

Self-adaptation via multi-objectivisation: an empirical study

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Appendix 1 Omitted algorithms in this paper

Algorithm 3 Multi-objective sorting mechanism [33]

Require: Population sizes $\lambda \in \mathbb{N}$. Population $P_t \in \mathcal{Y}^\lambda$. Fitness function f .

- 1: Sort P_t into strict non-dominated fronts $\mathcal{F}_0^t, \mathcal{F}_1^t, \dots$ based on $f_1(x, \chi) := f(x)$ and $f_2(x, \chi) := \chi$.
 - 2: **for** $\mathcal{F} = \mathcal{F}_0^t, \mathcal{F}_1^t, \dots$ **do**
 - 3: Sort \mathcal{F} such that $f_1(\mathcal{F}(1)) > f_1(\mathcal{F}(2)) > \dots$
 - 4: $P_t := (\mathcal{F}_0^t, \mathcal{F}_1^t, \dots)$.
 - 5: **return** P_t .
-

Algorithm 4 Strict non-dominated sorting [33]

Require: Population sizes $\lambda \in \mathbb{N}$. Population $P \in \mathcal{Z}^\lambda$, where \mathcal{Z} is a finite state space. Objective functions $f_1, f_2, \dots : \mathcal{Z} \rightarrow \mathbb{R}$ (assume to maximise all objective functions).

- 1: **for** each individual $P(i)$ **do**
 - 2: Set $S_i := \emptyset$ and $n_i := 0$.
 - 3: **for** $i = 1, \dots, \lambda$ **do**
 - 4: **for** $j = 1, \dots, \lambda$ **do**
 - 5: **if** $P(i) \prec P(j)$ based on f_1, f_2, \dots **then**
 - 6: $S_i := S_i \cup \{P(i)\}$,
 - 7: **else if** $P(j) \prec P(i)$ based on f_1, f_2, \dots **then**
 - 8: $n_i := n_i + 1$,
 - 9: **else if** $f_\ell(P(i)) = f_\ell(P(j))$ where $\ell = 1, 2, \dots$ **then**
 - 10: **if** $P(i) \notin S_j$ **then** $S_i := S_i \cup \{P(i)\}$ **else** $n_i := n_i + 1$.
 - 11: **if** $n_i = 0$ **then** $\mathcal{F}_0 = \mathcal{F}_0 \cup \{P(i)\}$.
 - 12: Set $k := 0$.
 - 13: **while** $\mathcal{F}_k \neq \emptyset$ **do**
 - 14: $Q := \emptyset$.
 - 15: **for** each individual $P(i) \in \mathcal{F}_k$ and $P(j) \in S_i$ **do**
 - 16: Set $n_j := n_j - 1$.
 - 17: **if** $n_j = 0$ **then** $Q := Q \cup \{P(j)\}$.
 - 18: Set $k := k + 1$, $\mathcal{F}_k := Q$.
 - 19: **return** $\mathcal{F}_0, \mathcal{F}_1, \dots$
-

Algorithm 5 Multi-objective sorting mechanism (alternative)

Require: Population sizes $\lambda \in \mathbb{N}$. Population $P_t \in \mathcal{Y}^\lambda$. Fitness function f .

- 1: Sort P_t into P_t^1, P_t^2, \dots where P_t^1 containing all individuals with the highest fitness f , P_t^2 containing all individuals with the 2nd highest fitness f , \dots
- 2: **for** $i = 1, \dots, \lambda$ **do**
- 3: Set $\hat{\chi} := -\infty$.
- 4: **for** $Q = P_t^1, P_t^2, \dots$ **do**
- 5: Find (x', χ') which is the element with the highest χ in Q .
- 6: **if** $Q \neq \emptyset$ and $\chi' > \hat{\chi}$ **then**
- 7: $P_t(i) := (x', \chi')$ and $\hat{\chi} := \chi'$.
- 8: Pop (x', χ') from Q .
- 9: Break.
- 10: **return** P_t .

Algorithm 6 (μ, λ) selection

Require: Population size $\lambda \in \mathbb{N}$. Parameter $\mu \in [\lambda]^3$.

- 1: $I_t \sim \text{Unif}([\mu])$.
- 2: **return** I_t .

