# Supplementary Material

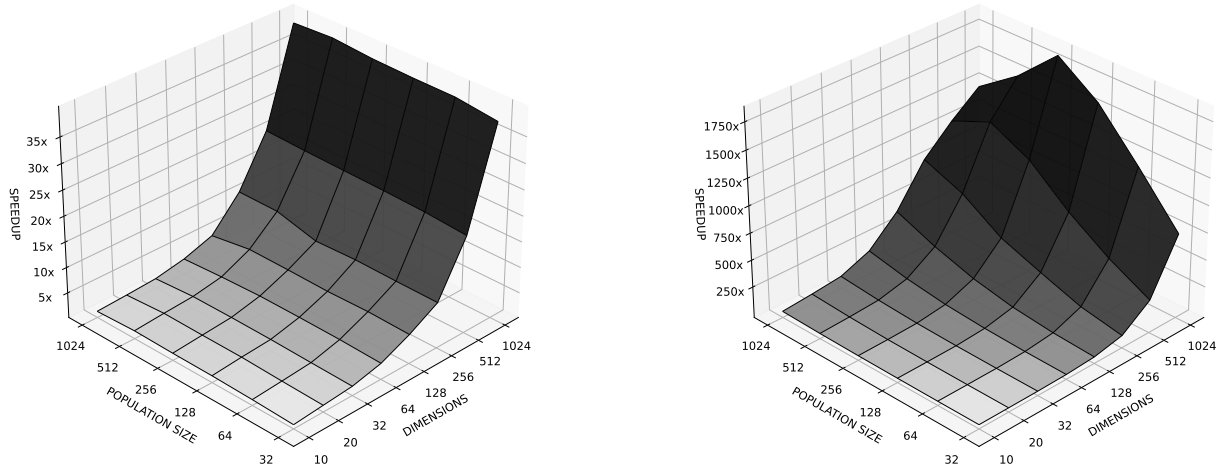
## Benchmark Problems on GPU: Accelerating Experiments on Metaheuristics

The supplementary results and codes are available on GitHub. The supplementary results are attached here because of the need for anonymity during submission.

January, 2023

TABLE I: Function 1 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 0.90 | 1.22 | 1.43 | 1.48 | 1.65 | 1.32 |
| 20 | 1.41 | 1.65 | 1.95 | 2.01 | 2.12 | 1.65 |
| 32 | 1.91 | 2.12 | 2.37 | 2.50 | 2.52 | 2.02 |
| 64 | 3.23 | 3.57 | 3.72 | 3.79 | 3.53 | 3.13 |
| 128 | 5.77 | 6.04 | 5.90 | 6.10 | 6.20 | 5.08 |
| 256 | 9.01 | 9.19 | 9.28 | 9.07 | 11.06 | 11.14 |
| 512 | 19.12 | 19.74 | 20.03 | 20.24 | 20.45 | 20.78 |
| 1024 | 37.92 | 38.90 | 39.02 | 39.24 | 39.87 | 39.46 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 0.72 | 1.33 | 2.81 | 5.60 | 11.04 | 20.43 |
| 20 | 1.47 | 3.04 | 6.24 | 11.66 | 24.20 | 44.43 |
| 32 | 2.84 | 5.63 | 11.33 | 21.83 | 42.95 | 75.40 |
| 64 | 7.71 | 15.56 | 30.67 | 58.08 | 108.31 | 183.14 |
| 128 | 23.60 | 46.44 | 88.31 | 164.03 | 278.73 | 427.09 |
| 256 | 77.68 | 148.57 | 276.37 | 413.59 | 649.28 | 793.18 |
| 512 | 266.85 | 463.23 | 709.65 | 1015.67 | 1194.89 | 1034.62 |
| 1024 | 744.55 | 1178.96 | 1585.83 | 1847.55 | 1501.13 | 1238.62 |

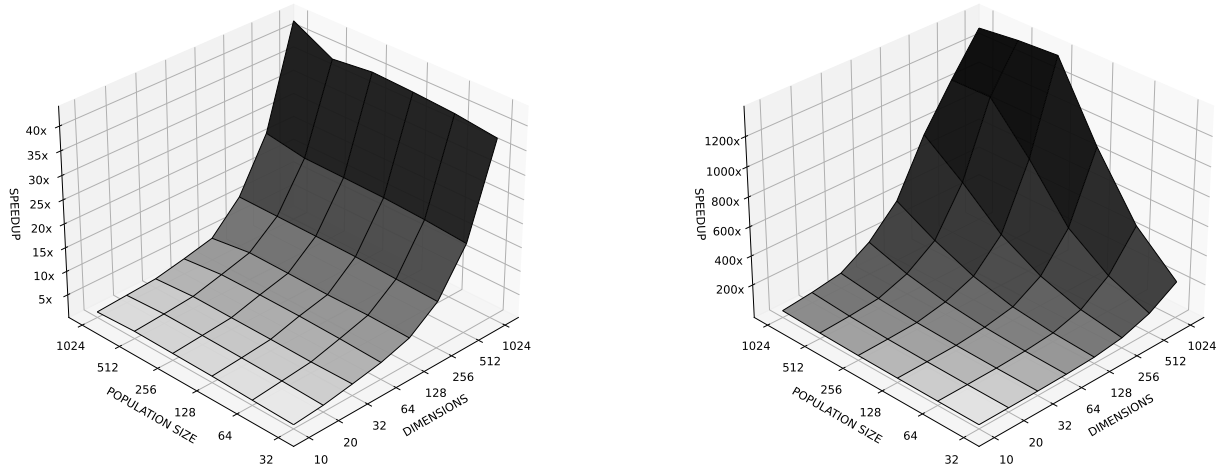



(a) CPUGPU (b) GPUGPU

Fig. 1: Function 1 - 3D plot varying population size and dimensionality.

TABLE II: Function 2 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 0.98 | 1.21 | 1.47 | 1.58 | 1.69 | 1.32 |
| 20 | 1.54 | 1.82 | 1.98 | 2.11 | 2.16 | 1.73 |
| 32 | 2.55 | 2.46 | 2.60 | 2.66 | 2.74 | 2.17 |
| 64 | 3.68 | 4.05 | 4.29 | 4.35 | 4.31 | 3.45 |
| 128 | 5.53 | 5.77 | 5.67 | 5.86 | 5.99 | 4.93 |
| 256 | 9.95 | 10.27 | 10.65 | 10.78 | 10.87 | 10.95 |
| 512 | 18.95 | 19.70 | 20.17 | 20.35 | 20.50 | 21.91 |
| 1024 | 37.57 | 38.67 | 39.26 | 39.65 | 38.69 | 43.07 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 0.74 | 1.49 | 3.12 | 5.91 | 11.54 | 20.06 |
| 20 | 1.71 | 3.15 | 6.48 | 12.06 | 24.26 | 44.29 |
| 32 | 3.36 | 6.01 | 11.82 | 21.66 | 44.04 | 78.48 |
| 64 | 7.45 | 15.29 | 31.23 | 61.75 | 116.95 | 197.67 |
| 128 | 16.10 | 34.08 | 67.95 | 138.41 | 249.77 | 391.10 |
| 256 | 42.52 | 90.20 | 180.41 | 330.73 | 559.80 | 765.39 |
| 512 | 106.18 | 223.53 | 415.65 | 758.51 | 1055.68 | 1058.61 |
| 1024 | 221.70 | 469.23 | 877.26 | 1368.18 | 1351.27 | 1322.62 |



