

KES 2025

Adaptive Metaheuristic Selection in Island-Based Optimization

Adam Żychowski¹, Xin Yao², Jacek Mańdziuk^{1,3}

¹Faculty of Mathematics and Information Science, Warsaw University of Technology

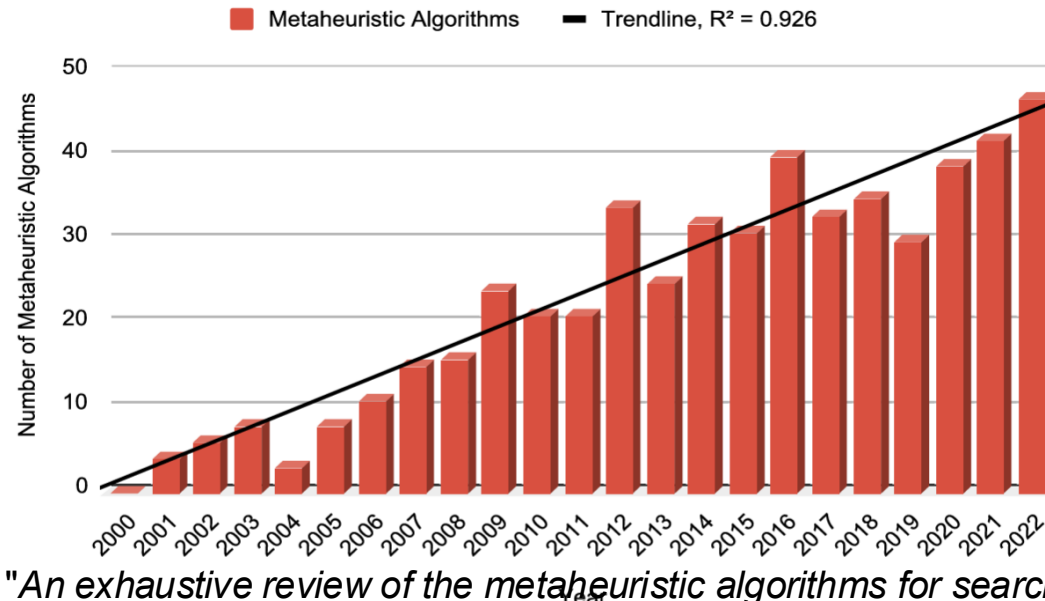
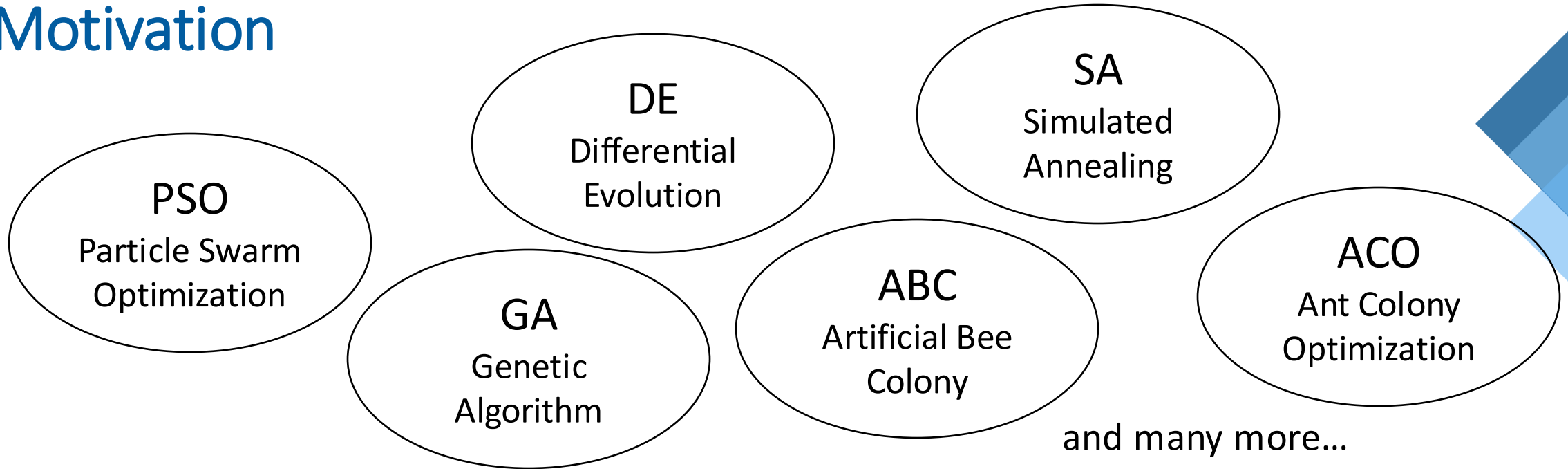
²School of Data Science, Lingnan University, Hong Kong SAR

