

# Design & Analysis of Algorithms Project - 1

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## DESCRIPTION

Insertion, Merge and Quicksort algorithms are implemented as part of this project. **Prudhvi Thumma** (Student ID: 1002033401) and **Rohith Kumar Boddu** (Student ID: 1002037081) are members of this team. We both contributed equally towards the implementation of algorithms, drawing comparisons, and documentation. File operations required for the project are mainly read and write operations. Parsing arrays are required while reading files or writing to files. Same text files consisting of auto-generated numbers are used for each sorting algorithm and time taken is noted and displayed as run. Comparisons of theoretical and obtained results are concluded and are detailed.

How to run files:

**insertion\_sort.py**, **merge\_sort.py**, **quick\_sort.py** are files with code to sort numbers generated in text files.

**arr\_20.txt**, **arr\_100.txt**, **arr\_1000.txt**, **arr\_4000.txt** are files where randomly generated are written.

Step 1: Install python and set up a runtime environment for python (check system environment variables in the path)

Step 2: Copy files mentioned above to any directory

Step 3: Open command prompt, navigate to your directory with files

Step 4: Enter python “file\_name.py” command compile and run given files. The output will be generated displaying sorted output and time taken to complete the given sort operation

Modules to import

- **random**: This module implements pseudo-random number generators for various distributions.
    - **sample()** function provides us randomly generated integers in specified range
  - **time**: This module provides various time-related functions.
    - **time()** function returns us the current time based on which I could calculate the difference in time to perform my sort algorithms.
- 
- **random\_number\_generator** is a method used to generate a required number of random numbers to run algorithms.
  - **read\_file** reads content from files, which are written after generating random numbers.
  - **time()** gives current time and is used to calculate the time elapsed to run each file content on sortalgorithm.
  - **open()** opens a file with the given mode.