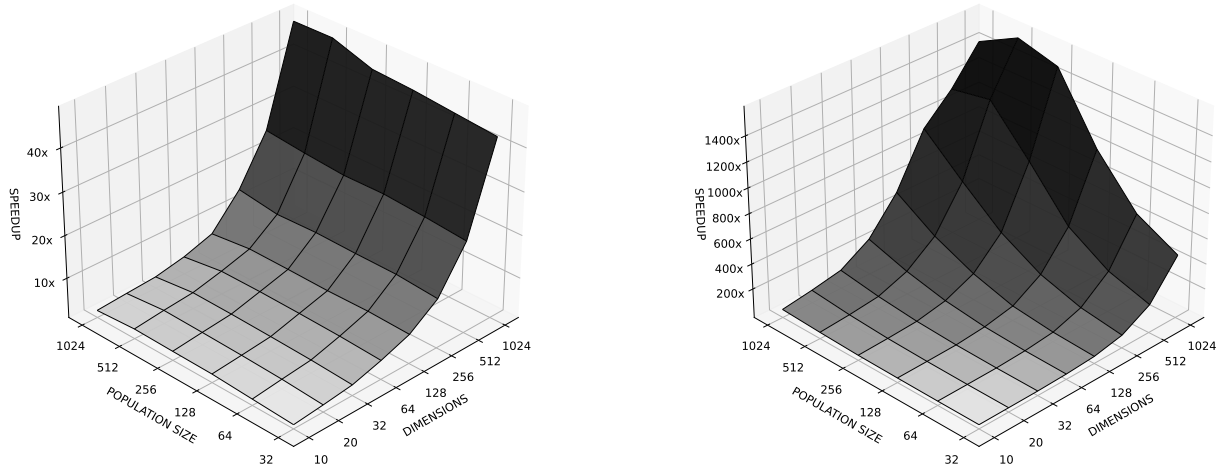

(a) CPUGPU

(b) GPUGPU

Fig. 2: Function 2 - 3D plot varying population size and dimensionality.

TABLE III: Function 3 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.61 | 2.12 | 2.65 | 2.77 | 2.94 | 2.35 |
| 20 | 2.30 | 2.94 | 3.31 | 3.57 | 3.77 | 2.90 |
| 32 | 3.14 | 3.69 | 4.04 | 4.32 | 4.47 | 3.38 |
| 64 | 5.07 | 5.60 | 5.90 | 6.11 | 6.11 | 4.80 |
| 128 | 7.48 | 7.85 | 7.75 | 7.95 | 8.07 | 7.03 |
| 256 | 12.21 | 13.02 | 13.11 | 13.35 | 13.05 | 14.44 |
| 512 | 22.13 | 23.04 | 23.77 | 23.66 | 24.46 | 25.50 |
| 1024 | 42.58 | 43.52 | 44.54 | 45.16 | 48.29 | 48.22 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.24 | 2.48 | 4.95 | 9.02 | 19.74 | 33.74 |
| 20 | 2.68 | 5.18 | 10.60 | 20.02 | 40.15 | 70.15 |
| 32 | 4.57 | 8.61 | 17.33 | 35.49 | 68.63 | 115.70 |
| 64 | 10.81 | 20.44 | 39.85 | 82.08 | 155.98 | 254.94 |
| 128 | 25.27 | 45.53 | 86.06 | 182.29 | 325.56 | 525.30 |
| 256 | 70.66 | 121.11 | 223.20 | 400.84 | 658.41 | 934.38 |
| 512 | 194.09 | 296.55 | 494.47 | 864.78 | 1228.28 | 1147.55 |
| 1024 | 471.04 | 642.11 | 1001.00 | 1507.19 | 1592.03 | 1429.77 |



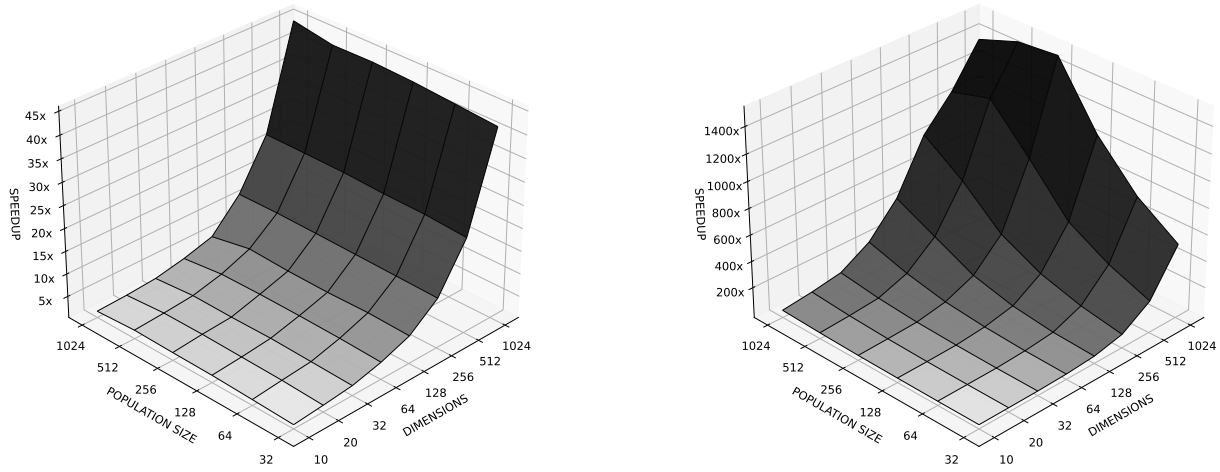

(a) CPUGPU

(b) GPUGPU

Fig. 3: Function 3 - 3D plot varying population size and dimensionality.