³Faculty of Computer Science, AGH University of Krakow

September 10, 2025

Osaka

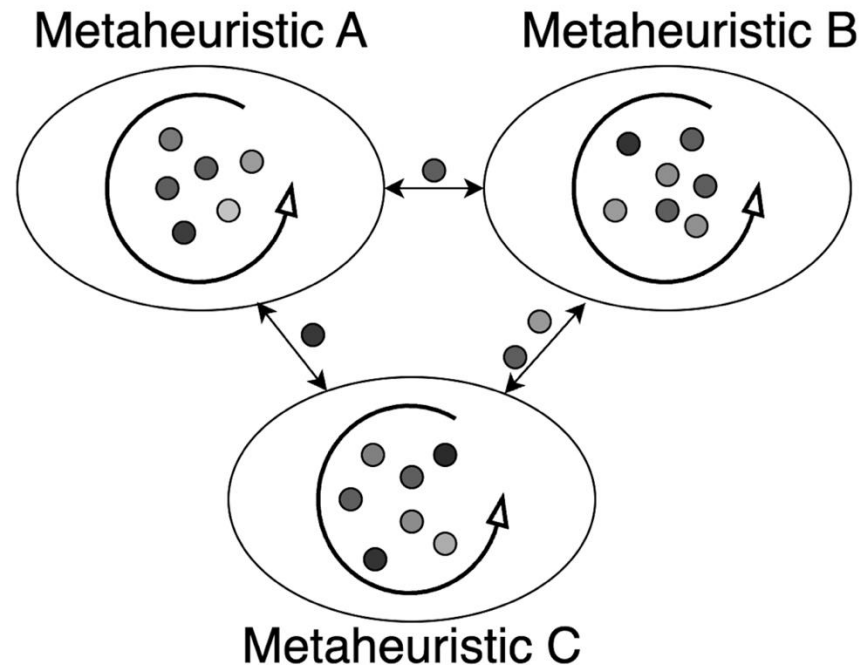
Motivation



Rajwar, Kanchan, et al. "An exhaustive review of the metaheuristic algorithms for search and optimization: taxonomy, applications, and open challenges" Artificial Intelligence Review 2023.

Idea

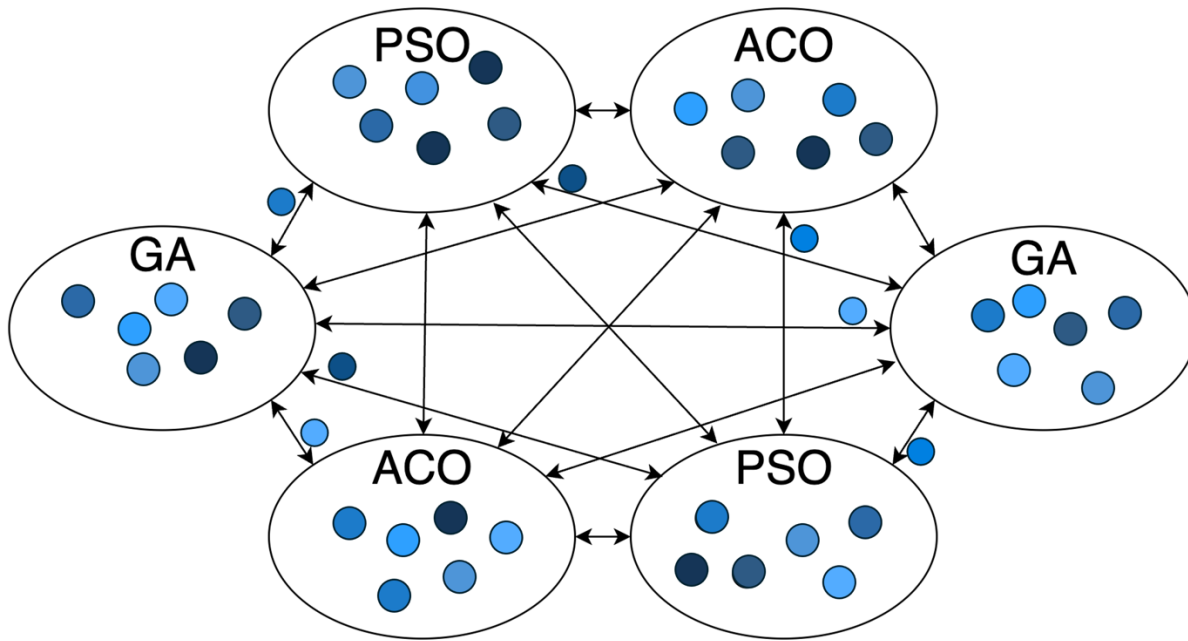
- Multiple metaheuristic into one framework to combine their strengths
- Inspiration from island genetic algorithms
- n islands each developed by a single metaheuristic