## Contributions towards the project:

Random number generation, File read and write operations: Prudhvi ThummaSort

algorithms: Rohith Kumar Boddu

Report Documentation and Time complexity comparison: Team

# INSERTION SORT

```
----- Time taken to sort 20 random integers : 0.0 nanoseconds -----
Sorted array is:
279 602 767 1077 1222 1243 1982 2224 2328 2353 2906 3163 3317 3830 3979 4502 4907 5281 5315 5736

----- Time taken to sort 100 random integers : 997.5 microseconds -----
Sorted array is:
145 201 300 315 436 494 565 621 694 705 750 803 821 880 921 953 1007 1016 1042 1045 1084 1152 1175 1355 1474 1525 1566 1588 1605 1828 1871 1921 1952 1994 2008 2010 2033 205
0 2052 2068 2151 2226 2365 2383 2436 2499 2682 2767 2780 2867 2873 2962 3081 3151 3184 3300 3404 3538 3554 3639 3643 4071 4142 4152 4164 4269 4290 4389 4573 4575 4589 4594
4689 4735 4778 4925 4937 5052 5084 5109 5110 5129 5212 5226 5313 5335 5481 5537 5612 5636 5672 5691 5695 5718 5741 5833 5863 5867 5928 5948

----- Time taken to sort 1000 random integers : 36.91357421875 milliseconds -----
Sorted array is:
4 8 27 28 32 34 41 42 51 52 67 76 77 91 92 93 99 102 112 119 120 123 126 131 132 133 134 136 146 150 153 159 174 176 180 189 198 203 223 229 230 241 243 250 252 256 276 290
308 309 314 318 330 332 333 341 343 352 359 361 368 369 378 383 386 397 400 406 412 420 424 439 445 446 450 460 464 465 491 492 505 506 509 513 516 519 522 525 527 530 533
536 538 539 547 553 568 570 574 589 612 621 623 627 649 652 655 657 661 662 673 675 676 686 688 699 709 724 741 757 764 767 773 782 787 788 793 797 800 802 807 808 822 827
830 831 834 847 856 857 864 866 874 883 889 892 895 897 898 899 901 904 905 908 917 919 920 936 943 948 949 957 958 964 965 972 981 985 986 988 995 1005 1014 1024 1027 103
1215 1220 1222 1237 1240 1247 1259 1268 1274 1278 1282 1289 1297 1314 1321 1337 1341 1351 1353 1354 1359 1382 1409 1413 1414 1417 1419 1431 1432 1434 1436 1451 1455 1462 14
74 1477 1481 1484 1491 1492 1502 1509 1519 1537 1540 1549 1550 1553 1556 1560 1566 1571 1574 1575 1578 1583 1584 1594 1597 1603 1609 1610 1619 1627 1629 1640 1643 1646 1655
1662 1664 1681 1682 1683 1689 1692 1693 1695 1699 1722 1734 1746 1747 1753 1759 1766 1767 1770 1772 1779 1787 1788 1795 1797 1803 1805 1811 1814 1818 1823 1824 1827 1845 1
849 1852 1856 1860 1862 1864 1866 1878 1879 1880 1885 1890 1905 1910 1927 1937 1954 1958 1967 1974 1975 1976 1985 1986 1994 2007 2015 2019 2026 2035 2036 2038 2047 2050 205
5 2059 2067 2079 2094 2096 2098 2102 2106 2113 2118 2122 2144 2146 2147 2148 2151 2156 2164 2178 2184 2186 2191 2194 2195 2202 2212 2218 2223 2228 2237 2243 2249 2251 2264
2268 2270 2280 2300 2302 2322 2325 2326 2328 2345 2348 2365 2381 2387 2390 2393 2399 2400 2414 2416 2419 2420 2427 2432 2433 2445 2453 2454 2456 2457 2479 2480 2487 2490 24
98 2506 2508 2510 2529 2552 2553 2554 2555 2558 2572 2588 2594 2596 2598 2602 2604 2605 2613 2618 2627 2628 2629 2631 2632 2633 2635 2636 2642 2643 2648 2649 2651 2659 2666
2696 2704 2707 2712 2716 2717 2721 2727 2738 2739 2740 2750 2753 2754 2764 2767 2785 2789 2790 2791 2809 2822 2827 2841 2855 2861 2869 2879 2896 2897 2898 2899 2905 2906 2
912 2934 2940 2942 2944 2947 2954 2971 2979 2984 2987 2990 3000 3001 3009 3011 3015 3021 3024 3027 3031 3033 3036 3071 3074 3080 3082 3086 3097 3106 3115 3120 3128 3131 313
2 3137 3138 3149 3152 3155 3156 3161 3166 3172 3178 3183 3187 3190 3197 3205 3213 3216 3218 3221 3222 3224 3230 3232 3250 3252 3276 3279 3280 3295 3306 3317 3328 3330 3339
3358 3362 3364 3365 3367 3370 3372 3380 3381 3386 3390 3391 3400 3409 3412 3413 3422 3423 3426 3432 3434 3444 3450 3452 3457 3480 3488 3489 3493 3505 3518 3521 3539 3544 35
48 3554 3560 3563 3570 3572 3587 3588 3590 3599 3612 3627 3637 3647 3654 3659 3672 3678 3686 3691 3693 3700 3710 3726 3732 3743 3755 3756 3758 3766 3769 3787
3791 3795 3799 3801 3828 3832 3835 3840 3846 3847 3868 3870 3872 3874 3886 3889 3890 3891 3895 3906 3911 3921 3922 3926 3927 3929 3938 3939 3940 3945 3946 3950 3964 3970 3
978 3980 3993 4001 4002 4021 4024 4029 4031 4037 4046 4048 4063 4074 4080 4089 4093 4095 4096 4099 4107 4112 4118 4124 4129 4139 4142 4144 4148 4158 4164 4166 4168 4169 417
5 4189 4190 4195 4197 4207 4209 4210 4111 4220 4225 4228 4230 4232 4233 4235 4241 4242 4255 4256 4259 4260 4267 4268 4272 4279 4281 4293 4297 4298 4299 4312 4316 4319 4328 4335
4347 4359 4361 4362 4367 4369 4370 4406 4424 4442 4446 4448 4451 4463 4474 4497 4499 4501 4503 4507 4511 4513 4515 4535 4537 4547 4559 4568 4570 4571 4573 4580 4582 4587 45
88 4600 4602 4603 4606 4609 4615 4623 4631 4635 4643 4644 4647 4650 4659 4666 4681 4699 4701 4704 4709 4713 4743 4745 4748 4751 4763 4770 4780 4783 4789 4791 4795 4796 4799
4806 4807 4809 4818 4821 4823 4833 4836 4837 4839 4841 4845 4851 4856 4859 4862 4879 4892 4896 4904 4905 4919 4922 4933 4937 4946 4958 4960 4961 4963 4971 4990 4992 4997 5
003 5012 5027 5034 5046 5050 5054 5059 5063 5066 5072 5073 5079 5084 5087 5089 5090 5093 5096 5099 5102 5103 5105 5106 5114 5123 5127 5128 5130 5133 5137 5140 5143 5151 515
5 5156 5162 5163 5168 5199 5208 5212 5219 5220 5221 5224 5226 5227 5228 5232 5233 5235 5239 5248 5251 5257 5258 5262 5268 5282 5283 5293 5295 5296 5300 5304 5305 5307
5308 5312 5317 5325 5327 5329 5336 5350 5353 5354 5364 5368 5378 5381 5397 5407 5408 5411 5420 5442 5444 5445 5446 5448 5470 5477 5486 5493 5501 5502 5506 5520 5523 5528 55
33 5543 5545 5558 5562 5564 5583 5585 5592 5593 5597 5601 5604 5607 5613 5614 5615 5616 5625 5642 5649 5656 5660 5663 5664 5665 5666 5669 5704 5709 5711 5717 5721 5728 5730
5735 5749 5751 5758 5772 5776 5779 5785 5786 5811 5832 5834 5847 5853 5858 5860 5869 5873 5878 5890 5895 5910 5918 5920 5922 5934 5939 5940 5946 5953 5961 5967 5997