TABLE IV: Function 4 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| | | | CPUCPU vs CPUGPU | | | |
| 10 | 1.16 | 1.54 | 1.86 | 1.97 | 2.15 | 1.67 |
| 20 | 1.74 | 2.18 | 2.39 | 2.59 | 2.59 | 1.96 |
| 32 | 2.43 | 2.76 | 3.08 | 3.04 | 3.18 | 2.50 |
| 64 | 4.03 | 4.45 | 4.70 | 4.81 | 4.75 | 3.78 |
| 128 | 6.36 | 6.71 | 6.58 | 6.76 | 7.25 | 5.62 |
| 256 | 11.27 | 11.52 | 11.79 | 12.03 | 12.22 | 12.17 |
| 512 | 21.20 | 21.88 | 22.07 | 22.52 | 22.65 | 22.72 |
| 1024 | 41.80 | 42.56 | 43.30 | 43.70 | 43.57 | 45.11 |
| | | | CPUCPU vs GPUGPU | | | |
| 10 | 0.94 | 1.69 | 3.92 | 7.32 | 14.83 | 25.54 |
| 20 | 2.05 | 4.15 | 8.22 | 15.95 | 30.47 | 52.99 |
| 32 | 3.88 | 7.16 | 14.74 | 27.41 | 51.57 | 91.25 |
| 64 | 9.79 | 18.89 | 37.23 | 68.69 | 132.67 | 219.69 |
| 128 | 25.59 | 42.38 | 82.48 | 159.62 | 305.68 | 453.00 |
| 256 | 73.26 | 128.87 | 218.50 | 370.15 | 631.97 | 843.61 |
| 512 | 211.98 | 333.93 | 507.01 | 843.36 | 1156.66 | 1072.29 |
| 1024 | 530.49 | 742.05 | 1061.33 | 1515.09 | 1486.45 | 1408.81 |

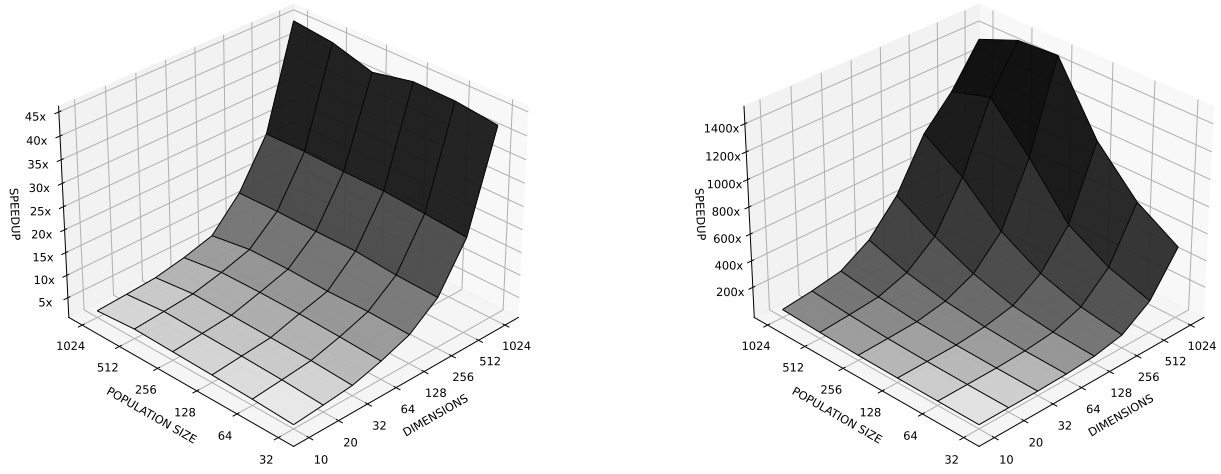



(a) CPUGPU (b) GPUGPU

Fig. 4: Function 4 - 3D plot varying population size and dimensionality.

TABLE V: Function 5 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.48 | 1.94 | 2.25 | 2.47 | 2.70 | 2.10 |
| 20 | 2.09 | 2.60 | 2.90 | 3.10 | 3.27 | 2.50 |
| 32 | 2.80 | 3.32 | 3.54 | 3.75 | 3.90 | 3.00 |
| 64 | 4.59 | 5.08 | 5.42 | 5.55 | 5.45 | 4.34 |
| 128 | 6.92 | 7.27 | 7.13 | 7.48 | 7.41 | 6.13 |
| 256 | 11.70 | 12.02 | 12.78 | 12.75 | 12.88 | 12.74 |
| 512 | 21.50 | 22.28 | 22.91 | 22.97 | 23.26 | 23.12 |
| 1024 | 42.24 | 43.35 | 43.50 | 41.67 | 44.26 | 45.27 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.17 | 2.33 | 4.52 | 8.40 | 17.76 | 30.87 |
| 20 | 2.39 | 4.72 | 9.28 | 18.03 | 37.25 | 60.22 |
| 32 | 3.81 | 7.65 | 15.54 | 30.71 | 60.52 | 102.31 |
| 64 | 10.20 | 18.60 | 38.15 | 72.95 | 138.02 | 233.15 |
| 128 | 25.43 | 43.61 | 83.28 | 171.19 | 303.51 | 468.42 |
| 256 | 68.65 | 119.68 | 218.01 | 385.62 | 649.95 | 839.44 |
| 512 | 211.48 | 308.62 | 477.84 | 839.71 | 1150.53 | 1059.20 |
| 1024 | 504.18 | 690.01 | 1003.60 | 1495.19 | 1475.22 | 1393.86 |

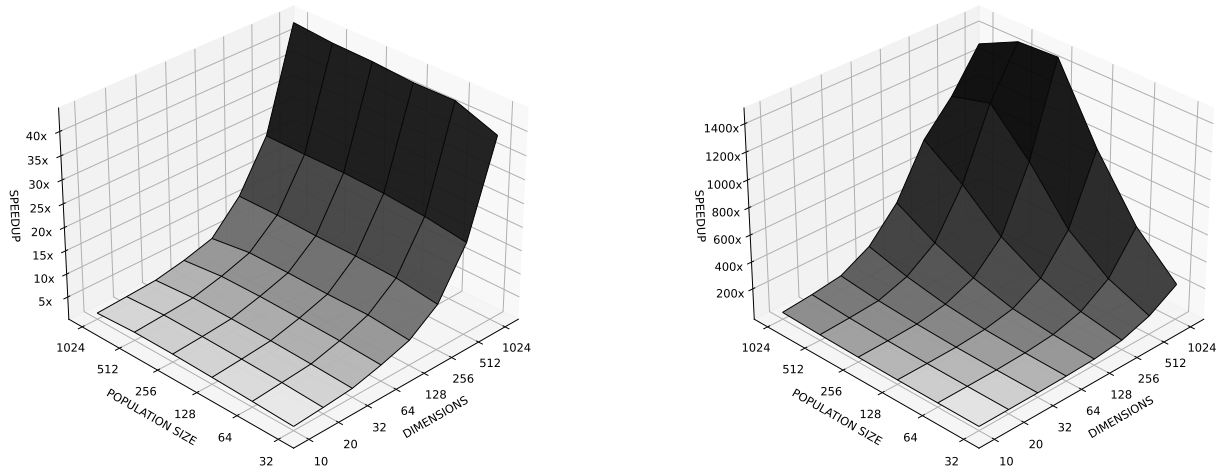



(a) CPUGPU (b) GPUGPU

Fig. 5: Function 5 - 3D plot varying population size and dimensionality.

