Diversity-driven Cooperating Portfolio of Metaheuristic Algorithms

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Jul 16, 2025

Motivation

PSO
Particle Swarm Optimization

DE
Differential Evolution

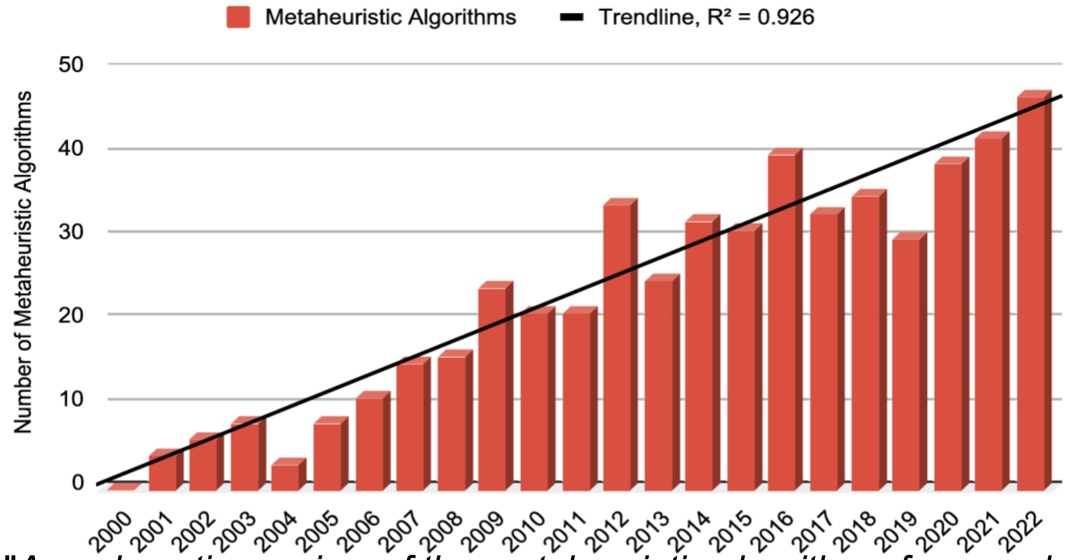
GA
Genetic Algorithm

ABC
Artificial Bee Colony

SA
Simulated Annealing

ACO
Ant Colony Optimization

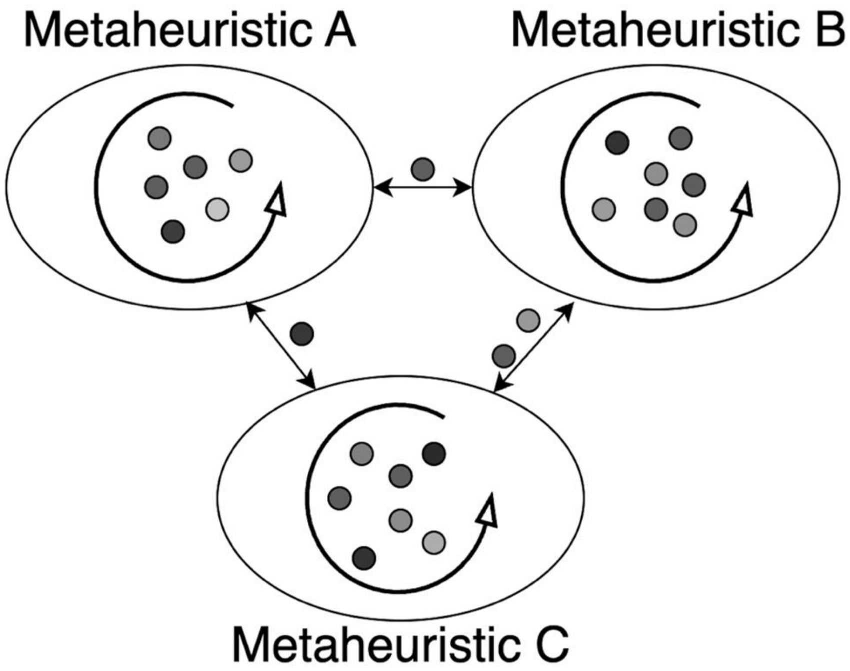
and many more…



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

Key questions in choosing migration strategies

When to migrate?

- How frequently should migration happen?
- What indicators trigger migration?

What to migrate?

- How many individuals should be migrated?
- Which individuals should be selected?
- How do different selection criteria affect algorithm performance?