Limitations of existing approaches

- Traditional island models use a single metaheuristic (usually genetic algorithm) across all islands
- Migration strategies often static and not diversity-aware
- Lack of synergy and adaptive cooperation
- Static algorithm to island assignment

Cooperating portfolio of metaheuristics (DdCPM)



Algorithm 1 Pseudocode of the baseline DdCPM method.

```
1: for each island  $I \in \mathcal{I}$  do
2:   initialize  $I_{population}$  with random individuals
3: end for
4: while  $evaluation\_budget > 0$  do
5:   for each island  $I \in \mathcal{I}$  do
6:     if  $needs\_migration(I)$  then
7:        $I_{population} = I_{population} \cup migrate\_from(I_{neighbours})$ 
8:     end if
9:   end for
10:  for each island  $I \in \mathcal{I}$  do
11:     $I_{population} = next\_generation(I_{population}, I_{metaheuristic})$ 
12:     $evaluate(I_{population})$ 
13:     $evaluation\_budget = evaluation\_budget - |I_{population}|$ 
14:  end for
15: end while
16: return the best individual from  $\mathcal{I}$ 
```

Żychowski, A., Yao, X., Mańdziuk, J.: *Diversity-driven cooperating portfolio of metaheuristic algorithms*.
In: The Genetic and Evolutionary Computation Conference (**GECCO 2025**)

Adaptive metaheuristic assignment

Previous solution: static assignment of algorithms to islands

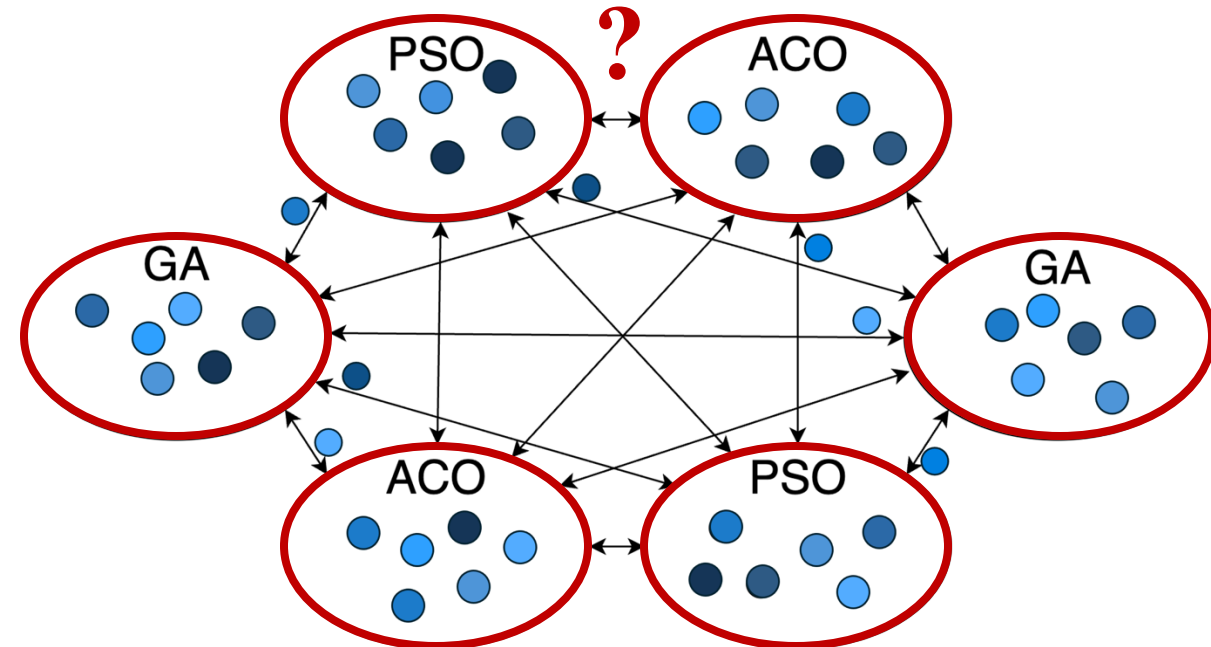
New idea: **dynamic reassignment** of metaheuristics during runtime

Key questions:

- **which island** should have its metaheuristic replaced? (*island selection*)
- **which metaheuristic** should replace the current one? (*algorithm selection*)
- **when** this adaptation should occur? (*adaptation timing*)

Island selection strategies

- A. *Random island selection* (Random)
- B. *Weakest performance island* (Weakest) - lowest average fitness of its top K individuals
- C. *Similarity-based selection* (Similar) - island whose population is most similar to populations on other islands



Metaheuristic selection strategies

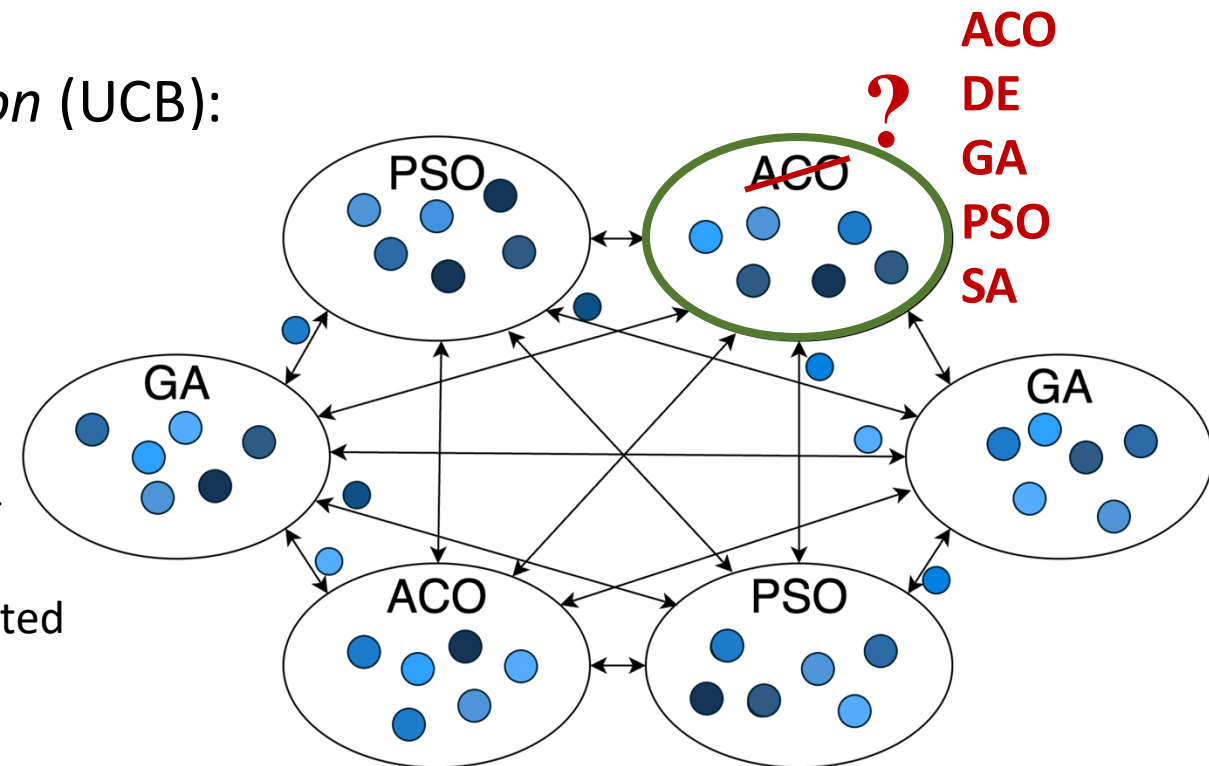
1. *Random Algorithm Selection* (Random)
2. *Best Individual Algorithm* (Best) - metaheuristic that is currently employed on the island which contains the overall best individual
3. *Highest Average Fitness Algorithm* (Avg Fitness) - metaheuristic from the island with the highest average population fitness
4. *Upper Confidence Bound Algorithm Selection* (UCB):

$$\text{UCB}_i(t) = \underbrace{\hat{\mu}_i(t)}_{\text{exploitation}} + C \underbrace{\sqrt{\frac{\ln(t)}{N_i(t)}}}_{\text{exploration}}$$