```

```
----- Time taken to sort 4000 random integers : 453.3076171875 milliseconds -----
Sorted array is:
1 2 3 5 6 7 8 9 11 14 15 16 17 18 19 20 21 22 24 26 27 28 29 31 33 34 37 38 40 41 42 43 44 46 48 49 51 52 53 58 61 62 64 65 66 67 68 69 70 72 77 78 79 81 82 83 85 86 87 88
89 90 91 92 93 95 96 98 99 101 102 105 106 107 109 110 111 112 113 114 115 116 117 118 120 121 123 125 128 130 131 134 135 136 138 143 144 146 147 148 149 150 151 152 154 1
155 156 158 161 162 163 164 165 166 169 171 172 173 174 175 176 177 178 180 181 183 185 186 188 189 190 191 193 194 195 196 197 198 199 203 205 206 207 208 209 213 214 2
16 217 218 219 220 221 222 223 224 225 226 227 228 229 232 234 235 236 237 238 239 243 244 245 248 249 251 253 254 255 256 257 258 259 260 261 263 264 265 266 268 270 272 2
73 275 276 277 278 279 280 281 284 285 286 289 290 291 292 293 296 297 298 299 300 301 302 304 305 306 308 309 311 313 314 315 319 321 323 324 325 327 329 334 335 336 337 3
38 339 341 343 344 345 347 348 349 350 351 352 355 356 357 358 359 360 361 362 365 366 367 368 369 370 371 372 375 377 378 381 382 385 386 387 388 390 391 393 396 397 399 4
400 402 403 406 407 408 409 411 412 413 414 415 420 422 423 425 431 432 435 436 437 439 441 448 454 456 457 458 459 460 462 463 464 465 466 467 468 469 471 473 474 477 478 4
79 480 481 483 484 485 486 487 488 490 491 494 495 496 497 498 499 502 505 506 507 508 509 510 511 514 515 516 518 519 521 523 525 526 527 528 529 530 531 532 534 535 536 5
37 539 540 541 542 543 544 547 548 549 550 551 553 555 556 557 558 559 560 561 564 565 567 572 573 574 576 579 582 584 587 588 589 590 593 594 595 596 598 600 601 603 604 6
05 606 607 609 610 612 614 618 622 623 624 626 627 628 629 632 633 634 635 636 637 638 639 640 641 642 645 646 647 648 649 650 651 653 654 656 662 663 667 669 671 672 676 6
77 680 688 690 691 693 695 696 698 699 700 701 703 704 705 706 711 713 714 717 718 720 721 722 724 726 727 728 731 733 734 735 736 737 739 740 741 742 743 744 746 748 749 7
51 752 754 755 756 759 760 761 763 765 766 767 768 769 770 772 775 777 778 780 781 783 784 785 786 788 790 792 793 794 797 798 799 800 802 803 805 806 807 808 810 812 813 8
14 815 816 817 818 819 820 821 822 823 826 829 830 833 834 837 839 841 842 843 844 845 846 849 853 854 855 856 859 861 862 863 864 865 866 867 868 870 871 875 877 878 879 8
80 881 882 883 884 885 887 889 890 891 893 895 897 902 903 904 905 906 907 908 909 910 911 912 914 916 917 918 920 922 923 924 926 927 928 931 933 936 937 938 940 941 943 9
945 947 948 950 952 953 954 956 959 960 961 962 963 964 965 966 970 972 974 975 976 977 978 979 980 981 982 983 987 988 989 991 992 993 994 995 997 999 1000 1001 1002 1003 1
004 1007 1008 1009 1010 1011 1014 1016 1017 1020 1021 1023 1024 1025 1026 1029 1030 1031 1032 1033 1037 1038 1039 1040 1041 1043 1044 1045 1046 1047 1048 1049 1050 1051 105
3 1054 1055 1058 1059 1060 1061 1062 1063 1064 1065 1067 1068 1070 1072 1073 1075 1076 1077 1078 1079 1081 1083 1084 1085 1092 1093 1097 1098 1099 1100 1101 1103 1105 1106
1109 1113 1114 1115 1117 1118 1122 1123 1124 1125 1126 1128 1131 1132 1134 1135 1137 1138 1139 1141 1142 1143 1145 1146 1147 1149 1150 1151 1153 1155 1157 1158 1164 1165 11
66 1169 1172 1173 1174 1175 1176 1178 1180 1181 1182 1183 1184 1185 1186 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1204 1205 1206 1207 1208 1210
1212 1213 1216 1219 1220 1222 1223 1224 1225 1227 1228 1229 1231 1232 1233 1234 1235 1237 1238 1240 1241 1242 1243 1244 1245 1246 1249 1250 1251 1252 1254 1255 1257 1258 1
260 1261 1263 1264 1265 1266 1268 1269 1270 1271 1272 1274 1275 1276 1279 1280 1281 1282 1283 1286 1287 1288 1291 1292 1293 1294 1296 1298 1299 1301 1305 1306 1308 1310 131
1 1313 1314 1315 1317 1318 1319 1320 1321 1323 1325 1328 1329 1330 1331 1332 1333 1334 1337 1338 1339 1340 1341 1342 1343 1344 1346 1347 1349 1350 1352 1353 1354 1355 1359
1360 1363 1366 1367 1370 1372 1373 1375 1376 1377 1378 1379 1380 1381 1383 1384 1385 1386 1387 1389 1391 1396 1397 1399 1401 1402 1403 1404 1405 1406 1410 1411 1412 1413 14
14 1417 1419 1421 1422 1423 1425 1426 1429 1432 1433 1434 1437 1438 1440 1441 1442 1443 1445 1447 1448 1449 1450 1451 1452 1453 1455 1456 1459 1460 1461 1462 1463 1466 1469 1470
1471 1472 1473 1475 1476 1478 1480 1481 1482 1483 1487 1488 1490 1492 1493 1494 1495 1496 1497 1498 1500 1501 1502 1503 1504 1505 1506 1507 1508 1509 1511 1512 1516 1518 1
519 1521 1523 1524 1525 1527 1529 1532 1535 1537 1538 1539 1540 1541 1542 1543 1544 1547 1550 1551 1553 1555 1556 1559 1561 1563 1565 1566 1567 1568 1569 1570 1571 157
3 1575 1576 1577 1578 1581 1582 1583 1584 1586 1587 1588 1589 1590 1594 1595 1596 1598 1599 1601 1603 1605 1606 1609 1612 1614 1615 1616 1617 1618 1620 1621 1622 1623 1624
1625 1627 1628 1631 1633 1634 1635 1637 1638 1640 1644 1646 1647 1649 1651 1652 1653 1654 1655 1656 1658 1660 1661 1662 1663 1664 1666 1667 1668 1671 1673 1674 1676 1678 16
179 1680 1681 1684 1685 1686 1687 1690 1694 1695 1696 1698 1700 1702 1703 1704 1706 1707 1710 1711 1712 1713 1714 1717 1718 1720 1721 1722 1724 1725 1726 1727 1728 1729 1730
1731 1732 1733 1737 1739 1740 1741 1743 1745 1746 1749 1750 1752 1753 1755 1756 1757 1758 1761 1762 1763 1764 1766 1767 1768 1770 1771 1772 1773 1774 1775 1776 1778 1
779 1780 1781 1782 1784 1786 1787 1788 1789 1791 1793 1794 1798 1799 1800 1801 1803 1805 1807 1808 1809 1810 1811 1813 1814 1815 1816 1817 1818 1819 1820 1822 1823 1824 182
5 1826 1827 1828 1829 1832 1835 1837 1838 1839 1840 1841 1842 1843 1845 1848 1849 1850 1851 1853 1854 1857 1860 1862 1863 1864 1865 1866 1867 1868 1871 1872 1874 1875 1876
```