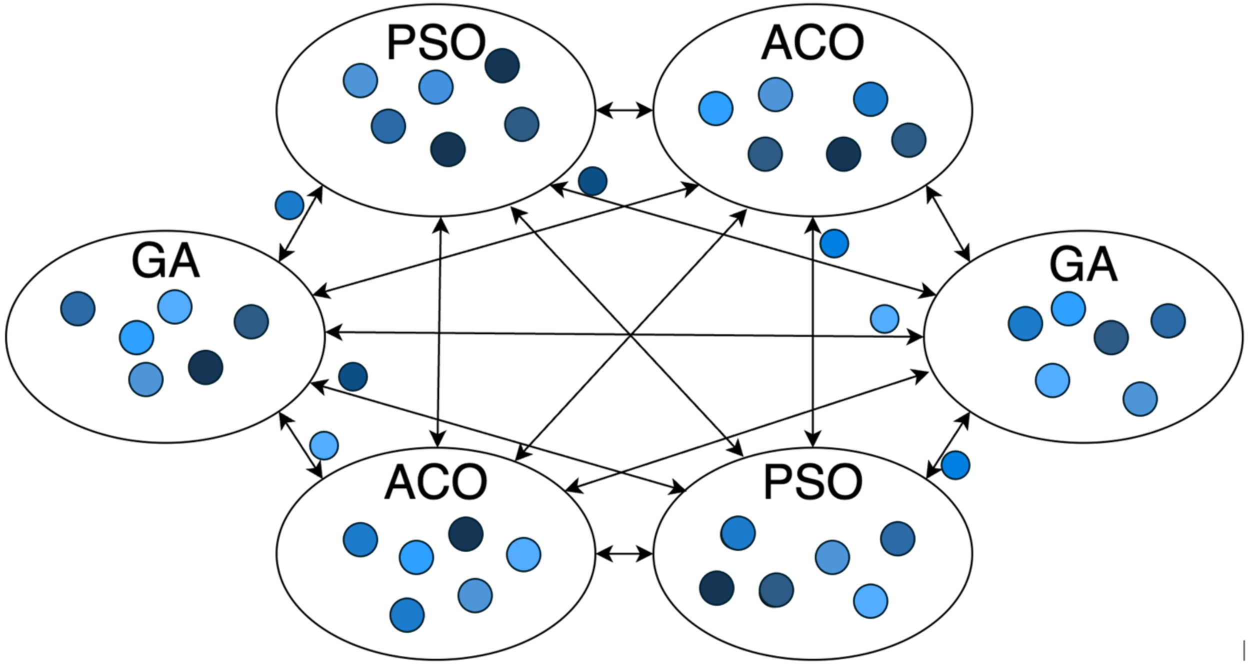
Where to migrate?

- How should the neighborhood between islands be defined?
- What connection topology should be chosen?

Diversity-driven Cooperating Portfolio of Metaheuristics (DdCPM)

Algorithm 1 Pseudocode of the baseline DdCPM method.

for each island $I \in \mathcal{I}$ **do**
  initialize $I_{population}$ with random individuals
end for
while *evaluation_budget* > 0 **do**
  for each island $I \in \mathcal{I}$ **do**
    if needs_migration(I) **then**
      $I_{population} = I_{population} \cup$ migrate_from($I_{neighbours}$)
    end if
  end for
  for each island $I \in \mathcal{I}$ **do**
    $I_{population}$ = next_generation($I_{population}, I_{metaheuristic}$)
    evaluate($I_{population}$)
    evaluation_budget = *evaluation_budget* $- |I_{population}|$
  end for
end while
return the best individual from $\mathcal{I}$



When to migrate?

T1: Periodic migration every *x* iterations

T2: Average fitness doesn't increase for *x* iterations

T3: Maximum fitness doesn't increase for *x* iterations

T4: Average and maximum fitness don't increase for *x* iterations

T5: Diversity doesn't increase for *x* iterations

T6: Combination of T4 and T5

What to migrate?