TABLE VI: Function 6 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.01 | 1.35 | 1.62 | 1.86 | 1.90 | 1.50 |
| 20 | 1.47 | 1.89 | 2.13 | 2.30 | 2.36 | 1.86 |
| 32 | 2.05 | 2.44 | 2.73 | 2.88 | 2.88 | 2.28 |
| 64 | 3.59 | 4.07 | 4.31 | 4.49 | 4.42 | 3.54 |
| 128 | 5.52 | 6.33 | 6.28 | 6.45 | 6.48 | 5.38 |
| 256 | 9.93 | 11.07 | 11.41 | 11.45 | 11.74 | 11.72 |
| 512 | 19.90 | 21.13 | 21.86 | 22.16 | 22.09 | 22.14 |
| 1024 | 39.22 | 42.42 | 42.32 | 42.95 | 43.15 | 43.88 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 0.81 | 1.53 | 3.22 | 6.86 | 12.86 | 22.41 |
| 20 | 1.69 | 3.47 | 6.83 | 13.47 | 25.75 | 45.45 |
| 32 | 3.15 | 6.22 | 12.22 | 24.84 | 44.56 | 79.00 |
| 64 | 7.59 | 15.85 | 30.48 | 62.17 | 116.86 | 194.96 |
| 128 | 16.39 | 37.48 | 73.35 | 152.28 | 267.06 | 423.82 |
| 256 | 41.32 | 97.45 | 194.54 | 358.38 | 608.36 | 799.92 |
| 512 | 109.55 | 233.48 | 451.66 | 817.66 | 1111.55 | 1026.06 |
| 1024 | 234.76 | 516.13 | 947.93 | 1482.30 | 1465.92 | 1323.46 |



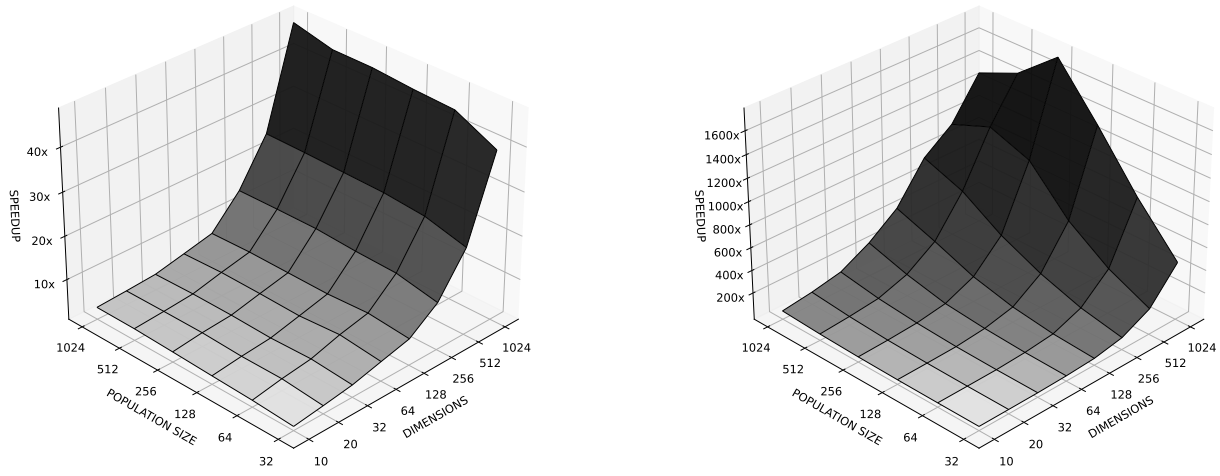

(a) CPUGPU

(b) GPUGPU

Fig. 6: Function 6 - 3D plot varying population size and dimensionality.

TABLE VII: Function 7 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.64 | 2.28 | 2.70 | 3.13 | 3.45 | 3.51 |
| 20 | 2.54 | 3.46 | 3.51 | 3.93 | 4.00 | 3.94 |
| 32 | 3.53 | 4.35 | 4.15 | 4.50 | 4.60 | 4.43 |
| 64 | 5.19 | 6.31 | 5.76 | 6.10 | 6.29 | 5.95 |
| 128 | 6.80 | 7.77 | 7.39 | 7.56 | 7.71 | 7.50 |
| 256 | 11.60 | 13.55 | 13.91 | 14.54 | 14.54 | 14.45 |
| 512 | 20.79 | 23.29 | 24.16 | 24.40 | 24.66 | 24.80 |
| 1024 | 39.42 | 44.10 | 44.51 | 45.29 | 45.36 | 47.62 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.45 | 2.88 | 5.63 | 11.32 | 22.17 | 40.06 |
| 20 | 2.91 | 5.95 | 11.66 | 22.16 | 43.65 | 76.65 |
| 32 | 4.96 | 9.72 | 19.39 | 39.63 | 73.41 | 130.05 |
| 64 | 11.70 | 23.36 | 44.94 | 80.19 | 158.42 | 264.04 |
| 128 | 26.31 | 51.66 | 102.72 | 190.46 | 328.05 | 451.72 |
| 256 | 72.55 | 148.57 | 271.77 | 436.18 | 657.29 | 786.13 |
| 512 | 193.96 | 366.20 | 616.42 | 979.41 | 1107.14 | 968.88 |
| 1024 | 475.57 | 876.89 | 1337.46 | 1759.29 | 1464.68 | 1312.63 |



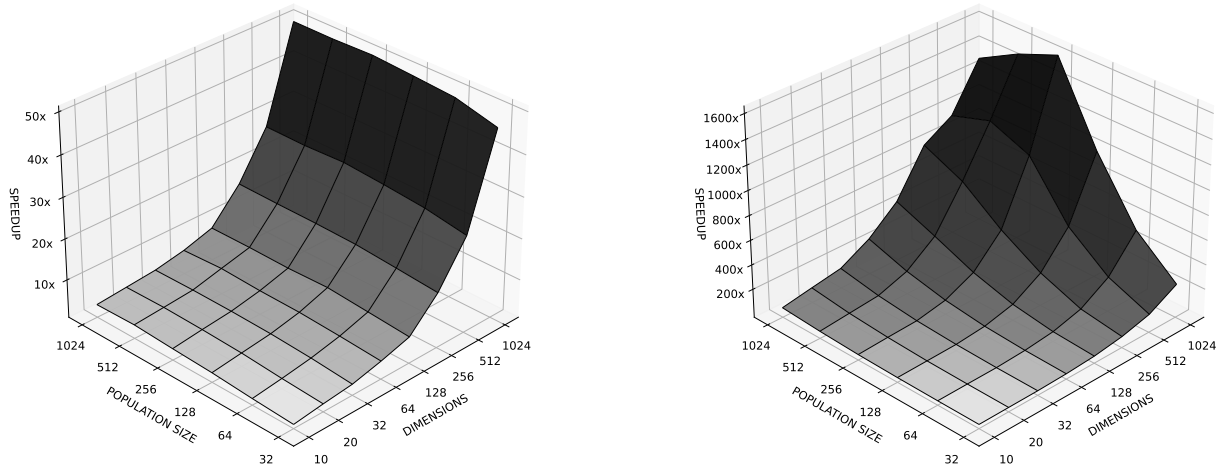

(a) CPUGPU

(b) GPUGPU

Fig. 7: Function 7 - 3D plot varying population size and dimensionality.