4000 random integers: 453.3076171875 milliseconds

Run merge\_sort.py file in command prompt as directed, which provides us output with the time taken as below

```

----- Time taken to sort 4000 random integers : 13.50537109375 milliseconds -----
Sorted array is:
1 2 3 5 6 7 8 9 11 14 15 16 17 18 20 21 22 24 26 27 28 29 31 33 34 37 39 40 41 42 43 44 46 48 49 51 52 53 58 61 62 64 65 66 68 69 70 72 77 78 79 81 82 83 85 86 87 88
89 90 91 92 93 95 96 98 99 101 102 105 106 107 109 110 111 112 113 114 115 116 117 118 120 121 123 125 128 130 131 134 135 136 138 143 144 146 147 148 150 155 157 158 159
155 156 158 162 163 164 165 166 169 171 172 173 174 175 176 177 178 179 180 181 183 185 186 188 189 190 191 193 194 195 196 197 198 199 203 205 206 207 208 213 214 216
217 218 219 220 221 222 223 224 225 226 227 228 229 232 234 235 236 237 238 239 243 244 245 248 249 251 253 254 255 256 257 258 259 260 263 264 266 268 269 270 272
273 275 276 277 278 279 280 281 284 285 286 289 290 291 292 293 296 297 298 299 300 301 302 304 305 306 308 309 311 313 314 315 319 321 323 324 325 327 329 334 335 336 337
389 341 343 344 345 347 348 349 350 351 352 355 356 357 358 359 360 361 362 365 366 367 368 369 370 372 375 377 378 381 382 383 386 387 388 390 391 393 396 397 399 400
402 403 406 407 408 409 411 412 413 414 415 418 420 422 423 425 431 432 435 436 437 439 441 448 454 456 457 458 459 460 462 463 464 465 466 467 468 469 471 473 474 477 478 480
481 482 483 484 485 486 487 488 489 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 553 555 556 557 558 559 560 561 562 563 567 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 600 601 603 604 605 606 607 608 609 610 612 614 618 622 623 624 626 627 628 629 632 633 634 635 636 637 638 639 640 641 642 645 646 647 648 649 650 651 653 654 656 662 663 667 669 671 672 676 678
680 682 683 686 691 693 695 696 698 699 700 701 703 704 705 706 711 713 714 717 718 720 721 722 724 726 727 728 731 733 734 735 736 737 739 740 741 742 743 746 748 749 750
51 752 754 755 756 759 760 761 763 765 766 767 768 769 770 772 775 777 778 780 781 783 784 786 788 789 790 792 793 794 797 798 799 800 802 803 805 806 807 808 810 812 813 816
14 815 816 817 818 819 820 821 822 823 826 829 830 833 834 837 839 841 842 843 845 846 849 853 854 855 856 859 861 862 863 865 866 867 868 870 873 875 877 878 879 881
800 881 882 883 884 885 887 889 890 891 893 895 897 902 903 904 905 906 907 908 909 910 911 912 914 916 917 918 920 922 923 924 926 927 928 931 933 936 937 938 940 941 943 949
945 947 948 950 952 953 954 956 959 960 961 962 963 964 965 966 970 972 974 975 976 977 978 979 980 981 982 983 987 988 989 991 992 993 994 995 997 999 1000 1001 1002 1003 1005
1004 1007 1008 1009 1010 1011 1014 1016 1017 1020 1021 1023 1024 1025 1026 1029 1030 1031 1032 1033 1037 1038 1039 1040 1041 1043 1044 1045 1046 1047 1048 1049 1050 1051 1055
3 1054 1055 1058 1059 1060 1061 1062 1063 1064 1065 1067 1068 1070 1073 1075 1076 1077 1078 1079 1081 1083 1084 1085 1089 1093 1097 1098 1099 1100 1101 1103 1105 1106
1099 1113 1114 1115 1117 1118 1122 1123 1124 1125 1126 1128 1131 1132 1134 1135 1137 1138 1139 1141 1142 1143 1145 1146 1147 1149 1150 1151 1153 1155 1157 1158 1164 1165 1167
1168 1169 1170 1171 1172 1173 1174 1175 1176 1177 1178 1179 1180 1181 1182 1183 1184 1185 1186 1187 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1202 1203 1204 1205
1210 1212 1213 1216 1218 1220 1222 1223 1224 1225 1227 1228 1229 1230 1231 1232 1233 1234 1235 1237 1238 1240 1241 1242 1243 1244 1245 1246 1248 1250 1251 1252 1254 1255 1257 1258 11
260 1261 1263 1264 1265 1266 1268 1269 1270 1271 1272 1274 1275 1276 1278 1280 1281 1282 1283 1286 1287 1288 1291 1292 1293 1294 1296 1298 1299 1301 1305 1306 1308 1310 1311
1 1313 1314 1315 1317 1318 1319 1320 1321 1323 1325 1328 1329 1330 1331 1332 1333 1334 1337 1338 1339 1340 1341 1342 1343 1344 1346 1347 1349 1350 1352 1353 1354 1355 1359
1360 1363 1366 1367 1370 1372 1373 1375 1376 1377 1378 1379 1380 1381 1383 1384 1385 1386 1387 1388 1390 1391 1396 1397 1399 1400 1402 1403 1404 
```



