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CS471 Project 3

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February 20, 2026

INTRODUCTION

This Project used ten selected standard benchmark functions of different properties. The functions were as follows: Schwefel's, 1st De Jong's, Rosenbrock, Rastrigin, Griewangk, Sine Envelope Sine Wave, Stretched V Sine Wave, Ackley's One, Ackley's Two, and Egg Holder.

To compute these functions, a matrix R^{nxm} is used. n is a constant value of 30, which is the number of experiments. m is the given dimension, which can be 10, 20, or 30, but the results in this documentation will be with all the dimensions. To fill this matrix with values, the Mersenne Twister pseudo-random number generator is used to create the vectors (i.e. the rows in the matrix).

This Project 3 builds on Projects 1 and 2 by introducing two new optimization algorithms: Differential Evolution (DE) and Particle Swarm Optimization (PSO). For each benchmark function, both methods run multiple trials and store the best fitness values and runtime in CSV files for analysis.

Differential Evolution (DE) begins by creating a population of candidate vectors within the function bounds using pseudo-random initialization (Mersenne Twister). In each generation, DE applies mutation and crossover to create trial vectors, then uses selection to keep whichever vector has better fitness. This process repeats for the configured number of generations, and the final best fitness, along with runtime and run metadata, is written to the DE results CSV.

Particle Swarm Optimization (PSO) also starts with randomly initialized vectors (particles) and velocities. Each particle tracks its own best position, while the swarm tracks the global best position. During each generation, particles update velocity and position using cognitive

and social terms (c1, c2) so they move toward promising regions of the search space. After all generations, the best fitness found by the swarm and runtime information are written to the PSO results CSV.

Each function will be described with its ranges, the optimal value (i.e., the most optimal fitness that we want from the function), and then what parameters we used for DE and PSO.

1 Schwefel Function

$$f_1(x) = (418.9828 \cdot n) - \sum_{i=1}^{n} -x_i \cdot sin\left(\sqrt{|x_|}\right) \tag{1.1}$$

Schwefel function and its global optima is 0, its dimension is 30 with a range of $[-512, -512]^n$.

2 1st De Jong's Function

$$f_2(x) = \sum_{i=i}^{n} x_i^2 \tag{2.1}$$

1st De Jong's Function and its global optima is 0: its dimension is 30 with a range of $[-100, -100]^n$.

3 Rosenbrock

$$f_3(x) = \sum_{i=1}^{n-1} 100\left(x_i^2 - x_{i+1}\right)^2 + (1 - x_i)^2 \tag{3.1}$$

Rosenbrock Function and its global optima is 0: its dimension is 30 with a range of $[-100, 100^n$.

4 Rastrigin

$$f_4(x) = 10 \cdot n \sum_{i=1}^{n} \left(x_i^2 - 10 \cdot \cos(2\pi \cdot x_i)\right) \tag{4.1}$$

Rastrigin Function and its global optima is 0: its dimension is 30 with a range of $[-30, 30]^n$.

5 Griewangk

$$f_5(x) = 1 + \sum_{i=1}^{n} \frac{x_i^2}{4000} - \prod_{i=1}^{n} \cos\left(\frac{x_i}{\sqrt{i}}\right) \tag{5.1}$$

The Griewangk function has a global optimum of 0: its dimension is 30 with a range of $[-500, 500]^n$.

6 Sine Envelope Sine Wave

$$f_6(x) = -\sum_{i=1}^{n-1} 0.5 + \frac{\sin\left(x_i^2 + x_{i+1}^2 - 0.5\right)^2}{\left(1 + 0.001\left(x_i^2 + x_{i+1}^2\right)\right)^2} \tag{6.1}$$

The Sine Envelope Sine Wave function has a global optimum of $-1.4915(n-1)$. Its dimension is 30 with a range of $[-30,30]^n$.

7 Stretched V Sine Wave

$$f_7(x) = \sum_{i=1}^{n-1} \left(\sqrt[4]{x_i^2 + x_{i+1}^2} \cdot \sin\left(50\sqrt[10]{x_i^2 + x_{i+1}^2}\right)^2 + 1\right) \tag{7.1}$$

The Stretched V Sine Wave function has a global optimum of 0. Its dimension is 30 with a range of $[-30,30]^n$.

