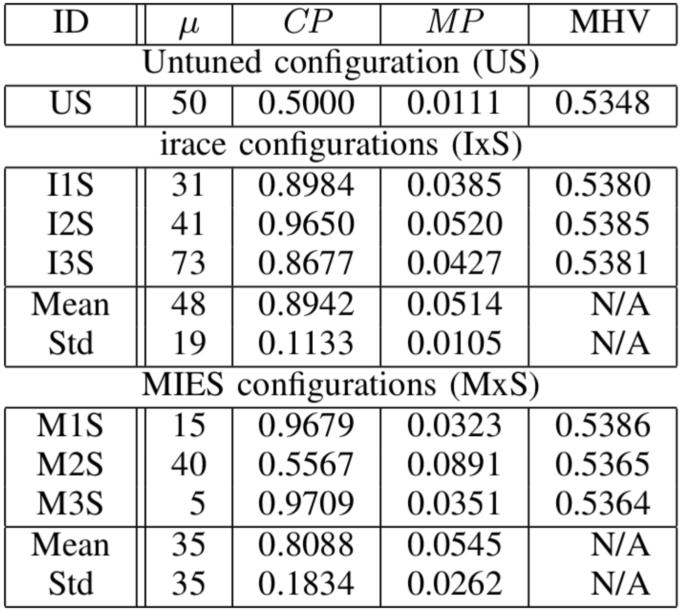
- How does the mutation operator behave?
- Distance between 5000 parents and their offspring



Parameter tuning – results

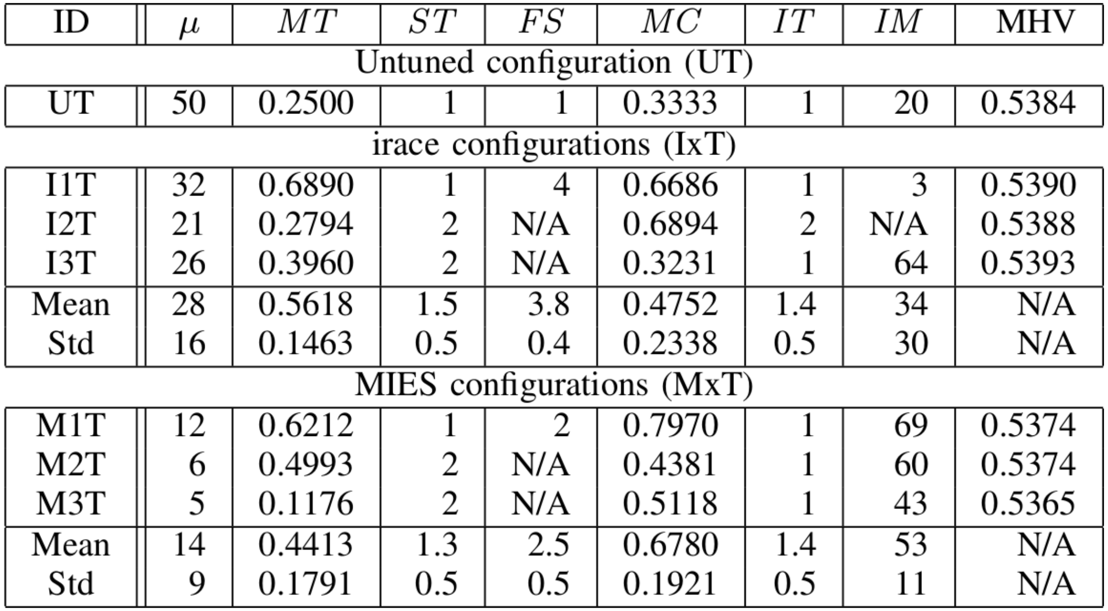
- US/T = Untuned Standard/Tailored
- IxS/T = irace
- MxS/T = Mixed Integer Evolution Strategy

Standard



ID	μ	CP	MP	MHV
Untuned configuration (US)				
US	50	0.5000	0.0111	0.5348
irace configurations (IxS)				
I1S	31	0.8984	0.0385	0.5380
I2S	41	0.9650	0.0520	0.5385
I3S	73	0.8677	0.0427	0.5381
Mean	48	0.8942	0.0514	N/A
Std	19	0.1133	0.0105	N/A
MIES configurations (MxS)				
M1S	15	0.9679	0.0323	0.5386
M2S	40	0.5567	0.0891	0.5365
M3S	5	0.9709	0.0351	0.5364
Mean	35	0.8088	0.0545	N/A
Std	35	0.1834	0.0262	N/A

Tailored



ID	μ	MT	ST	FS	MC	IT	IM	MHV
Untuned configuration (UT)								
UT	50	0.2500	1	1	0.3333	1	20	0.5384
irace configurations (IxT)								
I1T	32	0.6890	1	4	0.6686	1	3	0.5390
I2T	21	0.2794	2	N/A	0.6894	2	N/A	0.5388
I3T	26	0.3960	2	N/A	0.3231	1	64	0.5393
Mean	28	0.5618	1.5	3.8	0.4752	1.4	34	N/A
Std	16	0.1463	0.5	0.4	0.2338	0.5	30	N/A
MIES configurations (MxT)								
M1T	12	0.6212	1	2	0.7970	1	69	0.5374
M2T	6	0.4993	2	N/A	0.4381	1	60	0.5374
M3T	5	0.1176	2	N/A	0.5118	1	43	0.5365
Mean	14	0.4413	1.3	2.5	0.6780	1.4	53	N/A
Std	9	0.1791	0.5	0.5	0.1921	0.5	11	N/A