S1: Individual with the best fitness

S2: Individual that increases diversity the most

S3: Random individual that increases diversity

S4: Combined sum of diversity increment and fitness

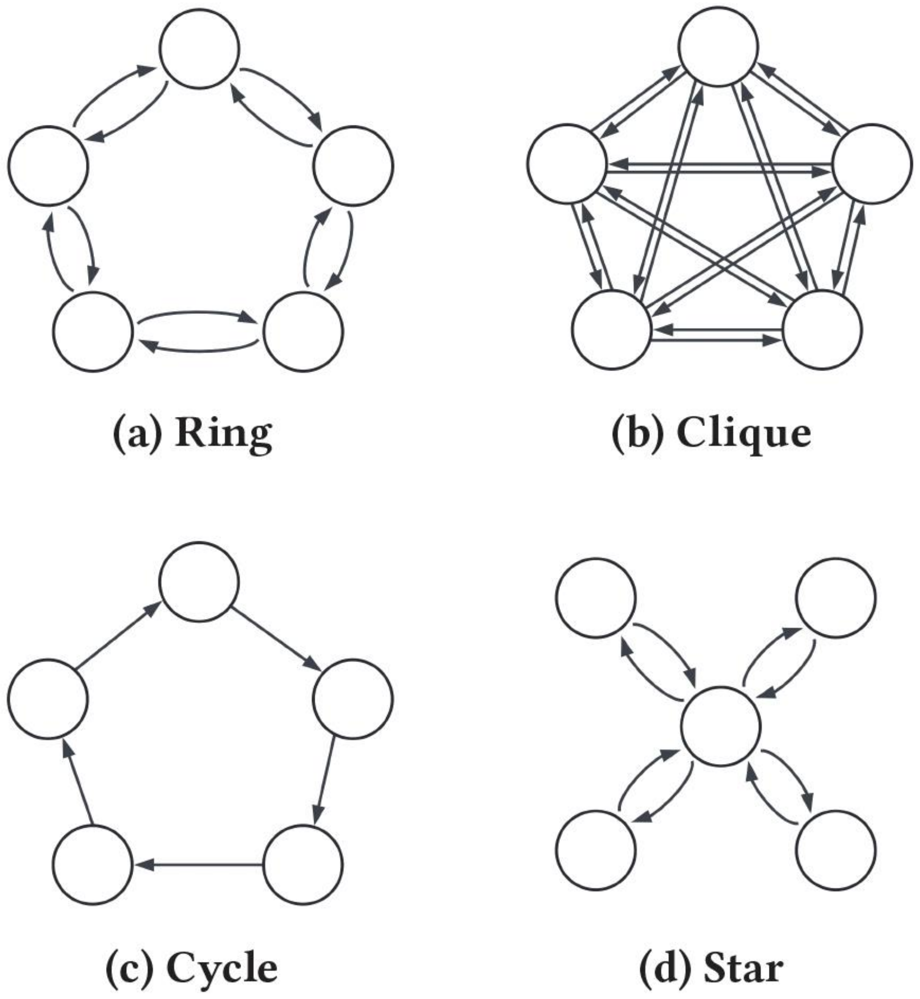
Where to migrate?

P1: Ring

P2: Clique

P3: Cycle

P4: Star

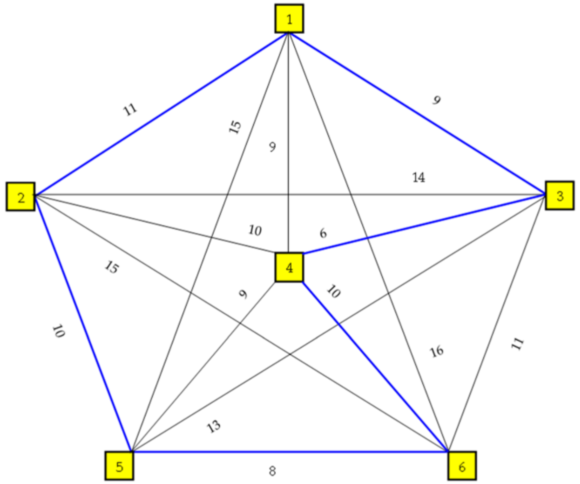


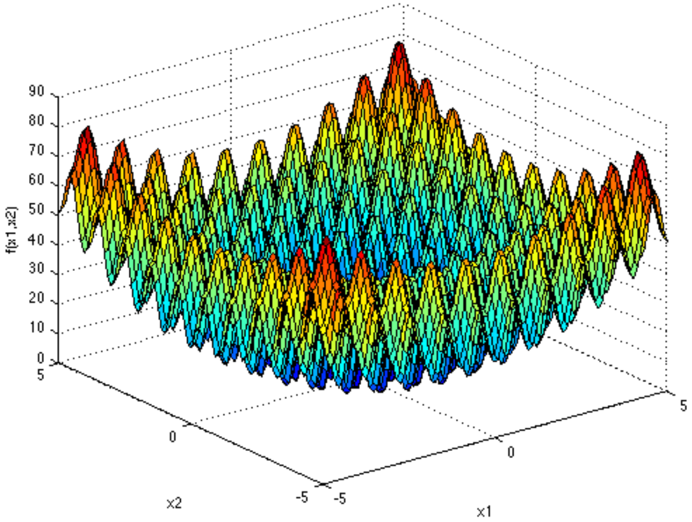
Experimental setup

- number of islands: 6 (2PSO, 2GA, 2ACO)
- population size: 100

Problems:

- discrete: Traveling Salesman Problem (TSP) – 400-700 nodes
- continuous: Black-box Optimization Benchmarking (BBOB) - 30 dimensions





Results

when to migrate

	TSP		BBOB	
	Avg rank	Avg fitness	Avg rank	Avg fitness
Periodic migration	15.9	35571	21.3	1.609
Average fitness	49.2	35605	46.8	1.635
Maximum fitness	11.6	35570	18.1	1.586
Average and maximum fitness	18.0	35579	20.8	**1.560**
Diversity	29.4	35588	32.9	1.593
Combination of fitness and diversity	**7.2**	**35559**	**12.1**	1.570

what to migrate

	TSP		BBOB	
	Avg rank	Avg fitness	Avg rank	Avg fitness
Best fitness	15.4	35580	41.3	1.609
Max diversity increasement	80.2	35623	59.9	1.672
Random diversity increasement	58.6	35610	54.8	1.646
Combined sum of fitness and diversity	**12.9**	**35571**	**25.3**	**1.584**

Results

where to migrate

Where variant	TSP		BBOB	
	Avg rank	Avg fitness	Avg rank	Avg fitness
Ring	**12.9**	**35571**	**22.4**	1.609
Clique	26.4	35588	31.3	**1.605**
Cycle	46.2	35605	49.3	1.649
Star	40.9	35600	41.6	1.649

Results - fitness-diversity balance

what to migrate

$$m = \alpha \cdot fitness + (1 - \alpha) \cdot diversity\_increasement$$

α	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
TSP	35558	35360	**35335**	35410	35397	35459	35594	35618	35680	35705	35742
BBOB	1.668	**1.432**	1.437	1.456	1.442	1.484	1.581	1.614	1.676	1.733	1.789

The impact of varying the balance parameter (α) between diversity and fitness in the selection of individuals for migration

Results – adaptive migration

1. Linearly decreasing α with iterations $\alpha = \frac{\text{current iteration}}{\text{total number of iterations}}$

2. Fitness stagnation-based adaptation

$$\alpha = \alpha + \delta \quad \text{if no improvement occurs for } x_\delta \text{ iterations}$$

3. Fitness stagnation-based adaptation $\alpha = \frac{\text{max fitness}_{\text{local}}}{\text{max fitness}_{\text{global}}}$

TSP instance	rd400	fl417	pcb442	d493	att532	si535	u574	p654	d657	u724
$\alpha = 0.2$	15408 ±18	11945 ±12	51159 ±57	35234 ±39	27845 ±32	48894 ±97	37244 ±65	34827 ±38	49285 ±49	42159 ±55
iterative decay	**15319** ±27	**11865** ±12	**50813** ±68	**35083** ±46	27739 ±51	48665 ±50	**37077** ±52	**34684** ±37	49138 ±59	**42047** ±50
stagnation based	15359 ±21	11908 ±21	50872 ±51	35000 ±38	27746 ±51	48738 ±80	37146 ±49	34724 ±54	**48991** ±50	41872 ±74
fitness based	15368 ±19	11875 ±18	50920 ±75	35103 ±40	**27669** ±34	**48600** ±90	37041 ±57	34612 ±48	49132 ±78	41948 ±60

BBOB instance	f2	f4	f6	f8	f10	f12	f14	f16	f18	f20	f22	f24
$\alpha = 0.1$	0.014 ±.000	1.392 ±.010	0.904 ±.005	1.857 ±.011	3.183 ±.045	4.459 ±.045	0.633 ±.005	0.801 ±.006	0.747 ±.007	1.428 ±.015	0.439 ±.005	1.404 ±.009
iterative decay	**0.013** ±.000	1.350 ±.012	**0.855** ±.007	**1.728** ±.018	3.053 ±.020	4.359 ±.057	0.608 ±.004	0.771 ±.011	**0.702** ±.007	1.377 ±.017	0.428 ±.004	**1.313** ±.014
stagnation based	**0.013** ±.000	1.349 ±.017	0.870 ±.009	1.789 ±.020	3.113 ±.022	**4.322** ±.063	**0.599** ±.004	0.773 ±.008	0.706 ±.008	1.340 ±.011	0.425 ±.003	1.316 ±.008
fitness based	**0.013** ±.000	**1.303** ±.008	0.885 ±.010	1.788 ±.024	**3.022** ±.032	4.350 ±.038	0.609 ±.008	**0.755** ±.005	0.722 ±.005	**1.331** ±.019	**0.415** ±.002	1.317 ±.017