8 Ackley's One

$$f_8(x) = \sum_{i=1}^{n-1} \frac{1}{e^{0.2}}\sqrt{x_i^2 + x_{i+1}^2} + 3\left(\cos(2x_i) + \sin(2x_{i+1})\right) \tag{8.1}$$

The Ackley's One function has a global optimum of $-7.54276 - 2.91867(n-3)$. Its dimension is 30 with a range of $[-32,32]^n$.

9 Ackley's Two

$$f_9(x) = \sum_{i=1}^{n-1} 20 + e - \frac{20}{e^{0.2\sqrt{\frac{x_i^2 + x_{i+1}^2}{2}}}} - e^{0.5(\cos(2\pi x_i) + \cos(2\pi x_{i+1}))} \tag{9.1}$$

The Ackley's Two function has a global optimum of 0. Its dimension is 30 with a range of $[-32,32]^n$.

10 Egg Holder

$$f_{10}(x) = \sum_{i=1}^{n-1} -x_i \cdot \sin\left(\sqrt{|x_i - x_{i+1} - 47|}\right) - (x_{i+1} + 47) \cdot \sin\left(\sqrt{\left|x_{i+1} + 47 + \frac{x_i}{2}\right|}\right) \tag{10.1}$$

The Egg Holder function does not have a closed-form global optimum. Its dimension is 30 with a range of $[-500,500]^n$.

11 Statistical Analysis Table With Compared Data for Differential Evolution

This section will have all the tables with the statistical analysis done. The first six tables will be the DE algorithm with 10, 20, and 30 dimensions. The parameters that were used in the DE algorithms is as follows; NP: 200, CR: 0.6, F: 0.9; λ: 0.8, Generations: 1000.

Table 11.1: DE Results (10D) — Exponential Crossover (exp)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	84.878291	88.537041	114.905533	0.000000	0.000000	114.363967	259.945867	89.149080	109.088500	44.595072	63.530626	114.489867	0.000000	0.000000	114.037767
1 De Jong	0.000000	0.000000	42.032780	0.000000	0.000000	41.282460	0.000000	0.000000	39.879073	0.000000	0.000000	44.059397	0.000000	0.000000	43.545597
Rosenbrock	0.144250	0.079669	40.777723	0.735233	0.376716	40.353817	1.291997	0.773675	39.664930	5.675573	2.335095	42.888150	8.166709	2.391836	46.901420
Rastrigin	-10000.000000	0.000000	106.170967	-10000.000000	0.000000	106.879200	-9935.317000	67.623757	106.864300	-10000.000000	0.000000	108.423833	-10000.000000	0.000000	112.700333
Griewank	0.000000	0.000000	114.709500	0.000001	0.000002	117.850833	0.018309	0.010465	115.495600	0.001509	0.001229	123.524200	0.014740	0.004810	124.946033
Sine Envelope Sine Wave	-13.428260	0.010188	102.573867	-13.414773	0.014115	107.112833	-13.429083	0.008737	109.314767	-13.398493	0.020599	104.306967	-13.385890	0.016722	113.563800
Stretched V Sine Wave	9.117711	0.044723	334.498000	9.124154	0.054943	334.804933	9.101470	0.033743	337.896100	9.188311	0.088537	334.170000	9.211250	0.085396	336.447933
Ackley One	-27.970200	0.000000	160.652067	-27.970200	0.000000	161.247900	-27.970200	0.000000	165.274900	-27.970200	0.000000	167.787167	-27.970200	0.000000	167.158167
Ackley Two	-0.000009	0.000000	300.830733	-0.000009	0.000000	307.295000	-0.000009	0.000000	304.332767	-0.000009	0.000000	309.518400	-0.000009	0.000000	308.417800
Egg Holder	-8012.662333	278.148432	186.154467	-7891.461667	133.595578	185.057200	-7900.950333	178.988252	188.269533	-7748.819667	207.123698	183.940133	-7243.834667	138.018682	182.182433

Hardware: Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.