Practical time taken:

20 random integers: 0 nanoseconds  
100 random integers: 0 microseconds  
1000 random integers: 3.053955078125 milliseconds  
4000 random integers: 13.50537109375 milliseconds

## QUICK SORT

Run quick\_sort.py file in command prompt as directed, which provides us output with the time taken as below

```
C:\Users\prudh\OneDrive\Desktop\Prun>python "quick_sort.py"
----- Time taken to sort 20 random integers : 0.0 nanoseconds -----
Sorted array is:
279 602 767 1077 1222 1243 1982 2224 2328 2353 2906 3163 3317 3830 3979 4502 4907 5281 5315 5736

----- Time taken to sort 100 random integers : 0.0 microseconds -----
Sorted array is:
145 201 300 315 436 494 565 621 694 705 750 803 821 880 921 953 1007 1016 1042 1045 1084 1152 1175 1355 1474 1525 1566 1588 1605 1828 1871 1921 1952 1994 2008 2010 2033 205
0 2052 2068 2151 2226 2365 2383 2436 2499 2682 2767 2780 2867 2873 2962 3081 3151 3184 3300 3404 3538 3554 3639 3643 4071 4142 4152 4164 4269 4290 4389 4573 4575 4589 4594
4689 4735 4778 4925 4937 5052 5084 5109 5110 5129 5212 5226 5313 5335 5451 5537 5651 5672 5691 5695 5718 5741 5833 5863 5867 5928 5948

----- Time taken to sort 1000 random integers : 0.9970703125 milliseconds -----
Sorted array is:
4 8 27 28 32 34 41 42 51 52 67 76 77 91 92 93 98 102 112 119 120 123 126 131 132 133 144 136 146 150 153 159 174 176 180 189 198 203 223 229 230 241 243 250 252 256 276 290
300 309 314 318 330 332 333 341 343 352 359 361 368 369 378 383 386 397 400 405 412 420 424 439 445 446 450 460 464 465 491 492 508 506 509 513 516 519 522 525 527 530 533
536 538 539 547 553 568 570 574 589 612 621 623 627 649 652 655 657 661 662 673 675 676 686 688 699 709 724 741 757 764 767 773 782 787 788 793 797 800 802 807 808 822 827
830 831 834 847 856 857 864 866 874 883 889 892 895 897 898 899 901 904 905 908 917 919 920 936 943 948 949 957 958 964 965 972 981 985 986 988 995 1005 1014 1024 1027 103
2 1036 1039 1042 1053 1054 1056 1057 1058 1062 1081 1082 1083 1090 1093 1103 1110 1114 1121 1129 1131 1140 1148 1152 1155 1159 1164 1167 1172 1177 1180 1194 1197 1207 1214
1215 1220 1222 1237 1240 1247 1259 1268 1274 1278 1282 1289 1297 1314 1321 1337 1341 1351 1353 1354 1359 1382 1409 1413 1414 1417 1419 1431 1432 1434 1436 1451 1455 1462 14
74 1477 1481 1484 1491 1492 1502 1509 1519 1537 1540 1549 1550 1553 1556 1560 1566 1571 1574 1575 1578 1583 1584 1594 1597 1603 1609 1610 1619 1627 1629 1640 1643 1646 1655
1662 1664 1681 1682 1683 1689 1692 1693 1695 1699 1722 1734 1746 1747 1753 1759 1766 1767 1770 1772 1779 1787 1788 1795 1797 1803 1805 1811 1814 1818 1823 1824 1827 1845 1
849 1852 1856 1860 1862 1864 1866 1876 1879 1880 1885 1890 1905 1910 1927 1937 1954 1958 1967 1974 1975 1976 1985 1986 1994 2007 2015 2019 2026 2035 2036 2038 2047 2050 205
5 2059 2067 2079 2094 2096 2098 2102 2106 2113 2118 2122 2144 2146 2147 2148 2151 2156 2164 2178 2184 2186 2191 2194 2195 2202 2212 2218 2223 2228 2237 2243 2249 2251 2264
2268 2270 2280 2300 2302 2322 2325 2326 2328 2345 2348 2365 2381 2387 2390 2393 2399 2400 2414 2416 2419 2420 2427 2432 2433 2445 2453 2454 2456 2457 2479 2480 2487 2490 24
98 2506 2508 2510 2529 2552 2553 2554 2555 2558 2572 2588 2594 2596 2598 2602 2604 2605 2613 2618 2627 2628 2629 2631 2632 2633 2635 2636 2642 2643 2648 2649 2651 2659 2666
2696 2704 2707 2712 2716 2717 2721 2727 2738 2739 2740 2750 2753 2754 2764 2767 2785 2789 2790 2791 2809 2822 2827 2841 2855 2861 2869 2879 2896 2897 2898 2899 2905 2906 2
912 2934 2940 2942 2944 2947 2954 2971 2979 2984 2987 2990 3000 3001 3009 3011 3015 3021 3024 3027 3031 3033 3036 3071 3074 3080 3082 3086 3097 3106 3115 3120 3128 3131 313
2 3137 3138 3140 3152 3155 3156 3161 3166 3172 3178 3183 3187 3190 3197 3205 3213 3216 3218 3221 3222 3224 3230 3232 3250 3252 3276 3279 3280 3295 3306 3317 3328 3330 3339
3358 3362 3364 3365 3367 3370 3372 3380 3381 3386 3390 3391 3400 3409 3412 3413 3422 3423 3426 3432 3434 3444 3450 3452 3457 3480 3488 3489 3493 3505 3518 3521 3539 3544 35