TABLE VIII: Function 8 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.78 | 2.36 | 3.10 | 3.57 | 4.11 | 3.90 |
| 20 | 2.67 | 3.27 | 4.05 | 4.47 | 4.70 | 4.60 |
| 32 | 3.48 | 4.37 | 5.00 | 5.28 | 5.36 | 5.25 |
| 64 | 5.17 | 5.89 | 6.47 | 6.68 | 7.12 | 6.64 |
| 128 | 7.21 | 8.07 | 8.86 | 8.69 | 8.82 | 8.79 |
| 256 | 14.20 | 15.07 | 15.89 | 16.17 | 16.26 | 16.45 |
| 512 | 24.36 | 26.08 | 27.02 | 27.76 | 27.34 | 27.45 |
| 1024 | 46.36 | 48.93 | 49.67 | 50.33 | 50.04 | 50.10 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.69 | 3.49 | 6.72 | 13.39 | 27.67 | 47.64 |
| 20 | 3.39 | 6.96 | 13.29 | 27.54 | 51.13 | 90.89 |
| 32 | 5.00 | 9.78 | 20.03 | 39.16 | 74.97 | 132.58 |
| 64 | 11.65 | 22.35 | 43.93 | 86.24 | 158.16 | 261.49 |
| 128 | 26.58 | 49.33 | 103.40 | 195.83 | 331.78 | 458.52 |
| 256 | 63.10 | 112.35 | 249.51 | 432.65 | 673.00 | 817.04 |
| 512 | 117.90 | 254.37 | 516.19 | 940.39 | 1059.65 | 952.82 |
| 1024 | 244.25 | 526.76 | 1016.08 | 1657.28 | 1496.83 | 1319.55 |



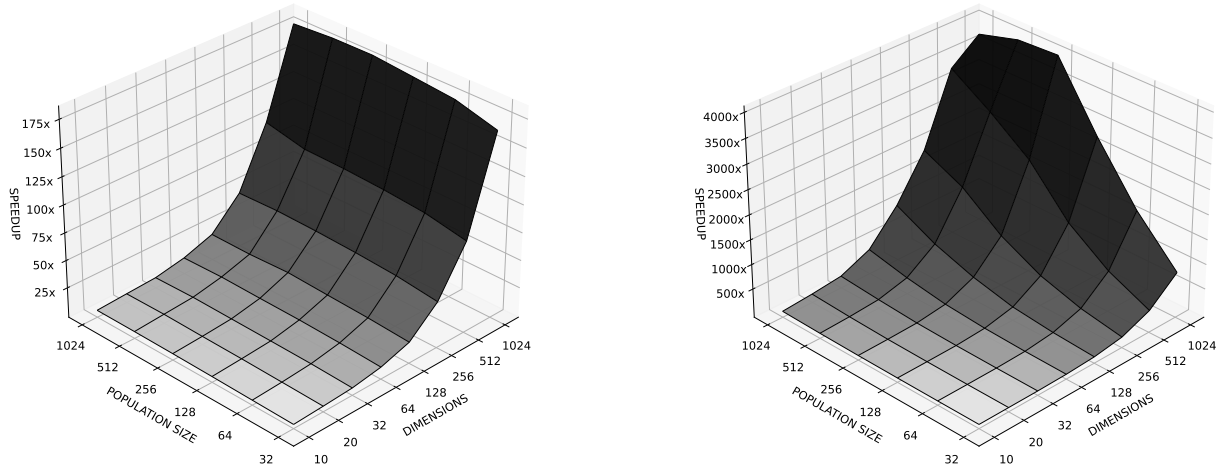

(a) CPUGPU

(b) GPUGPU

Fig. 8: Function 8 - 3D plot varying population size and dimensionality.

TABLE IX: Function 9 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.55 | 2.32 | 3.06 | 3.67 | 4.06 | 4.21 |
| 20 | 2.86 | 3.84 | 4.76 | 5.33 | 6.12 | 5.89 |
| 32 | 4.48 | 6.05 | 6.84 | 7.45 | 8.17 | 7.41 |
| 64 | 8.84 | 10.80 | 12.11 | 12.66 | 13.51 | 12.61 |
| 128 | 17.07 | 19.60 | 21.53 | 23.02 | 21.55 | 21.77 |
| 256 | 39.73 | 44.34 | 46.73 | 48.21 | 48.93 | 47.73 |
| 512 | 80.87 | 87.98 | 91.03 | 92.84 | 93.44 | 101.35 |
| 1024 | 165.53 | 175.66 | 179.20 | 182.59 | 182.18 | 179.69 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.46 | 2.92 | 5.80 | 11.45 | 22.55 | 40.46 |
| 20 | 3.30 | 6.43 | 13.21 | 25.48 | 52.16 | 91.80 |
| 32 | 5.85 | 12.54 | 24.33 | 47.91 | 99.79 | 164.12 |
| 64 | 16.24 | 32.79 | 64.51 | 127.17 | 251.11 | 423.83 |
| 128 | 48.58 | 103.34 | 192.82 | 384.90 | 659.36 | 1058.79 |
| 256 | 135.43 | 286.30 | 536.60 | 947.11 | 1548.85 | 1920.11 |
| 512 | 367.96 | 751.27 | 1329.28 | 2214.22 | 2811.67 | 3326.09 |
| 1024 | 846.07 | 1694.85 | 2790.57 | 4041.02 | 3993.69 | 3764.66 |



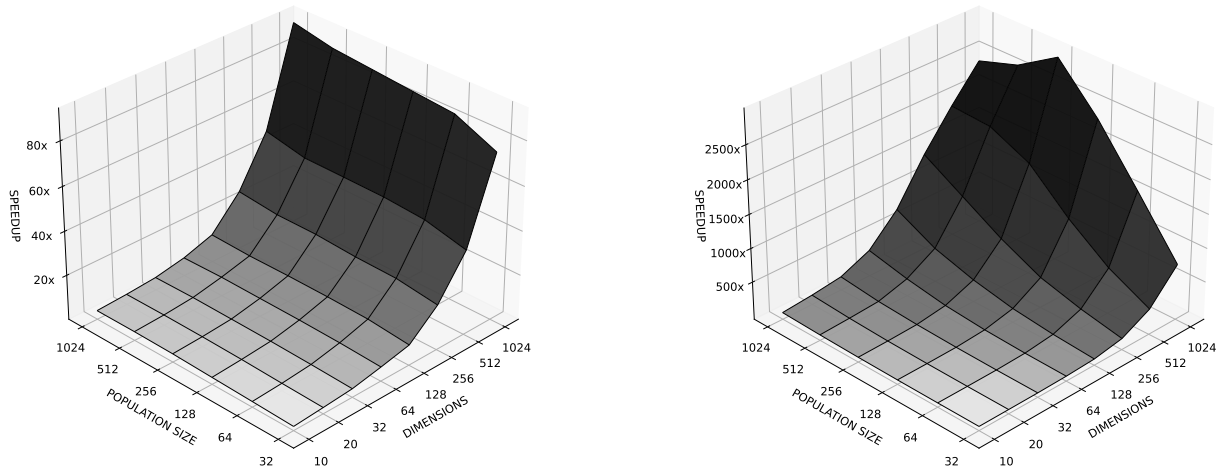

(a) CPUGPU

(b) GPUGPU

Fig. 9: Function 9 - 3D plot varying population size and dimensionality.