$\hat{\mu}_i(t)$ - average fitness improvement of metaheuristic i

$N_i(t)$ - number of times metaheuristic i has been selected

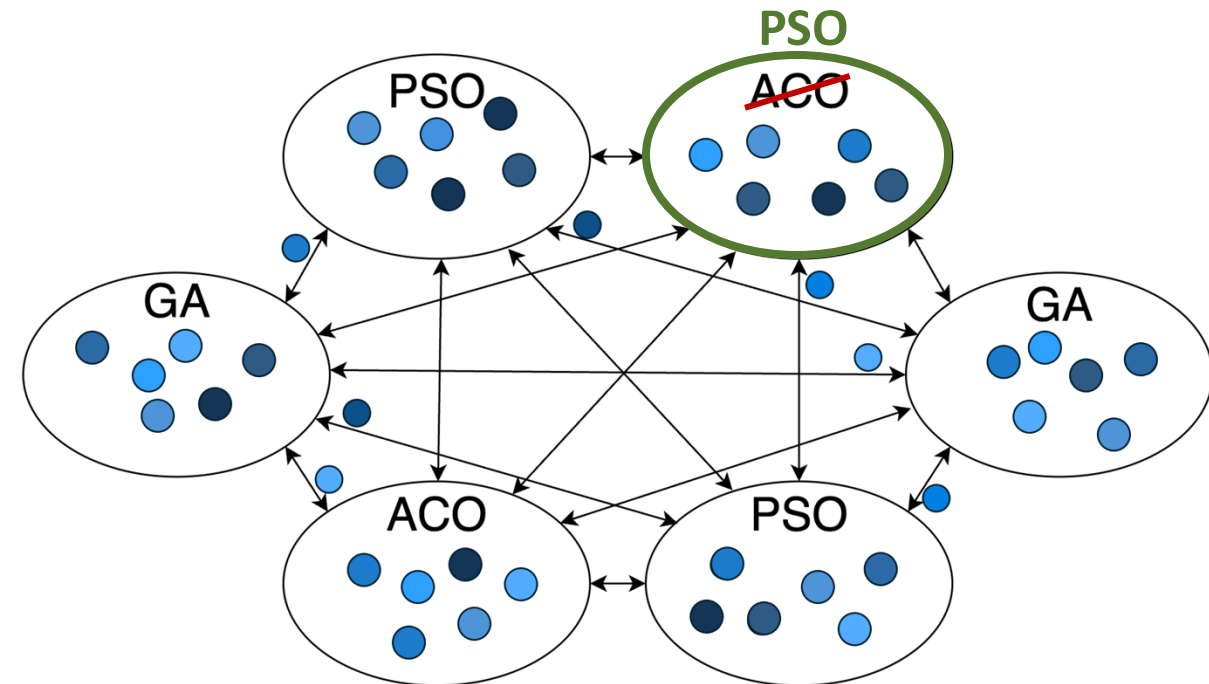
C - parameter



Adaptation timing

Adaptation is triggered:

- every K_i generations
- when stagnation is detected (no fitness improvement) for K_s generations



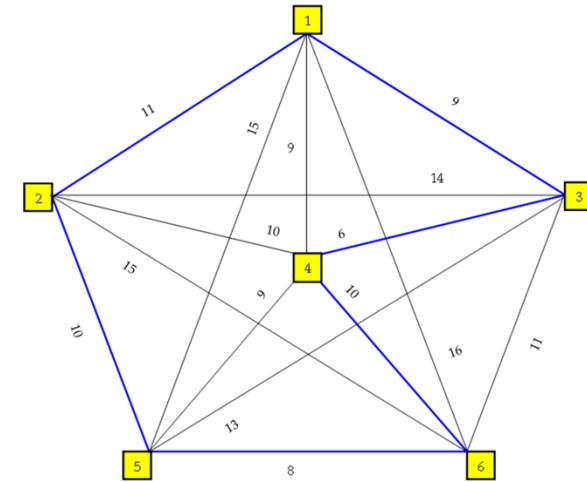
Experimental setup - parameterization

- number of islands: 10
- number of individuals in each island: 100
- tested metaheuristics:
 - ACO (Ant Colony Optimization)
 - DE (Differential Evolution)
 - GA (Genetic Algorithm)
 - PSO (Particle Swarm Optimization)
 - SA (Simulated Annealing)
- adaptation every $K_i=20$ generation or $K_s=10$ generations of stagnation

Experimental setup – evaluated problems

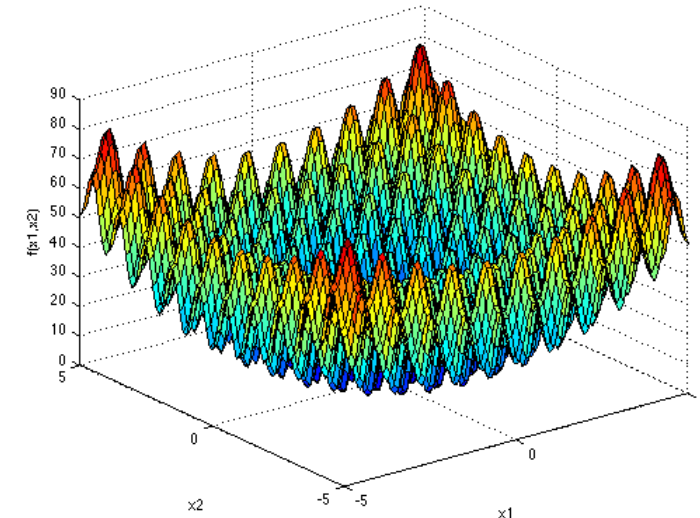
Discrete:

- Traveling Salesman Problem (**TSP**)
- 400-700 nodes
- 10 instances



Continuous:

- Black-box Optimization Benchmarking (**BBOB**)
- 30 dimensions
- 24 instances



Results – static configurations

	BBOB		TSP	
	Top 5 best combinations	Result	Top 5 best combinations	Result
1.	2ACO+5DE+2GA+1PSO+0SA	1.547 $\pm$ 0.023	3ACO+4DE+2GA+1PSO+0SA	34724 $\pm$ 17
2.	1ACO+6DE+2GA+1PSO+0SA	1.548 $\pm$ 0.029	2ACO+5DE+2GA+1PSO+0SA	34727 $\pm$ 23
3.	2ACO+4DE+2GA+1PSO+1SA	1.551 $\pm$ 0.021	3ACO+3DE+3GA+1PSO+0SA	34729 $\pm$ 19
4.	1ACO+5DE+2GA+1PSO+1SA	1.553 $\pm$ 0.019	2ACO+4DE+2GA+1PSO+1SA	34731 $\pm$ 22
5.	2ACO+5DE+1GA+2PSO+1SA	1.556 $\pm$ 0.022	2ACO+4DE+1GA+2PSO+1SA	34737 $\pm$ 20

The best static combinations of tested 5 metaheuristics for 10 islands.

Metaheuristic	BBOB		TSP	
	% gain	absolute gain	% gain	absolute gain
ACO	2.00	0.034	0.89	323.8
DE	9.50	0.157	1.60	567.5
GA	2.70	0.047	0.24	24.3
PSO	2.30	0.041	0.18	78.5
SA	0.80	0.015	0.05	113.1

Performance gains when a given metaheuristic is added to an island-based setup.

Key observation: DE is the most useful metaheuristic, SA is the least useful.