Algorithm 7 Fitness-first sorting mechanism [7]

Require: Population sizes $\lambda \in \mathbb{N}$. Population $P_t \in \mathcal{Y}^\lambda$. Fitness function f .

- 1: Sort P_t such that $P_t(1) \succeq \dots \succeq P_t(\lambda)$, according to
- 2: $(x, \chi) \succeq (x', \chi') \Leftrightarrow f(x) > f(x') \vee (f(x) = f(x') \wedge \chi \geq \chi')$.
- 3: **return** P_t .

³ For any $n \in \mathbb{N}$, we define $[n] := \{1, \dots, n\}$

Appendix 2 Omitted statistical results of experiments

Table 2: Statistical results of experiments on random NK-LANDSCAPE problems. The p -values of each algorithm come from Wilcoxon rank-sum tests between the algorithm and MOSA-EA.

k	Stat.	RS	cGA	UMDA	RLS	SA-(1, λ)EA	(1 + 1)EA	FastGA (1 + (λ , λ))GA	(μ , λ)EA	3-tour.EA	MOSA-EA
5	Median	66.6591	72.9964	74.8631	71.3547	74.8418	76.6613	76.9230	79.2846	79.2846	79.2846
	p -value	$2.1e-22$	$2.3e-04$	0.0213	$6.5e-08$	0.0226	0.2668	0.4215	0.9299	0.7985	0.8805
10	Median	66.4442	69.5499	73.2968	68.3100	71.0248	75.5792	76.1340	77.1520	79.2680	82.5270
	p -value	$2.6e-34$	$1.5e-26$	$2.0e-15$	$2.6e-34$	$3.5e-34$	$5.0e-18$	$1.1e-12$	$2.2e-09$	0.0030	0.0063
15	Median	66.2055	66.5517	70.9576	66.4446	67.8968	73.7253	74.2253	74.6407	76.0777	80.4417
	p -value	$2.6e-34$	$2.6e-34$	$5.5e-22$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$1.8e-33$	$5.2e-33$	$1.3e-20$	$1.1e-17$
20	Median	66.1233	64.4191	69.6786	64.9865	66.0533	72.8025	72.8783	73.0882	74.2380	78.5247
	p -value	$2.6e-34$	$2.6e-34$	$7.0e-31$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$4.0e-33$	$1.2e-31$
25	Median	66.2207	63.1222	68.5683	64.3685	65.1886	70.8648	71.7564	71.9623	73.4398	77.5024
	p -value	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$2.6e-34$	$1.4e-33$

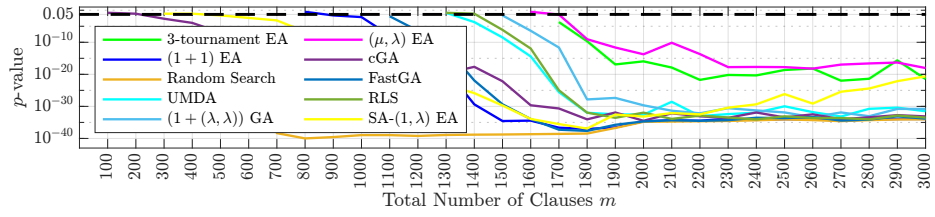


Fig. 11: The p -values of Wilcoxon rank-sum tests between the algorithms and the MOSA-EA on 100 random k -SAT instances. The y -axis is log-scaled.

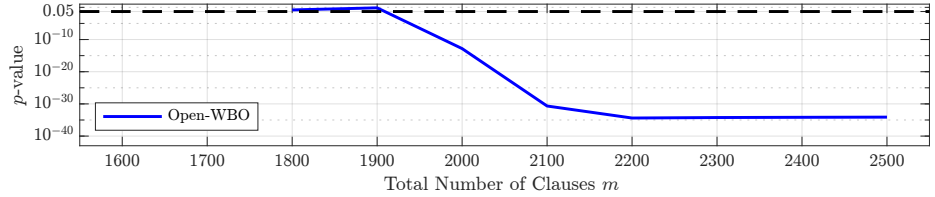


Fig. 12: The p -value of Wilcoxon rank-sum test between Open-WBO and the MOSA-EA on 100 random k -SAT instances. The y -axis is log-scaled.