TABLE X: Function 10 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.56 | 2.24 | 2.84 | 3.47 | 3.72 | 3.72 |
| 20 | 2.52 | 3.10 | 3.77 | 4.22 | 4.49 | 4.43 |
| 32 | 3.59 | 4.38 | 4.99 | 5.37 | 5.70 | 5.51 |
| 64 | 6.12 | 7.15 | 7.72 | 8.07 | 8.37 | 8.09 |
| 128 | 9.02 | 10.97 | 11.51 | 11.73 | 11.75 | 12.46 |
| 256 | 20.13 | 22.69 | 23.13 | 24.33 | 24.41 | 26.33 |
| 512 | 38.15 | 42.69 | 44.04 | 44.30 | 44.52 | 48.41 |
| 1024 | 75.26 | 83.48 | 85.09 | 86.81 | 88.48 | 92.26 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.51 | 2.95 | 6.04 | 12.06 | 23.44 | 41.06 |
| 20 | 3.15 | 5.98 | 12.00 | 23.47 | 46.50 | 82.83 |
| 32 | 5.63 | 10.84 | 21.90 | 42.02 | 79.21 | 142.44 |
| 64 | 14.14 | 28.23 | 53.80 | 104.34 | 198.96 | 329.32 |
| 128 | 34.17 | 79.23 | 148.64 | 271.35 | 448.05 | 744.24 |
| 256 | 109.93 | 234.91 | 396.90 | 682.42 | 1027.79 | 1373.83 |
| 512 | 326.93 | 634.64 | 1067.92 | 1604.69 | 1873.27 | 1906.59 |
| 1024 | 789.14 | 1590.72 | 2337.95 | 2964.40 | 2587.34 | 2392.29 |

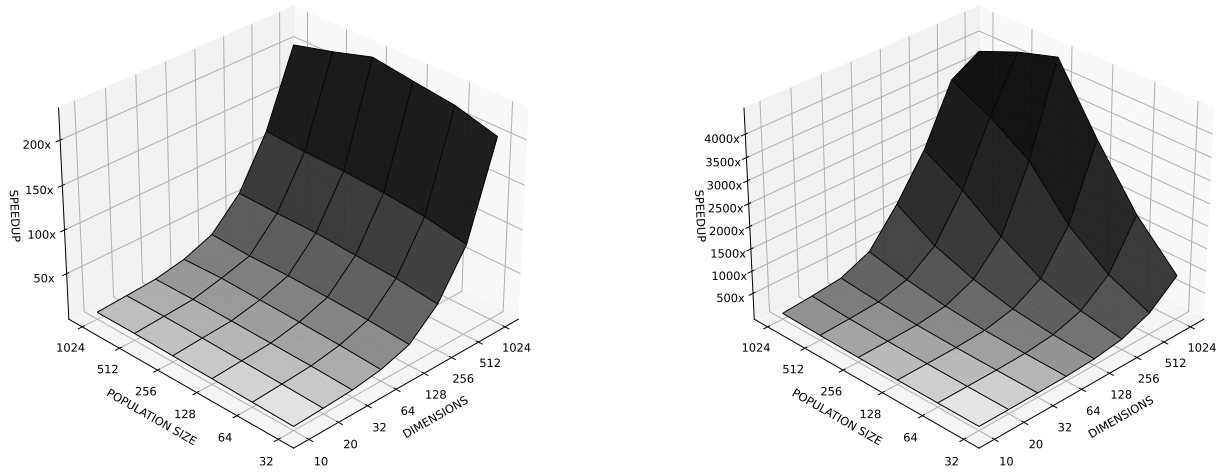



(a) CPUGPU (b) GPUGPU

Fig. 10: Function 10 - 3D plot varying population size and dimensionality.

TABLE XI: Function 11 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.73 | 2.63 | 3.45 | 4.28 | 5.06 | 5.11 |
| 20 | 3.28 | 4.71 | 5.78 | 6.82 | 7.40 | 7.44 |
| 32 | 5.35 | 7.16 | 8.12 | 9.15 | 9.90 | 9.77 |
| 64 | 10.29 | 13.08 | 14.89 | 16.30 | 17.71 | 16.49 |
| 128 | 20.90 | 24.43 | 26.33 | 27.51 | 27.30 | 29.72 |
| 256 | 49.51 | 54.90 | 57.92 | 60.72 | 61.02 | 62.07 |
| 512 | 100.02 | 108.49 | 113.38 | 116.11 | 116.99 | 119.68 |
| 1024 | 203.88 | 217.03 | 223.21 | 229.95 | 216.40 | 204.62 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.68 | 3.13 | 6.38 | 12.71 | 25.13 | 44.47 |
| 20 | 3.72 | 7.27 | 14.89 | 29.94 | 56.74 | 103.25 |
| 32 | 6.68 | 13.62 | 26.94 | 51.85 | 104.71 | 183.58 |
| 64 | 17.00 | 34.96 | 68.79 | 141.49 | 279.26 | 465.42 |
| 128 | 53.65 | 109.37 | 215.81 | 422.50 | 734.87 | 1244.16 |
| 256 | 148.75 | 309.18 | 572.90 | 1074.02 | 1687.72 | 2178.16 |
| 512 | 395.72 | 795.80 | 1460.94 | 2469.61 | 3032.91 | 3461.70 |
| 1024 | 903.91 | 1814.90 | 3064.15 | 4464.54 | 4189.11 | 3824.29 |