48 3554 3560 3563 3570 3572 3587 3588 3590 3599 3612 3627 3637 3647 3654 3659 3672 3678 3686 3691 3693 3700 3710 3726 3732 3743 3746 3752 3754 3755 3756 3758 3766 3769 3787
3791 3795 3799 3801 3828 3832 3835 3840 3846 3847 3868 3870 3872 3874 3886 3889 3890 3891 3895 3906 3911 3921 3922 3926 3927 3929 3938 3939 3940 3945 3946 3950 3964 3970 3
978 3980 3993 4001 4002 4021 4024 4029 4031 4037 4046 4048 4063 4074 4080 4089 4093 4095 4096 4099 4107 4112 4118 4124 4129 4139 4142 4144 4148 4158 4164 4166 4168 4169 417
5 4189 4190 4195 4197 4207 4209 4210 4211 4220 4225 4228 4230 4232 4235 4241 4242 4255 4254 4260 4267 4268 4272 4279 4281 4293 4297 4298 4299 4312 4316 4319 4328 4335
4347 4359 4361 4362 4367 4369 4370 4406 4424 4442 4446 4448 4451 4463 4474 4497 4499 4501 4503 4507 4511 4513 4515 4535 4537 4547 4559 4568 4570 4571 4573 4580 4582 4587 45
88 4600 4602 4603 4606 4609 4615 4623 4631 4635 4643 4644 4647 4650 4659 4666 4681 4699 4701 4704 4709 4713 4743 4745 4748 4751 4763 4770 4780 4783 4789 4791 4795 4796 4799
4806 4807 4809 4818 4821 4823 4833 4836 4837 4839 4841 4845 4851 4856 4859 4862 4879 4892 4896 4904 4905 4919 4922 4933 4937 4946 4958 4960 4961 4963 4971 4990 4992 4997 5
003 5012 5027 5034 5046 5050 5054 5059 5063 5066 5072 5073 5079 5084 5087 5089 5090 5093 5096 5099 5102 5103 5105 5106 5114 5123 5127 5128 5130 5133 5137 5140 5143 5151 515
5 5157 5162 5163 5168 5199 5208 5211 5219 5228 5221 5224 5226 5227 5228 5233 5235 5239 5245 5248 5251 5257 5258 5262 5268 5282 5283 5293 5298 5296 5306 5308 5304 5305 5307
5308 5312 5317 5325 5327 5329 5335 5336 5353 5354 5364 5368 5378 5381 5392 5407 5408 5411 5420 5442 5444 5445 5446 5448 5454 5477 5486 5493 5501 5502 5506 5520 5523 5528 55
53 5543 5545 5550 5562 5564 5583 5585 5592 5593 5597 5601 5604 5607 5613 5614 5615 5616 5625 5642 5649 5656 5660 5663 5664 5665 5666 5669 5704 5709 5711 5717 5721 5728 5730
```

```
----- Time taken to sort 4000 random integers : 3.060302734375 milliseconds -----
Sorted array is:
1 2 3 5 6 7 8 9 11 14 15 16 17 18 19 20 21 22 24 26 27 28 29 31 33 34 37 39 40 41 42 43 44 46 48 49 51 52 53 58 61 62 64 65 66 67 68 69 70 72 77 78 79 81 82 83 85 86 87 88
98 90 91 92 93 95 96 98 99 101 102 105 106 107 109 110 111 112 113 114 115 116 117 118 120 121 123 125 128 130 131 134 135 136 138 143 144 146 147 148 149 150 151 152 154 1
55 156 158 161 162 163 164 165 166 169 171 172 173 174 175 176 177 178 179 180 181 183 185 186 188 189 190 191 193 194 195 196 197 198 199 203 205 206 207 208 209 213 214 2
16 217 218 219 220 221 222 223 224 225 226 227 228 229 232 234 235 236 237 238 239 243 244 245 248 249 251 253 254 255 256 257 258 259 260 261 263 264 265 266 268 270 272 2
73 275 276 277 278 279 280 281 284 285 286 289 290 291 292 293 296 297 298 299 301 302 304 305 306 308 309 311 313 314 315 319 321 323 324 325 327 329 334 335 336 337 3
38 339 341 343 344 345 347 348 349 350 351 352 355 356 357 358 359 360 361 362 365 366 367 368 369 370 371 372 375 377 378 381 382 385 386 387 388 390 391 393 396 397 399 4
00 402 403 406 407 408 409 411 412 413 414 415 420 422 423 425 431 432 435 436 437 439 441 448 454 456 457 458 459 460 462 463 464 465 466 467 468 469 471 473 474 477 478 4
79 480 481 483 484 485 486 487 488 490 491 494 495 496 497 498 499 502 505 506 507 508 509 511 514 515 516 518 519 521 523 525 526 527 528 529 530 531 532 534 535 536 5
57 539 540 541 542 543 544 547 548 549 550 551 553 555 556 557 558 559 560 561 564 565 567 572 573 574 576 579 582 584 587 588 589 590 591 594 595 596 598 600 601 603 604 6
05 606 607 609 610 612 614 618 622 623 624 626 627 628 629 633 634 635 636 637 638 639 640 641 642 645 646 647 648 649 650 651 653 654 656 662 663 667 669 671 672 676 6
77 680 688 690 691 693 695 696 698 699 700 701 703 704 705 706 711 713 714 717 718 719 721 722 724 726 727 728 731 733 734 735 736 737 739 740 741 742 743 744 746 748 749 7
51 752 754 755 756 759 760 761 763 765 766 767 768 769 770 772 775 777 778 780 783 784 785 786 788 790 792 793 794 797 798 799 800 802 803 805 806 807 808 811 812 813 8