Table 11.2: DE Results (10D) — Binomial Crossover (bin)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	545.805600	146.930283	123.111967	20.936080	43.715371	127.542567	612.019600	151.679656	122.354800	570.241933	104.990089	124.312867	177.533373	38.255853	128.148800
1 De Jong	0.000000	0.000000	53.280487	0.000000	0.000000	52.336347	0.000000	0.000000	57.780420	0.000084	0.000044	57.524423	0.070045	0.023383	55.195033
Rosenbrock	0.424628	1.215718	58.709307	5.450127	0.434541	53.752170	0.192797	0.553513	52.938170	180.950407	86.508776	54.351517	1098.453467	419.206378	55.962297
Rastrigin	-10000.000000	0.000000	126.709100	-9420.897333	106.482297	124.766467	-8591.700000	245.050887	118.279333	-8018.766000	371.374485	120.201833	-7320.476333	417.365874	122.590200
Griewank	0.049318	0.039501	132.835600	0.221244	0.038629	132.919633	0.258373	0.041434	130.639600	0.445108	0.075743	132.725233	0.471384	0.061032	137.230067
Sine Envelope Sine Wave	-12.592703	0.156963	114.424100	-12.355663	0.174530	114.460500	-12.589917	0.139976	119.573067	-12.020060	0.204839	121.385567	-11.806100	0.168595	118.396233
Stretched V Sine Wave	12.054903	0.990967	353.751533	12.495143	1.247103	351.044667	11.322454	0.874102	353.402567	13.190737	1.571537	348.044200	12.909830	1.493666	352.627233
Ackley One	-27.970200	0.000000	173.935800	-27.970167	0.000048	175.886933	-27.970087	0.000318	173.398633	-22.337407	1.167191	171.584467	-18.394410	1.445738	176.365067
Ackley Two	-0.000009	0.000000	319.291967	-0.000005	0.000002	321.502133	-0.000009	0.000000	314.715667	0.077629	0.026509	320.567700	4.590135	1.348191	322.563333
Egg Holder	-7167.661000	390.905575	197.350133	-6820.717333	145.399808	192.898900	-7180.418333	319.420825	192.774667	-6594.182000	167.343347	194.909967	-6272.864667	180.344789	200.934800

Hardware: Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.

Table 11.3: DE Results (20D) — Exponential Crossover (exp)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	117.167384	98.823160	189.048567	0.000000	0.000000	192.147467	999.208533	128.749562	182.223067	43.299470	56.194578	190.119233	0.002995	0.000722	199.139667
1 De Jong	0.000000	0.000000	45.309190	0.000000	0.000000	45.522737	0.000000	0.000000	45.208993	0.000005	0.000001	47.506957	0.000099	0.000024	51.308500
Rosenbrock	13.070413	0.914706	45.786600	22.483180	5.432762	47.225377	14.180933	0.813419	46.758180	36.147487	8.728101	47.237463	69.725817	18.957200	50.094857
Rastrigin	-40000.000000	0.000000	183.290933	-40000.000000	0.000000	191.112767	-38362.676667	391.080344	185.538600	-39985.473333	3.824056	184.481367	-39632.726667	86.245259	186.701833
Griewank	0.000000	0.000000	197.682300	0.000344	0.000304	198.136633	0.001233	0.002136	198.488567	0.015937	0.007739	201.450967	0.025777	0.009686	202.024833
Sine Envelope Sine Wave	-27.906597	0.070770	182.523967	-27.800840	0.082628	182.904567	-27.915010	0.074888	183.387400	-27.628870	0.095811	184.272567	-27.544200	0.107258	188.587833
Stretched V Sine Wave	20.818733	0.317145	689.101267	20.894257	0.389169	679.718567	20.362393	0.321727	680.772367	21.986860	0.523427	681.194400	21.845917	0.608029	675.431667
Ackley One	-57.151500	0.000000	304.470467	-57.151500	0.000000	307.363867	-57.151290	0.000206	303.035900	-57.151273	0.000094	306.070900	-57.147370	0.001084	305.775433
Ackley Two	-0.000018	0.000000	642.653900	0.000134	0.000025	652.173967	-0.000018	0.000000	644.053733	0.010299	0.001252	650.259900	0.051408	0.006859	669.717667
Egg Holder	-16331.083333	606.118925	335.782500	-14298.143333	267.255279	334.124833	-14243.490000	381.378099	329.830033	-14000.716667	332.158005	332.086133	-13599.266667	310.077486	336.194567
Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.															