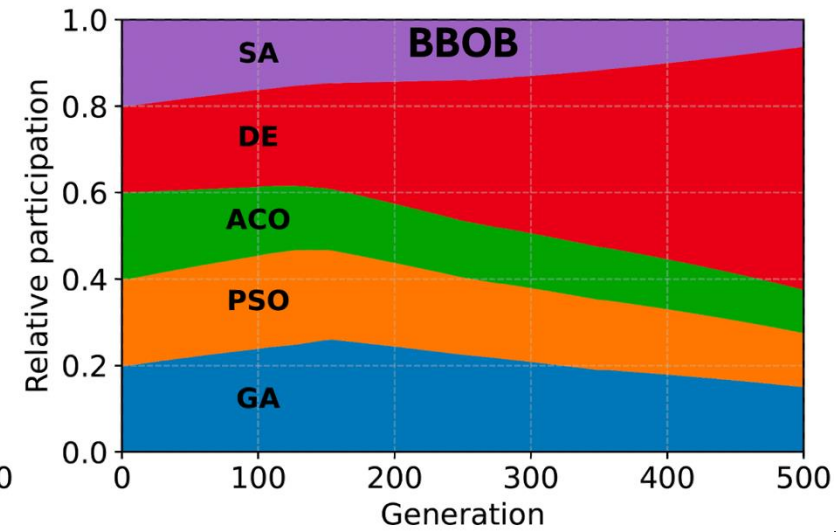
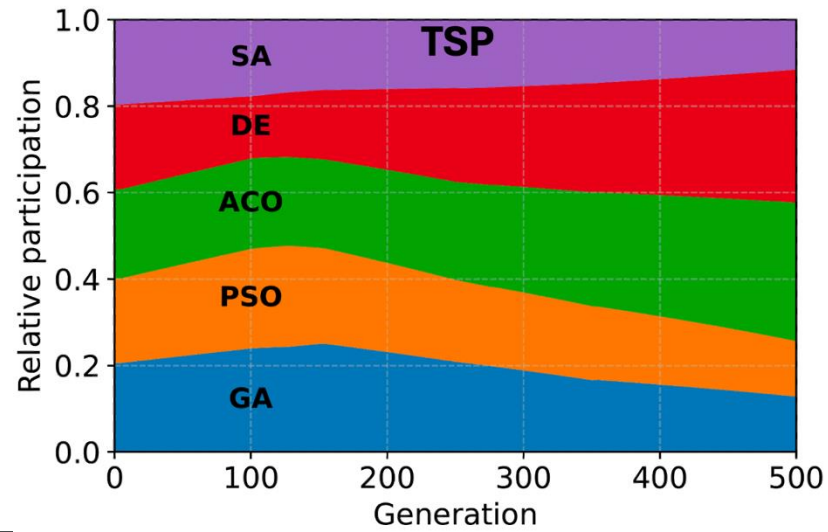
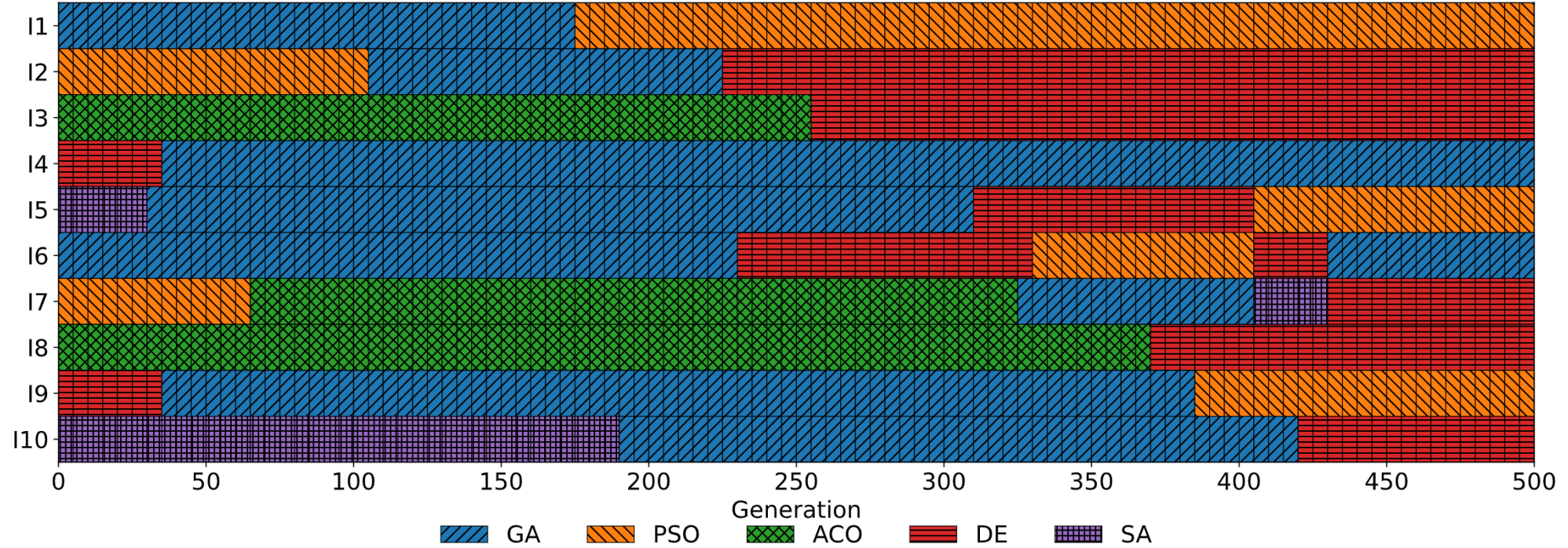
Results