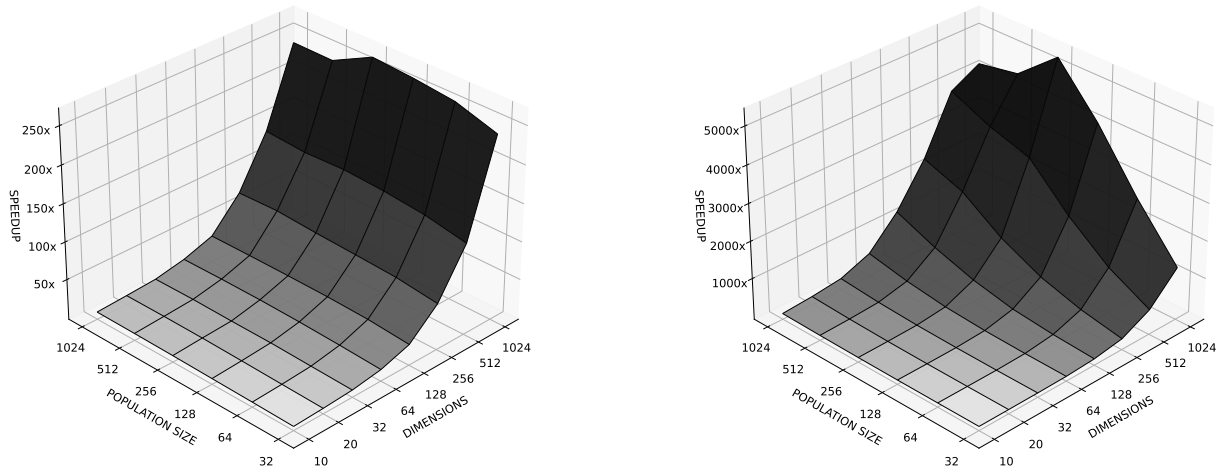



(a) CPUGPU (b) GPUGPU

Fig. 11: Function 11 - 3D plot varying population size and dimensionality.

TABLE XII: Function 12 speed up analysis on both scenarios.

| D | Population Size 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|
| CPUCPU vs CPUGPU | | | | | | |
| 10 | 1.85 | 3.07 | 4.02 | 5.04 | 5.72 | 6.08 |
| 20 | 3.55 | 5.01 | 6.50 | 7.85 | 8.43 | 8.48 |
| 32 | 6.00 | 7.75 | 9.68 | 10.23 | 11.37 | 11.25 |
| 64 | 11.77 | 14.93 | 17.30 | 18.81 | 19.27 | 18.92 |
| 128 | 24.21 | 28.89 | 31.04 | 32.02 | 32.29 | 32.00 |
| 256 | 57.83 | 64.76 | 67.72 | 70.27 | 73.85 | 72.37 |
| 512 | 117.54 | 128.41 | 133.74 | 136.74 | 134.84 | 138.58 |
| 1024 | 239.63 | 256.60 | 262.85 | 266.71 | 239.57 | 240.30 |
| CPUCPU vs GPUGPU | | | | | | |
| 10 | 1.74 | 3.62 | 6.99 | 13.83 | 26.93 | 47.38 |
| 20 | 3.92 | 7.62 | 15.38 | 31.29 | 60.36 | 108.67 |
| 32 | 7.54 | 14.54 | 29.31 | 58.28 | 112.83 | 213.28 |
| 64 | 18.87 | 38.88 | 76.59 | 150.13 | 294.54 | 511.68 |
| 128 | 64.88 | 137.80 | 253.05 | 485.01 | 831.10 | 1275.69 |
| 256 | 190.34 | 414.04 | 738.86 | 1255.15 | 1982.44 | 2363.04 |
| 512 | 578.69 | 1155.49 | 2010.79 | 3052.77 | 3379.70 | 3846.32 |
| 1024 | 1326.82 | 2661.17 | 4169.64 | 5365.68 | 4451.50 | 4248.53 |




(a) CPUGPU (b) GPUGPU

Fig. 12: Function 12 - 3D plot varying population size and dimensionality.

TABLE XIII: Optimization effectiveness comparison between CPUCPU, CPUGPU, and GPUGPU versions considering 10 dimensions.

| | | CPUCPU | CPUGPU | GPUGPU |
|---|---|---|---|---|
| F1 | Best | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Median | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Worst | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Mean | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Std | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| F2 | Best | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Median | $1.05E-09$ | $0.00E+00$ | $0.00E+00$ |
| | Worst | $9.25E-02$ | $3.44E-05$ | $9.91E-08$ |
| | Mean | $2.41E-03$ | $3.45E-07$ | $9.95E-10$ |
| | Std | $1.33E-02$ | $3.43E-06$ | $9.86E-09$ |
| F3 | Best | $1.70E-09$ | $1.00E-09$ | $8.20E-09$ |
| | Median | $7.97E-08$ | $6.94E-08$ | $8.48E-08$ |
| | Worst | $5.42E-07$ | $3.22E-07$ | $4.34E-07$ |
| | Mean | $1.03E-07$ | $8.41E-08$ | $1.05E-07$ |
| | Std | $9.30E-08$ | $6.58E-08$ | $8.56E-08$ |
| F4 | Best | $1.29E+01$ | $1.36E+01$ | $1.45E+01$ |
| | Median | $2.47E+01$ | $2.58E+01$ | $2.66E+01$ |
| | Worst | $3.43E+01$ | $3.28E+01$ | $3.41E+01$ |
| | Mean | $2.45E+01$ | $2.53E+01$ | $2.65E+01$ |
| | Std | $4.12E+00$ | $3.83E+00$ | $3.68E+00$ |
| F5 | Best | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Median | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Worst | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Mean | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Std | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| F6 | Best | $2.86E-02$ | $3.58E-01$ | $4.14E-01$ |
| | Median | $2.52E-01$ | $5.00E-01$ | $5.00E-01$ |
| | Worst | $1.45E+00$ | $5.00E-01$ | $1.49E+00$ |
| | Mean | $2.91E-01$ | $4.97E-01$ | $5.08E-01$ |
| | Std | $1.80E-01$ | $1.81E-02$ | $9.98E-02$ |
| F7 | Best | $8.45E+00$ | $1.04E+01$ | $9.65E+00$ |
| | Median | $2.50E+01$ | $2.48E+01$ | $2.52E+01$ |
| | Worst | $3.23E+01$ | $3.14E+01$ | $3.13E+01$ |
| | Mean | $2.44E+01$ | $2.38E+01$ | $2.41E+01$ |
| | Std | $3.90E+00$ | $4.16E+00$ | $4.45E+00$ |
| F8 | Best | $1.59E+00$ | $1.43E+00$ | $1.53E+00$ |
| | Median | $3.32E+00$ | $3.28E+00$ | $3.17E+00$ |
| | Worst | $8.21E+00$ | $7.18E+00$ | $6.19E+00$ |
| | Mean | $3.56E+00$ | $3.52E+00$ | $3.31E+00$ |
| | Std | $1.30E+00$ | $1.28E+00$ | $9.94E-01$ |
| F9 | Best | $1.55E+02$ | $1.55E+02$ | $1.55E+02$ |
| | Median | $1.55E+02$ | $1.55E+02$ | $1.55E+02$ |
| | Worst | $1.55E+02$ | $1.55E+02$ | $1.55E+02$ |
| | Mean | $1.55E+02$ | $1.55E+02$ | $1.55E+02$ |
| | Std | $2.84E-14$ | $2.84E-14$ | $2.84E-14$ |
| F10 | Best | $1.00E+02$ | $1.00E+02$ | $1.00E+02$ |
| | Median | $1.00E+02$ | $1.00E+02$ | $1.00E+02$ |
| | Worst | $2.29E+02$ | $2.28E+02$ | $2.24E+02$ |
| | Mean | $1.23E+02$ | $1.17E+02$ | $1.02E+02$ |
| | Std | $4.70E+01$ | $4.09E+01$ | $1.23E+01$ |
| F11 | Best | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Median | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Worst | $3.00E+02$ | $3.00E+02$ | $0.00E+00$ |
| | Mean | $6.00E+00$ | $3.00E+00$ | $0.00E+00$ |
| | Std | $4.20E+01$ | $2.98E+01$ | $0.00E+00$ |
| F12 | Best | $2.10E+02$ | $2.10E+02$ | $2.10E+02$ |
| | Median | $2.11E+02$ | $2.11E+02$ | $2.12E+02$ |
| | Worst | $2.19E+02$ | $2.15E+02$ | $2.15E+02$ |
| | Mean | $2.12E+02$ | $2.12E+02$ | $2.12E+02$ |
| | Std | $1.19E+00$ | $6.00E-01$ | $6.66E-01$ |