14 815 816 817 818 819 820 821 822 823 826 829 830 833 834 837 839 841 842 843 844 845 846 849 853 854 855 856 859 861 862 863 864 865 866 867 868 870 871 875 877 878 879 8
80 881 882 883 884 885 887 889 890 891 893 895 897 902 903 904 905 906 907 908 909 910 911 912 914 916 917 918 920 922 923 924 926 927 928 931 933 936 937 938 940 941 943 9
45 947 948 950 952 953 954 956 959 960 961 962 963 964 965 966 970 972 974 975 976 977 978 979 980 981 982 983 987 988 989 991 992 993 994 995 997 999 1000 1001 1002 1003 1
004 1007 1008 1009 1010 1011 1014 1016 1017 1020 1021 1023 1024 1025 1026 1029 1030 1031 1032 1033 1037 1038 1039 1040 1041 1043 1044 1045 1046 1047 1048 1049 1050 1051 105
3 1054 1055 1058 1059 1060 1061 1062 1063 1064 1065 1067 1068 1070 1072 1073 1075 1076 1077 1078 1079 1081 1083 1084 1085 1092 1093 1097 1098 1099 1100 1101 1103 1105 1106
1109 1113 1114 1115 1117 1118 1122 1123 1124 1125 1126 1128 1131 1132 1134 1135 1137 1138 1139 1141 1142 1143 1145 1146 1147 1149 1150 1151 1153 1155 1157 1158 1164 1165 11
66 1169 1172 1173 1174 1175 1176 1178 1180 1181 1182 1183 1184 1185 1186 1188 1189 1190 1191 1192 1193 1194 1195 1196 1197 1198 1199 1200 1201 1204 1205 1206 1207 1208 1210
1212 1213 1216 1210 1220 1222 1223 1224 1225 1227 1228 1229 1231 1232 1233 1234 1235 1237 1238 1240 1241 1242 1243 1244 1245 1246 1249 1250 1251 1252 1254 1255 1257 1259 1
260 1261 1263 1264 1265 1266 1268 1269 1270 171 1272 1274 1275 1276 1277 1280 1283 1286 1287 1288 1291 1292 1293 1294 1296 1298 1299 1301 1305 1306 1308 1310 131
1 1313 1314 1315 1317 1318 1319 1320 1321 1323 1325 1328 1329 1330 1331 1332 1333 1334 1337 1338 1339 1340 1341 1342 1343 1344 1346 1347 1349 1350 1352 1353 1354 1355 1359
1360 1363 1366 1367 1370 1372 1373 1375 1376 1377 1378 1379 1380 1381 1383 1384 1385 1386 1387 1389 1391 1396 1397 1399 1401 1404 1405 1406 1410 1411 1412 1413 1414
1417 1418 1419 1421 1422 1423 1425 1426 1429 1432 1433 1434 1437 1438 1440 1441 1442 1443 1445 1447 1448 1449 1450 1451 1452 1453 1455 1456 1459 1462 1465 1466 1469 1470
1471 1472 1473 1475 1476 1478 1480 1481 1482 1483 1487 1488 1490 1492 1493 1494 1495 1496 1497 1498 1500 1501 1502 1503 1504 1505 1506 1507 1508 1509 1511 1512 1516 1518 1
519 1521 1523 1524 1525 1527 1529 1532 1536 1537 1538 1539 1540 1541 1542 1543 1544 1547 1550 1551 1553 1555 1556 1559 1561 1563 1564 1565 1566 1567 1568 1569 1570 1571 157
1575 1576 1577 1578 1582 1583 1584 1586 1587 1588 1589 1590 1594 1595 1596 1598 1599 1601 1603 1605 1606 1609 1612 1614 1615 1616 1617 1618 1620 1621 1622 1623 1624
1625 1627 1628 1631 1633 1634 1635 1637 1638 1640 1644 1646 1647 1649 1651 1652 1653 1654 1655 1656 1658 1660 1661 1662 1663 1664 1666 1667 1668 1671 1673 1674 1676 1678 16
79 1680 1681 1684 1685 1686 1687 1690 1694 1695 1696 1698 1700 1702 1703 1704 1706 1707 1710 1711 1712 1713 1714 1717 1718 1720 1721 1722 1724 1725 1726 1728 1729 1730
1731 1732 1733 1735 1737 1739 1740 1741 1743 1745 1746 1749 1750 1752 1753 1755 1756 1757 1758 1761 1762 1763 1764 1766 1767 1768 1770 1771 1772 1773 1774 1775 1776 1778 1
779 1780 1781 1782 1784 1786 1787 1788 1789 1791 1793 1794 1798 1799 1800 1801 1803 1805 1807 1808 1809 1810 1811 1813 1814 1815 1816 1817 1818 1819 1820 1822 1823 1824 182
5 1826 1827 1828 1829 1832 1835 1837 1838 1839 1840 1841 1842 1843 1845 1848 1849 1850 1851 1853 1854 1857 1860 1862 1863 1864 1865 1866 1867 1868 1871 1872 1874 1875 1876
1877 1878 1879 1881 1882 1884 1885 1886 1888 1891 1892 1896 1898 1899 1900 1901 1902 1904 1906 1907 1909 1910 1911 1912 1913 1916 1918 1919 1921 1922 1924 1925 1926 1928 19
29 1931 1932 1936 1937 1939 1940 1941 1942 1943 1945 1947 1948 1949 1951 1952 1953 1955 1956 1959 1961 1962 1963 1964 1966 1967 1968 1969 1970 1971 1972 1973 1974 1976 1977
1978 1980 1982 1984 1985 1986 1987 1988 1990 1993 1994 1995 1996 1997 1998 1999 2000 2002 2003 2005 2006 2007 2008 2009 2010 2012 2013 2014 2015 2016 2017 2018 2019 2020 2
```