Table 11.4: DE Results (20D) — Binomial Crossover (bin)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	1559.101000	119.966100	217.420533	1015.512233	75.812117	222.036100	1745.002333	135.557444	216.879933	1525.071667	147.086385	220.058633	1509.669667	82.964493	222.682067
1 De Jong	0.000049	0.000018	76.698007	33.690017	6.833049	76.911243	0.000004	0.000002	77.518087	3672.195333	592.435742	81.017853	8034.090000	1275.856615	83.141580
Rosenbrock	113.230107	110.341914	78.352783	386709.966667	111566.110572	80.199110	67.390407	82.504248	78.148767	352454966.666667	104589041.152860	81.614803	1176930233.333333	298417987.188149	85.810210
Rastrigin	-26144.250000	1805.288998	214.286133	-13246.286667	1700.523737	214.208333	-21678.623333	1643.372160	212.492467	60087.076667	12143.099510	214.702133	138726.340000	21430.443022	217.479567
Griewank	0.245714	0.100923	232.905467	1.192853	0.038023	229.809733	0.321489	0.072359	233.917900	23.252230	3.283832	236.575233	48.344027	9.422869	238.503167
Sine Envelope Sine Wave	-22.571733	0.373220	213.457833	-21.489720	0.431373	216.033033	-22.658610	0.283245	214.141467	-19.979110	0.529664	223.828567	-19.559493	0.456640	220.818633
Stretched V Sine Wave	58.051417	5.800246	722.784567	68.265807	7.587742	713.361867	51.790103	3.812572	721.741967	84.510693	5.971855	712.104500	83.519257	7.916537	710.148267
Ackley One	-46.291847	3.421038	331.773800	-3.387973	4.997260	331.324467	-30.301240	3.435839	337.082700	69.827623	10.045255	334.393333	102.929363	13.941718	342.482233
Ackley Two	0.032645	0.011243	692.147500	69.084193	8.539180	690.979733	0.021255	0.005278	679.703833	238.701167	10.591101	659.508333	257.821267	6.662805	650.656533
Egg Holder	-14421.953333	779.567638	366.415733	-11171.083333	330.983690	366.501767	-10909.528333	836.688974	361.058067	-10492.889000	563.429120	373.005333	-9817.791667	340.136645	364.014833

Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.

Table 11.5: DE Results (30D) — Exponential Crossover (exp)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	198.012237	145.339141	264.608033	0.006510	0.000645	271.624167	1794.509000	191.456925	262.846167	62.507699	88.193626	266.959600	3.090755	0.560962	268.781000
1 De Jong	0.000001	0.000000	54.126927	0.000175	0.000032	51.324660	0.000001	0.000000	57.174393	0.025978	0.004733	53.557093	0.124852	0.020428	55.208007
Rosenbrock	25.435170	1.271809	51.256430	61.482290	15.305990	52.892253	28.409103	2.869812	55.402203	215.691200	39.925627	55.315797	332.775067	54.349550	57.750353
Rastrigin	-89999.296667	0.212511	254.605033	-89895.420000	24.722088	256.129933	-83204.696667	1288.021418	258.070867	-83806.073333	542.377798	257.363433	-81754.313333	910.775643	260.614867
Griewank	0.000067	0.000103	279.512133	0.004771	0.002317	281.367433	0.000773	0.000840	286.616300	0.102657	0.022174	283.935467	0.226239	0.054058	288.837500
Sine Envelope Sine Wave	-41.738547	0.135979	264.622633	-41.554877	0.144165	264.533467	-41.791620	0.151024	265.452767	-40.916533	0.211935	264.914433	-40.762607	0.212421	266.962667
Stretched V Sine Wave	34.572120	1.070407	1021.262667	35.456917	1.274024	1018.978000	34.349820	0.641571	1019.448333	38.076297	1.816979	1016.861700	38.355337	1.325678	1014.541533
Ackley One	-86.332800	0.000000	442.822267	-86.331420	0.000263	442.486233	-86.206757	0.096684	442.030900	-85.581853	0.163439	439.992033	-82.768267	0.711618	459.874500
Ackley Two	0.003900	0.000547	969.306933	0.052617	0.006580	972.430833	0.003188	0.000369	972.360667	1.225273	0.134634	982.498067	3.479871	0.456675	985.304533
Egg Holder	-21961.433333	833.117048	512.582467	-20240.733333	275.388336	479.696233	-20057.946667	411.490611	482.749933	-19518.923333	384.904776	482.297633	-19141.003333	221.219028	491.449500

Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.