BBOB							
Replacement strategy	Selection strategy	Result	ACO	DE	GA	PSO	SA
Random	Random	1.604 ± 0.048	2.04	2.26	1.95	1.82	1.93
Random	Weakest	1.576 ± 0.044	1.82	3.64	2.03	1.58	0.93
Random	Similar	1.587 ± 0.041	1.91	3.49	2.11	1.47	1.02
Best	Random	1.592 ± 0.043	1.67	3.82	2.08	1.45	0.98
Best	Weakest	1.558 ± 0.038	1.54	4.25	2.01	1.32	0.88
Best	Similar	1.573 ± 0.037	1.61	3.93	2.07	1.49	0.90
Avg Fitness	Random	1.579 ± 0.040	1.73	3.78	2.04	1.38	1.07
Avg Fitness	Weakest	1.545 ± 0.046	1.49	4.31	1.98	1.36	0.87
Avg Fitness	Similar	1.567 ± 0.037	1.58	3.89	2.12	1.41	1.00
UCB	Random	1.563 ± 0.042	1.63	4.07	2.05	1.35	0.90
UCB	Weakest	1.534 ± 0.035	1.66	4.43	1.95	1.09	0.87
UCB	Similar	1.539 ± 0.038	1.55	4.13	2.01	1.34	0.97
TSP							
Replacement strategy	Selection strategy	Result	ACO	DE	GA	PSO	SA
Random	Random	34761 ± 40	2.06	2.11	1.99	1.96	1.88
Random	Weakest	34752 ± 31	2.74	3.68	2.11	0.97	0.50
Random	Similar	34755 ± 35	2.95	3.25	2.35	0.85	0.60
Best	Random	34755 ± 32	3.00	3.41	2.06	1.00	0.52
Best	Weakest	34758 ± 23	2.84	3.47	2.21	0.94	0.43
Best	Similar	34753 ± 26	3.07	3.24	2.13	0.90	0.55
Avg Fitness	Random	34750 ± 33	3.15	3.63	1.93	0.83	0.66
Avg Fitness	Weakest	34748 ± 25	3.28	3.81	1.78	0.68	0.45
Avg Fitness	Similar	34745 ± 22	3.17	3.50	1.98	0.92	0.43
UCB	Random	34754 ± 29	2.95	3.70	1.94	0.89	0.52
UCB	Weakest	34705 ± 23	3.35	4.03	1.70	0.45	0.47
UCB	Similar	34716 ± 21	3.11	3.70	2.01	0.67	0.51

Results for the proposed adaptive metaheuristic selection strategies.

Key observation: *UCB+Weakest* is the best combination and the combination of metaheuristics usage matches the best static combinations.

Visualisation



Results – computation time

	BBOB	TSP
Static configuration	542.6	753.3
Adaptive metaheuristic selection	543.3	754.1
Difference %	0.13%	0.11%

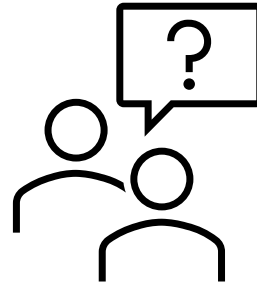
Averaged computation time comparison.

Key observation: adaptation mechanism imposes a negligible computational cost, while offering significant performance benefit.

Summary

- novel adaptive metaheuristic selection strategy for island-based optimization
- combination of UCB for algorithm replacement in the *weakest* performance island yielded the best results
- outperformed the best static metaheuristic configuration
- elimination of exhaustive pre-tuning - more efficient and flexible across diverse problem domains

Thank you



Full paper

Results – static configurations

Islands configuration	BBOB	TSP	Islands configuration	BBOB	TSP
ACO	1.928±0.063	35461 ± 59	ACO+DE+GA	1.678±0.040	35100 ± 45
DE	1.677±0.037	35239 ± 49	ACO+DE+PSO	1.668±0.033	35016 ± 35
GA	1.788±0.051	35830 ± 83	ACO+DE+SA	1.648±0.023	34906 ± 35
PSO	1.842±0.050	36006 ± 79	ACO+GA+PSO	1.788±0.060	35468 ± 55
SA	1.988±0.026	36193 ± 74	ACO+GA+SA	1.758±0.053	35526 ± 55
ACO+DE	1.688±0.038	34993 ± 39	ACO+PSO+SA	1.778±0.050	35249 ± 45
ACO+GA	1.808±0.059	35465 ± 60	DE+GA+PSO	1.655±0.043	35176 ± 50
ACO+PSO	1.812±0.055	35446 ± 55	DE+GA+SA	1.658±0.035	35197 ± 50
ACO+SA	1.858±0.045	35397 ± 55	DE+PSO+SA	1.645±0.028	35120 ± 40
DE+GA	1.665±0.048	35225 ± 50	GA+PSO+SA	1.748±0.058	35760 ± 65
DE+PSO	1.672±0.039	35198 ± 45	ACO+DE+GA+PSO	1.658±0.030	35050 ± 35
DE+SA	1.668±0.030	35096 ± 45	ACO+DE+GA+SA	1.638±0.025	34960 ± 40
GA+PSO	1.768±0.056	35728 ± 75	ACO+DE+PSO+SA	1.625±0.015	34811 ± 30
GA+SA	1.775±0.054	35646 ± 70	ACO+GA+PSO+SA	1.738±0.055	35325 ± 50
PSO+SA	1.798±0.050	35784 ± 65	DE+GA+PSO+SA	1.637±0.023	35148 ± 45
			ACO+DE+GA+PSO+SA	1.618±0.013	34778 ± 25

Static island-based configurations of metaheuristics.

Key observation: combination of diverse metaheuristic approaches creates a synergy that enhances overall performance.