Practical time taken:

20 random integers: 0 nanoseconds

100 random integers: 0 microseconds

1000 random integers: 0.9970703125 milliseconds

4000 random integers: 3.060302734375 milliseconds

# Theoretical and Practical Time Complexity Comparison

We will analyze differences in theoretical time complexity and achieve experimental time complexity. Let's check the time complexity of individual sort algorithms

## **Insertion Sort Theoretical:**

- Average Time Complexity:  $O(n^2)$
- Worst-case Time Complexity:  $O(n^2)$
- Best case Time Complexity:  $O(n)$

Theoretically, time taken to sort “n” numbers will increase by order  $n^2$

Time taken to sort 100 numbers is approximately 1 millisecond and for 1000 numbers is 37 milliseconds and to sort 4000 is 453.3 milliseconds.

|            |             |
|------------|-------------|
| 100numbers | 1000numbers |
| 1ms        | 37ms        |

The difference is 37 times, but as per average case difference can be in the range of

|             |             |
|-------------|-------------|
| 1000numbers | 4000numbers |
| 37ms        | 453.3ms     |

The difference is approx. 13 times, but average case expects difference to be in the range of 16times

Insertion Sort justified with average case time complexity but not accurate as we are not considering lower order and coefficients.

## **Merge Sort Theoretical:**

- Average Time Complexity:  $O(n \log n)$
- Worst-case Time Complexity:  $O(n \log n)$
- Best case Time Complexity:  $O(n \log n)$

Theoretically, time taken to sort “n” numbers will increase by order  $n \cdot (\log n)$

Time taken to sort 1000 numbers is approximately 3.05ms and for 4000 numbers is 13.5 milliseconds.

|             |             |
|-------------|-------------|
| 1000numbers | 4000numbers |
| 3.05 ms     | 13.5 ms     |

The difference is approx. 4.4 times, but the average case expects difference to be in the range of 4.8times

Merge Sort average case time complexity is approximated correctly

**Quick Sort Theoretical:**

- Average Time Complexity:  $O(n \log n)$
- Worst-case Time Complexity:  $O(n^2)$
- Best case Time Complexity:  $O(n \log n)$

Theoretically, time taken to sort “n” numbers will increase by order  $n \cdot (\log n)$

Time taken to sort 1000 numbers is approximately 1 millisecond and for 4000 numbers is 3.06 milliseconds.

|             |             |
|-------------|-------------|
| 1000numbers | 4000numbers |
| 1ms         | 3.06ms      |

The difference is approx. 3.06 times, but the average case expects difference to be in the range of 4.8times

Quick Sort average case time complexity is justified by our experiment.



## **REFERENCES**

- [1] <https://docs.python.org/3/library/random.html>
- [2] <https://docs.python.org/3/library/time.html>

## HONOR CODE

### HONOR CODE

I pledge, on my honor, to uphold UT Arlington's tradition of academic integrity, a tradition that values hard work and honest effort in the pursuit of academic excellence.

I promise that I will submit only work that I personally create or that I contribute to group collaborations, and I will appropriately reference any work from other sources. I will follow the highest standards of integrity and uphold the spirit of honor code.

I will not participate in any form of cheating/storing the questions/solutions

*Prudhvi*

PRUDHVI THUMMA  
1002033401

*Rohith*

ROHITH KUMAR BODDU  
1002037081

5<sup>th</sup> March 2022