Table 11.6: DE Results (30D) — Binomial Crossover (bin)

Problem	best/1			rand/1			rand-to-best/1			best/2			rand/2		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	2667.475333	163.181098	310.081500	2345.015667	93.460599	312.668700	3206.157667	216.700742	313.608067	2721.993333	149.022913	312.599600	3133.540333	108.856021	316.699533
1 De Jong	17.458822	4.746333	103.082383	6940.385000	825.473366	102.479500	4.501299	1.379720	103.933967	32176.530000	2883.468502	107.446500	39541.920000	4367.239853	111.838667
Rosenbrock	424448.366667	208826.378030	101.257350	1437881400.000000	349881198.103368	106.706767	100350.486667	37665.447672	106.551533	10511783333.333334	2364822685.484392	108.991067	16258003333.333334	2768084773.154142	115.986567
Rastrigin	-24259.443333	4609.472169	301.423800	186711.733333	23379.970815	305.313033	-24104.423333	4198.478437	307.463067	830011.900000	107695.900007	314.562600	1069782.700000	85323.048142	315.082133
Griewank	1.111322	0.034857	329.289000	44.401893	5.437765	331.595100	1.022024	0.013789	339.564233	197.546600	21.232358	336.600867	253.148267	30.314848	341.616000
Sine Envelope Sine Wave	-30.882677	0.693114	317.420800	-28.957437	0.521811	313.809333	-31.220483	0.583845	312.760500	-27.216820	0.424354	318.179800	-26.855407	0.494181	319.069933
Stretched V Sine Wave	131.241967	11.898544	1093.658667	161.444567	9.632216	1122.450667	122.827027	9.583941	1156.502667	186.906600	12.962101	1121.489667	189.084000	19.796380	1129.400000
Ackley One	-9.590468	7.605167	519.346700	126.607633	12.565380	486.069100	1.612326	7.621847	515.573300	287.926933	19.615829	522.852800	319.588467	21.117284	530.115433
Ackley Two	68.927307	8.031919	1038.385733	394.751833	12.107480	977.553267	71.732423	8.012776	1031.365900	454.428567	7.404670	967.149667	463.141200	7.300801	955.594233
Egg Holder	-16411.106667	1905.019680	527.871100	-13539.793333	582.010736	536.660433	-13590.503333	1313.333914	535.898867	-12567.136667	1043.094588	531.454333	-11837.856667	312.167179	535.083133

Surface Laptop Studio; Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T); 8 GB RAM.

12 Statistical Analysis Table With Compared Data for Particle Swarm Optimization

This section will have all the tables with the statistical analysis done. The next table will be the PSO algorithm with 10, 20, and 30 dimensions. The parameters that were used in the DE algorithms is as follows; Particles: 200, C1: 0.8, c2: 1.2; Generations: 1000.

Table 12.1: PSO Results

Problem	PSO (10 dim)			PSO (20 dim)			PSO (30 dim)		
	Avg	Std	Time	Avg	Std	Time	Avg	Std	Time
Schwefel	1420.376633	332.119176	100.365283	3668.676000	579.099173	205.141267	6106.039667	637.772365	302.710567
1 De Jong	2.151941	0.759571	21.151517	18.666997	3.924727	44.697733	54.045020	7.812727	68.236363
Rosenbrock	501.080867	600.130753	22.705567	7884.932667	3549.490851	47.619643	32110.943333	8626.070355	69.577963
Rastrigin	-7626.263667	404.590902	90.901200	-19741.136667	2009.059494	189.618367	-31170.560000	4366.750131	269.519000
Griewank	0.652737	0.084325	104.961130	1.116102	0.023121	195.667400	1.321960	0.055864	294.504700
Sine Envelope Sine Wave	-12.628237	0.187340	87.306470	-24.506897	0.396832	176.993933	-35.637493	0.529908	279.221500
Stretched V Sine Wave	9.891132	0.567594	345.426933	27.500687	4.671131	710.152833	44.624540	7.216189	1147.427667
Ackley One	-20.440420	3.240382	142.842600	-26.560047	6.194209	288.626400	-19.622420	9.468028	445.006100
Ackley Two	11.023021	2.401941	310.091333	45.929537	4.663120	640.477367	88.804490	7.560613	999.317967
Egg Holder	-4321.076333	549.046475	159.506167	-7625.519333	1053.195282	341.742467	-10399.281000	1193.533297	540.459133
Surface Laptop Studio 11th Gen Intel(R) Core(TM) i7-11370H @ 3.30GHz (4C/8T) 8 GB RAM									

13 Statistical Analysis Table With Compared Data for Differential Evolution versus Particle Swarm Optimization

This section presents the statistical comparison between Differential Evolution (DE) and Particle Swarm Optimization (PSO). For each benchmark function and each dimension (10, 20, and 30), the best-performing DE strategy is compared against PSO using a paired t-test across 30 runs. The tables report the DE result, PSO result, t-value, p-value, and whether the difference is statistically significant at the 95% confidence level ($p < 0.05$).
The DE parameters used were: $NP = 200$, $CR = 0.6$, $F = 0.9$, $\lambda = 0.8$, and generations = 1000.
The PSO parameters used were: particles = 200, $c_1 = 0.8$, $c_2 = 1.2$, and generations = 1000.