Results

TSP instance	rd400	fl417	pcb442	d493	att532	si535	u574	p654	d657	u724
ACO	15562 ±16	12094 ±11	51455 ±97	35487 ±67	28102 ±49	49113 ±81	37477 ±53	35141 ±41	49571 ±87	42495 ±47
GA	15531 ±54	12095 ±33	51426 ±161	35441 ±125	28112 ±84	49098 ±155	37360 ±141	35114 ±121	49541 ±110	42472 ±136
PSO	15561 ±27	12108 ±14	51416 ±90	35518 ±58	28101 ±27	49068 ±95	37412 ±53	35164 ±63	49560 ±93	42436 ±62
ACO islands	15522 ±23	12070 ±25	51419 ±106	35489 ±46	28095 ±47	49080 ±71	37377 ±54	35103 ±69	49578 ±86	42483 ±92
GA islands	15480 ±48	12039 ±31	51332 ±126	35418 ±83	28040 ±61	49013 ±134	37373 ±94	35030 ±80	49498 ±180	42380 ±91
PSO islands	15527 ±17	12069 ±16	51391 ±106	35498 ±48	28064 ±48	49078 ±55	37431 ±52	35130 ±68	49531 ±57	42506 ±107
ACO+GA+PSO	15576 ±53	12112 ±31	51488 ±158	35497 ±122	28147 ±83	49123 ±153	37418 ±137	35162 ±118	49592 ±109	42485 ±135
DdCPM	**15448** ±23	**11996** ±27	**51294** ±107	**35365** ±38	**27987** ±29	**48984** ±69	**37305** ±87	**35012** ±37	**49418** ±62	**42366** ±52

BBOB instance	f2	f4	f6	f8	f10	f12	f14	f16	f18	f20	f22	f24
ACO	0.015 ±.000	1.558 ±.020	1.089 ±.010	2.228 ±.023	3.708 ±.067	5.046 ±.050	0.707 ±.008	0.859 ±.015	0.843 ±.010	1.613 ±.021	0.480 ±.006	1.492 ±.027
GA	0.015 ±.000	1.491 ±.053	1.050 ±.035	2.092 ±.067	3.571 ±.103	4.930 ±.181	0.739 ±.025	0.881 ±.026	0.790 ±.017	1.575 ±.038	0.466 ±.015	1.561 ±.052
PSO	0.015 ±.000	1.579 ±.024	1.060 ±.018	2.201 ±.042	3.447 ±.066	5.102 ±.071	0.720 ±.008	0.889 ±.015	0.833 ±.010	1.574 ±.024	0.466 ±.006	1.511 ±.019
ACO islands	0.015 ±.000	1.466 ±.019	1.008 ±.022	2.132 ±.040	3.466 ±.038	4.706 ±.088	0.699 ±.013	0.872 ±.018	0.817 ±.010	1.573 ±.029	0.487 ±.008	1.574 ±.028
GA islands	**0.014** ±.000	1.457 ±.050	1.041 ±.028	2.058 ±.061	3.546 ±.124	4.993 ±.122	0.683 ±.018	0.859 ±.029	0.781 ±.026	1.514 ±.047	0.468 ±.018	1.488 ±.039
PSO islands	0.015 ±.000	1.528 ±.040	1.003 ±.018	2.017 ±.050	3.669 ±.071	5.007 ±.117	0.690 ±.010	0.887 ±.015	0.817 ±.012	1.509 ±.019	0.481 ±.011	1.492 ±.016
ACO+GA+PSO	0.016 ±.000	1.495 ±.051	1.053 ±.034	2.098 ±.065	3.580 ±.101	4.945 ±.178	0.741 ±.024	0.885 ±.025	0.792 ±.016	1.580 ±.037	0.468 ±.014	1.565 ±.050
DdCPM	**0.014** ±.000	**1.411** ±.023	**0.927** ±.011	**1.886** ±.036	**3.229** ±.057	**4.639** ±.108	**0.653** ±.009	**0.818** ±.011	**0.777** ±.016	**1.450** ±.024	**0.444** ±.009	**1.421** ±.026

Comparison of hybridized metaheuristics (DdCPM) with individual methods for TSP (top) and BBOB (bottom) instances

Summary

- A novel hybrid **framework combining metaheuristics** via adaptive, diversity-aware migration
- Outperforms traditional and island-based models
- **Diversity is essential** for avoiding stagnation and improving solution quality
- **Combination of fitness and diversity** yields the best results
- **Strong results** across different problem types

THANK YOU

Full paper

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