TABLE XIV: Optimization effectiveness comparison between CPUCPU, CPUGPU, and GPUGPU versions considering 20 dimensions.

| | | CPUCPU | CPUGPU | GPUGPU |
|---|---|---|---|---|
| F1 | Best | $7.88E-03$ | $4.22E-03$ | $4.89E-02$ |
| | Median | $6.66E-02$ | $6.04E-02$ | $4.60E-01$ |
| | Worst | $6.35E-01$ | $3.89E-01$ | $4.50E+00$ |
| | Mean | $1.10E-01$ | $8.08E-02$ | $7.61E-01$ |
| | Std | $1.20E-01$ | $6.59E-02$ | $8.38E-01$ |
| F2 | Best | $2.90E-03$ | $8.46E-04$ | $2.69E-04$ |
| | Median | $4.32E-01$ | $1.72E-01$ | $1.41E-01$ |
| | Worst | $1.68E+00$ | $4.17E+00$ | $4.04E+00$ |
| | Mean | $5.40E-01$ | $4.43E-01$ | $3.15E-01$ |
| | Std | $4.01E-01$ | $9.04E-01$ | $6.87E-01$ |
| F3 | Best | $9.98E-04$ | $8.05E-04$ | $1.35E-03$ |
| | Median | $2.94E-03$ | $2.77E-03$ | $3.71E-03$ |
| | Worst | $6.43E-03$ | $8.97E-03$ | $1.11E-02$ |
| | Mean | $3.06E-03$ | $3.15E-03$ | $4.21E-03$ |
| | Std | $1.19E-03$ | $1.51E-03$ | $1.80E-03$ |
| F4 | Best | $7.55E+01$ | $8.54E+01$ | $7.82E+01$ |
| | Median | $1.04E+02$ | $1.04E+02$ | $1.05E+02$ |
| | Worst | $1.19E+02$ | $1.18E+02$ | $1.17E+02$ |
| | Mean | $1.04E+02$ | $1.03E+02$ | $1.02E+02$ |
| | Std | $7.68E+00$ | $6.35E+00$ | $9.56E+00$ |
| F5 | Best | $0.00E+00$ | $0.00E+00$ | $0.00E+00$ |
| | Median | $0.00E+00$ | $0.00E+00$ | $2.00E-10$ |
| | Worst | $5.00E-10$ | $7.00E-10$ | $4.40E-09$ |
| | Mean | $6.80E-11$ | $7.30E-11$ | $5.07E-10$ |
| | Std | $1.05E-10$ | $1.08E-10$ | $7.54E-10$ |
| F6 | Best | $7.49E+01$ | $8.08E+01$ | $8.67E+01$ |
| | Median | $1.86E+02$ | $1.81E+02$ | $1.89E+02$ |
| | Worst | $1.11E+03$ | $7.96E+02$ | $7.49E+02$ |
| | Mean | $2.10E+02$ | $2.07E+02$ | $2.29E+02$ |
| | Std | $1.25E+02$ | $1.08E+02$ | $1.31E+02$ |
| F7 | Best | $5.56E+01$ | $5.54E+01$ | $5.89E+01$ |
| | Median | $7.58E+01$ | $7.67E+01$ | $1.15E+02$ |
| | Worst | $1.01E+02$ | $1.01E+02$ | $1.61E+02$ |
| | Mean | $7.61E+01$ | $7.68E+01$ | $1.14E+02$ |
| | Std | $1.07E+01$ | $1.05E+01$ | $2.07E+01$ |
| F8 | Best | $2.84E+01$ | $2.98E+01$ | $3.02E+01$ |
| | Median | $3.38E+01$ | $3.37E+01$ | $3.55E+01$ |
| | Worst | $4.00E+01$ | $4.03E+01$ | $5.08E+01$ |
| | Mean | $3.37E+01$ | $3.39E+01$ | $3.66E+01$ |
| | Std | $2.34E+00$ | $2.25E+00$ | $4.56E+00$ |
| F9 | Best | $2.69E+02$ | $2.69E+02$ | $2.69E+02$ |
| | Median | $2.69E+02$ | $2.69E+02$ | $2.69E+02$ |
| | Worst | $2.69E+02$ | $2.69E+02$ | $2.69E+02$ |
| | Mean | $2.69E+02$ | $2.69E+02$ | $2.69E+02$ |
| | Std | $1.56E-09$ | $1.65E-09$ | $2.06E-06$ |
| F10 | Best | $1.00E+02$ | $1.00E+02$ | $1.00E+02$ |
| | Median | $1.00E+02$ | $1.00E+02$ | $1.02E+02$ |
| | Worst | $3.01E+02$ | $3.51E+03$ | $1.05E+02$ |
| | Mean | $1.11E+02$ | $1.74E+02$ | $1.02E+02$ |
| | Std | $4.19E+01$ | $4.57E+02$ | $1.24E+00$ |
| F11 | Best | $2.42E-06$ | $1.13E-05$ | $1.02E-04$ |
| | Median | $4.00E+02$ | $4.00E+02$ | $4.00E+02$ |
| | Worst | $4.00E+02$ | $4.00E+02$ | $4.00E+02$ |
| | Mean | $3.45E+02$ | $3.70E+02$ | $3.53E+02$ |
| | Std | $7.79E+01$ | $5.74E+01$ | $6.08E+01$ |
| F12 | Best | $2.54E+02$ | $2.54E+02$ | $2.61E+02$ |
| | Median | $2.65E+02$ | $2.63E+02$ | $2.66E+02$ |
| | Worst | $2.70E+02$ | $2.69E+02$ | $2.76E+02$ |
| | Mean | $2.64E+02$ | $2.63E+02$ | $2.67E+02$ |
| | Std | $3.95E+00$ | $3.94E+00$ | $1.86E+00$ |