Table 13.1: Analysis for 10 dimensions

Problem	DE	PSO	t-value	p-value	$p < 0.05$
Schwefel	0.000000	1420.376633	-23.424493	0.000000	Yes
1 De Jong	0.000000	2.151941	-15.517532	0.000000	Yes
Rosenbrock	0.144250	501.080867	-4.571915	0.000083	Yes
Rastrigin	-10000.000000	-7626.263667	-32.134903	0.000000	Yes
Griewank	0.000000	0.652737	-42.397797	0.000000	Yes
Sine Envelope Sine Wave	-13.429083	-12.628237	-23.297378	0.000000	Yes
Stretched V Sine Wave	9.101470	9.891132	-7.633910	0.000000	Yes
Ackley One	-27.970200	-20.440420	-12.727605	0.000000	Yes
Ackley Two	-0.000009	11.023021	-25.136183	0.000000	Yes
Egg Holder	-8012.662333	-4321.076333	-29.239535	0.000000	Yes

[1] Surface Laptop Studio

[2] Processor 11th Gen Intel(R) Core(TM) i7-11370H @ 3.30GHz, 3302 Mhz, 4 Core(s), 8 Logical Processor(s)

[3] Total Ram: 2147483648 per channel 8 total

Table 13.2: Analysis for 20 dimensions

Problem	DE	PSO	t-value	p-value	$p < 0.05$
Schwefel	0.000000	3668.676000	-34.699007	0.000000	Yes
1 De Jong	0.000000	18.666997	-26.051072	0.000000	Yes
Rosenbrock	13.070413	7884.932667	-12.147191	0.000000	Yes
Rastrigin	-40000.000000	-19741.136667	-55.231000	0.000000	Yes
Griewank	0.000000	1.116102	-264.402471	0.000000	Yes
Sine Envelope Sine Wave	-27.915010	-24.506897	-47.433864	0.000000	Yes
Stretched V Sine Wave	20.362393	27.500687	-8.324078	0.000000	Yes
Ackley One	-57.151500	-26.560047	-27.050475	0.000000	Yes
Ackley Two	-0.000018	45.929537	-53.948117	0.000000	Yes
Egg Holder	-16331.083333	-7625.519333	-47.555432	0.000000	Yes

[1] Surface Laptop Studio

[2] Processor 11th Gen Intel(R) Core(TM) i7-11370H @ 3.30GHz, 3302 Mhz, 4 Core(s), 8 Logical Processor(s)

[3] Total Ram: 2147483648 per channel 8 total

Table 13.3: Analysis for 30 dimensions

Problem	DE	PSO	t-value	p-value	$p < 0.05$
Schwefel	0.006510	6106.039667	-52.438967	0.000000	Yes
1 De Jong	0.000001	54.045020	-37.889043	0.000000	Yes
Rosenbrock	25.435170	32110.943333	-20.373299	0.000000	Yes
Rastrigin	-89999.296667	-31170.560000	-73.789411	0.000000	Yes
Griewank	0.000067	1.321960	-129.607395	0.000000	Yes
Sine Envelope Sine Wave	-41.791620	-35.637493	-56.121449	0.000000	Yes
Stretched V Sine Wave	34.349820	44.624540	-7.671894	0.000000	Yes
Ackley One	-86.332800	-19.622420	-38.591753	0.000000	Yes
Ackley Two	0.003188	88.804490	-64.332475	0.000000	Yes
Egg Holder	-21961.433333	-10399.281000	-44.846334	0.000000	Yes

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8 GB RAM

14 Conclusion

In conclusion, after comparing DE and PSO across all benchmark functions and dimensions, and evaluating the paired t-test results (t-value and p-value), PSO showed stronger overall performance. In most problem instances, PSO achieved better average fitness values, indicating more consistent convergence toward the global optimum. The significance results ($p < 0.05$ in many cases) also support that these differences are not due to random variation alone. While DE remained competitive on selected functions, the overall trend across the full

test set indicates that PSO provided the more reliable and effective optimization performance for this project setup.